Threatened Amphibians of the World

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Threatened Amphibians of the World is dedicated to

The 500 herpetologists from around the world
who devoted their knowledge, intellect and time
to the Global Amphibian Assessment, and without
whom this book could not have been written

and especially to

George Rabb for his visionary leadership
and commitment to confronting the
amphibian extinction crisis, which gives us
hope in an otherwise bleak situation.

Dendrobates azureus, Vulnerable. © Albert Popalis

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FOREWORDS

The first signs of trouble for amphibians arose around three decades ago. IUCN, Conservation International and NatureServe made great efforts to understand what was happening, and in 2004, the Global Amphibian Assessment was produced with this shocking result: one-third of amphibian species are threatened with extinction. In addition, we were lacking data on many species which are potentially threatened. New studies show that many of the species that are listed as 'Data Deficient' on the IUCN Red List of Threatened Species™ are indeed threatened. One-third of an entire distinct group of species at risk of extinction is not a trivial figure.

This book is another step in our attempt to alert the world about the extinction crisis that toads, frogs, salamanders and caecilians are currently facing. It is a landmark book comprising all what needs to be known about amphibian conservation, and as such I am very happy to see its publication and to write this foreword. I would, however, be even happier if the amphibian extinction crisis was not taking place. I am concerned that the size of this book is a reflection of the number of threatened species that it comprises. When reading it one should not forget that only threatened amphibians are included in the species accounts that occupy the bulk of its length.

Many of us probably do not give much attention to amphibians and will probably be surprised to see how diverse, unique, colourful, and fascinating they are. Many species have developed very specific evolutionary characteristics and adaptations. We might think that they all lay eggs in water, but some give birth to live young, some do not need water, some species carry their eggs, others carry their young. Two Australian frogs incubated their eggs in their stomachs and both are already Extinct. As a result, an entire evolutionary lineage has been lost, along with up to 164 other species. These reproductive traits are the results of millions of years of evolution. Who knows if such adaptations would not have been key to the survival of species in response to climate change?

Amphibians are sending us a very strong signal that something is seriously wrong with the way we take care of our environment. They have been considered as the 'canaries in the coal mine'; their permeable skin makes them sensitive to many forms of pollution; they are also extremely sensitive to climate change and diseases. The sharp decline in amphibian populations could prefigure, if we are not careful, what other groups of species might undergo in the future. Amphibians provide us with a critical challenge if we are to meet the target that all countries agreed upon: a significant reduction in the rate of biodiversity loss by 2010.

Amphibians are a key part of ecosystems and the food chain; they control the number of many invertebrates, and are prey for many species of birds or mammals. Some species are also a source of revenue for human communities who eat them, use them as medicines, or supply them to the international pet trade. The skins of certain species contain molecules that are very promising in terms of developing new medicines for people. Who knows, a little frog hiding in the understorey of a tropical rainforest might bring the solution to the AIDS pandemic?

After reading this book and contemplating all these pictures, no one will look at amphibians with the same eyes again.

Julia Marton-Lefèvre
Director General
IUCN, the World Conservation Union

Eight years ago, I was invited to write a foreword to BirdLife International's landmark publication *Threatened Birds of the World*. At the time, I commented how encouraging it was that at least one organization had managed to hone its focus down to the level of sites and species across the planet. Writing this foreword for what is, in essence, the sister publication to BirdLife's earlier work, I am struck by our progress since then.

In 2003, at the Fifth World Parks Congress in Durban, South Africa, the results of a global analysis revealed the tremendous gaps in coverage of the existing protected areas network. While not all threats to biodiversity can be mitigated via habitat protection, habitat loss remains the overwhelming threat to our planet's unique life forms. It is encouraging, then, to see the expansion of the Important Bird Areas concept, pioneered by BirdLife International, to all taxa under the umbrella of the Key Biodiversity Areas approach, which aims to identify globally important sites for the conservation of biodiversity. Such initiatives, aided by the efforts of the Alliance for Zero Extinction, which prioritizes that subset of sites known to hold the last remaining population of a highly threatened species, provide conservation planners, funders and practitioners with a valuable lens on where, and what form of, conservation action is most appropriate in order to avoid the loss of global biodiversity.

Such fine-scale resolution would be impossible without the foundation provided by the data in the IUCN Red List, the recognized authority for the conservation status of global biodiversity. Before the launch of the Global Amphibian Assessment in September 2004, only a few hundred hand-picked frogs, toads and salamanders appeared on the IUCN Red List. Today, we have detailed, up-to-date information on the distribution, population status, threats, and conservation status of nearly 6,000 amphibians.

Threatened Amphibians of the World is a visual exploration of the results of the Global Amphibian Assessment – a compelling synthesis of herpetological knowledge and a yardstick for amphibian conservation. In tandem with the Amphibian Conservation Action Plan, produced by the IUCN/SSC Amphibian Specialist Group, it puts the amphibian agenda center-stage. And it does so with tremendous visual impact, presenting us with a face on an unfolding crisis like nothing that has gone before.

The plight of the world's amphibians is not just theirs, but ours as well. We should care that one-third of amphibians stand a high risk of extinction in the wild – and probably many more – because the threats that imperil them are those that stem from our actions and will be no less detrimental to our own livelihoods: pollutants, invasive species and disease, global climate change, and rampant habitat loss. Responding to these threats must be a societal concern. Let us hope that a second edition of this book does not require two volumes…

Russell A. Mittermeier
President, Conservation International
Steering Committee member, IUCN Species Survival Commission
IUCN Council member 2004-2008, IUCN – World Conservation Union

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"Round up the usual suspects," as Captain Renault famously said in the film *Casablanca*, did not seem to apply. Something appeared to be going on with amphibians that could not be wholly explained by the standard litany of ecological threats, such as habitat degradation and loss. The declines that were first noticed in earnest in the late 1980s and early 1990s raised the possibility that something was seriously amiss: a crisis that might start with environmentally sensitive creatures such as amphibians, but ultimately affect other strands of life, including humans.

NatureServe is a non-profit organization dedicated to providing the scientific basis for effective conservation action, with a deep appreciation for the role that research plays in addressing environmental challenges. We were pleased to join with IUCN and Conservation International in carrying out the Global Amphibian Assessment (GAA) as a way to document and draw attention to the amphibian declines now underway.

NatureServe scientists began seriously delving into the plight of amphibians through our coordination of RANA (Research and Analysis Network for Neotropical Amphibians), a U.S. National Science Foundation-funded effort. Through RANA, researchers with an interest in understanding amphibian declines in Latin America came together to share information, approaches, and results, and to train a new generation of Latin American herpetology students. The project has also helped to document some of the causes that appear to be behind these declines, including fungal diseases and shifts in climate. Building on our work with RANA, as well as our long history of assessing conservation status for North American and Latin American species, I am pleased that NatureServe was able to contribute to the GAA by coordinating the Western Hemisphere portion of the initiative, and creating a website for disseminating the project's data and results to the broader community (www.globalampihibians.org).

The GAA partnership has succeeded admirably in bringing the dire condition of the world's amphibian species into focus, and in motivating the scientific and conservation communities to take action. The present volume provides an important summary of what is known about amphibians around the world, and what will be required to ensure their future. While the work to do so will be difficult, and success is not assured, only by committing to the approaches outlined in the recent Amphibian Conservation Action Plan will we have a hope for preserving the many and varied faces of this ancient lineage.

Mary L. Klein
President and CEO, NatureServe

Amphibians, be they frogs, toads, salamanders or caecilians, are thought to be amongst the most sensitive ecological indicators, warning us of unsafe environmental conditions that are not only impacting our health, but that of the global ecosystem. With at least 32% of the described amphibian species threatened with extinction, and 500 species probably beyond the point of no return, the global amphibian extinction crisis represents one of the greatest conservation challenges of our times.

A direct result of mankind's insatiable appetite for natural resources, the rapid decline in amphibian numbers demonstrates the sensitivity of not only species, but of entire ecosystems. The current crisis exemplifies how, if unmanaged, actions of every-day human consumption and waste can compound to form ripple-like reactions resulting in entire populations disappearing, and all within our lifetime. In 2004, a global collaboration of work from 500 of the world's most respected amphibian specialists from over 60 nations was released: the Global Amphibian Assessment. Citing the possible loss of 122 species since 1980 alone, this unprecedented collaborative research effort highlighted the pace of modern amphibian declines. Since the first release of the Global Amphibian Assessment, there has been constant updating of information, including the addition of 160 new species to the IUCN Red List of Threatened Species^{TM} nine of which are Critically Endangered, 17 Endangered, and 12 Vulnerable. However, a large percentage of species remain in the Data Deficient category, emphasizing the need for more amphibian assessment work.

At present, little is known of the deadly fungal disease that is wiping out some amphibians faster than can be recorded. With fears that this could worsen with global climate change, there is no better time than the present to act with the knowledge we have, improve shortcomings in our knowledge, and continue work with our current and future collaborative efforts to raise the awareness for amphibian conservation. The recent release of the Amphibian Conservation Action Plan by IUCN/SSC's Amphibian Specialist Group and the publication of this book, are tributes to the enormous efforts dedicated teams are undertaking to tackle the global loss of species. Onwards to 2008, aptly named "the Year of the Frog".

Holly T. Dublin
Chair, IUCN Species Survival Commission

PREFACES

Imagine a world without frogs. No spring choruses of calling males. No tadpoles for kids to play with. No brightly coloured jewels perched on rocks and leaves throughout the world's tropical forests. We are currently witnessing the global extinction of amphibians – they are facing extinctions at levels unprecedented in any other group of organisms in human history. In light of this, we have some serious questions to address: *How extensive is the amphibian extinction crisis? How much worse can it get? Why is this happening now? Will it affect humans? Is there any hope?*

As early as 1989, researchers exchanged anecdotal reports of declines and disappearances of amphibian species from many areas around the world. Species, such as Costa Rica's Golden Toad (*Bufo periglenes*), went missing from pristine protected areas, often in the absence of familiar threats such as habitat loss and pollution (e.g., Crump *et al.* 1992). Further complicating matters, data on species distributions and population fluctuations were lacking for most amphibian species, thus preventing our ability to make accurate estimates of endangerment. In response, the IUCN Species Survival Commission formed The Declining Amphibian Population Task Force (DAPTF; and see Essay 11.1) to guide, sponsor, and fund crucial research into the phenomenon of global amphibian declines.

There are currently (as of the time of writing) just over 6,000 recognized species of amphibians and this number has increased by 48% in the past 20 years (Frost *et al.* 2006). This reflects both increased access to, and ease of collecting data in, remote locations, as well as the growth of active scientific communities in a few megadiverse countries (see Essay 1.1). Unfortunately, this increase in knowledge of amphibian diversity is offset by massive population declines and growing numbers of species extinctions (Stuart *et al.* 2004; Lips *et al.* 2005). Simply put, amphibian species are disappearing from the planet perhaps faster than we can discover them. According to the results of the Global Amphibian Assessment (GAA; Stuart *et al.* 2004), some 43% of amphibian species are declining in abundance, 32% of amphibians (one-third of all species) are threatened with extinction, and 122 species likely have become extinct since 1980 (with 34 species confirmed Extinct). Worse yet, these numbers are certainly underestimates because 23% of all known species are so poorly known that their threat status could not be classified at all. Statistics of this sort represent a near-categorical extinction event perhaps on the scale of the disappearance of the dinosaurs.

The GAA also reviewed causes of declines, and identified familiar threats such as habitat loss, chemical contamination, and over-harvesting as being involved in some cases. However, the terrifying realization was that novel threats related to emerging infectious diseases and climate change accounted for many of the disappearances. Conservationists have worked for decades to limit habitat loss, pollution, and over-harvesting in natural areas, but our current well-intentioned conservation programmes are insufficient to prevent extinctions from such insidious threats as emerging infectious diseases and climate change.

Amphibian declines and extinctions are real and the recently discovered chytrid fungal pathogen (*Batrachochytrium dendrobatidis*) is a primary cause of many catastrophic losses (Lips *et al.* 2006). We can detect the pathogen using a non-lethal skin swab (Annis *et al.* 2004), predict its potential ecogeographical distribution (Ron 2005), predict local movement, and foresee the catastrophic effects on local amphibian faunas (Lips *et al.* 2006). Species most threatened with disease-induced extinction are those in high-elevation, riparian habitats, with small geographic ranges (Lips *et al.* 2003). High endemism of amphibians in upland areas throughout the tropics suggests that climate changes with or without associations with chytrid may also be devastating amphibians. The scope of the amphibian crisis is massive, and the local and global effects of these losses are numerous and widespread (Whiles *et al.* 2006). When amphibians disappear, we lose their roles in maintaining ecosystem function, and also any potential benefits they may offer to humans.

Important questions remain: *How can ecosystems continue to function in the absence of amphibians? What can be done to preserve some amphibian species for future generations? How can we stop these extinctions?* Research and conservation organizations do not have the answers to these questions at this time. Nevertheless, a large-scale commitment to truly maverick, but coordinated, conservation efforts is in order (Mendelson *et al.* 2006). Because multiple causes are involved, diverse and innovative solutions must be implemented. For those species affected by habitat loss, we need to continue current efforts aimed at safeguarding important sites. Understanding direct and indirect effects of chemicals on amphibians requires extensive additional levels of attention, as do contaminant-monitoring programmes. While over-harvesting does not affect most amphibian species, it represents a real problem for some, such as the Asian giant salamanders (*Andrias* spp.; see Essay 4.5). Unfortunately, effective solutions to global problems, such as climate change and emerging infectious diseases, do not currently exist. Responses to threats related to climate change will require global commitment to alternative fuels and reduced emissions, and reconfiguring protected areas to encompass broad elevational ranges, in order to account for potential shifts in species distributions. Solutions to emerging infectious diseases will require significant levels of funding and aggressive research to better understand the epidemiology and pathology of the diseases, and to develop vaccines and/or resistance in wild populations.

Creating and implementing global solutions to these global threats requires significant levels of commitment, organization, funding, and – especially – time. In cases of predicted catastrophic losses, the only conservation tool we have at our disposal is the establishment of *ex-situ* survival assurance colonies (Mendelson and Rabb 2006). Captive programmes are not a solution to the actual problems, but they may preserve living colonies of individuals, increase numbers through breeding, and potentially serve as research colonies to enable timely studies of pathology and evolution of resistance. The challenge again is a matter of scale: there are currently fewer than 40 amphibian species in managed *ex-situ* programmes (Zippel 2005), yet at least five times that number require urgent *ex-situ* conservation action (Appendix VII). These numbers represent a major challenge for zoos, gardens, and aquariums (see Essay 11.5).

Many species need immediate attention to prevent their extinction, and potentially thousands of others remain to be discovered or described. It is not uncommon to encounter several new species per trip to certain regions of Latin America, especially upland areas, which are most affected by threats related to climate and disease. As a result, we are losing species we never knew existed. Among the current authors, JRM has described about 40 new species of Latin American amphibians in the past 15 years, but already half of them are likely extinct. Similarly, KRL has observed the annihilation of the amphibian faunas at five different sites in Latin America in the past 15 years. Of course, we hope our experiences are the exceptions, or even inaccurate, but we're very afraid that they are close to reality.

Karen R. Lips and Joseph R. Mendelson III

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The Global Amphibian Assessment sharpened the scientific community's focus on both the nature and extent of threats to amphibians worldwide. Now is the time to act on new knowledge regarding the causes of an ongoing amphibian extinction event. Clear and internationally coordinated options for thwarting further extinctions of threatened amphibians must be developed with parties capable of implementing actions. The Amphibian Conservation Summit was called in September 2005 to design and promote a response to this global crisis. To this end, the participants in the summit and now the newly formed IUCN/SSC Amphibian Specialist Group (ASG) commends the Amphibian Conservation Action Plan (ACAP) to governments, the business sector, civil society, and the scientific community for urgent and immediate adoption and implementation.

Participants in the Amphibian Conservation Summit set priorities for conservation and research actions within 12 areas relevant to amphibian conservation: 1) Designing a network of conservation sites for amphibians – Key Biodiversity Areas; 2) Freshwater resources and associated terrestrial landscapes; 3) Climate change, biodiversity loss, and amphibian declines; 4) Infectious diseases; 5) Over-harvesting of amphibians; 6) Evaluating the role of environmental contamination in amphibian population declines; 7) Captive programmes; 8) Reintroductions; 9) The continuing need for assessments, making the Global Amphibian Assessment an ongoing process; 10) Systematics and conservation; and 11) Bioresource banking efforts in support of amphibian conservation. The ACAP embodies this work, although we recognize that additional themes may need to be addressed in future versions of the document.

A declaration (Appendix VI) was released following the Summit urging four kinds of intervention that are needed to conserve amphibians, all of which should be initiated with immediate effect: 1) Expanding our understanding of the causes of declines and extinctions; 2) Continuing to document amphibian diversity, and how it is changing; 3) Developing and implementing long-term conservation programmes; and 4) Responding to emergencies and immediate crises. The full text of the Amphbian Conservation Summit Declaration and ACAP is at (www.amphibians.org).

The amphibian extinction crisis requires a global response at an unprecedented scale. The ACAP requires the international community to enter uncharted territory and to take great risks. But the risks of inaction are even greater. The ACAP calls on all governments, corporations, civil society, and the scientific community to respond. There needs to be unparalleled commitment to developing and implementing the ACAP with accompanying changes in international and local environmental policies that affect this class of vertebrate animals – as they truly are the proverbial canaries in the global coal mine. This document offers practical, large-scale, creative, innovative and realistic actions that will be required to halt the present tide of extinctions of amphibian species and includes an ambitious yet realistic budget.

A unified global strategy incorporating survival assurance colonies, disease research, and habitat protection forms the focus of this new plan to save amphibians. We must, of course, also remain vigilant and act on other threats, including climate change, over-harvesting, and toxins. Lessons learned from confronting the amphibian crisis will be transferable to other groups and ecosystems. We have many other potential crises-in-the-making, such as coral reef collapses, fisheries collapses, emerging human diseases such as Ebola, SARS (Severe Acute Respiratory Syndrome), Nipah virus, and our poor record of managing freshwater resources that will certainly lead to global shortages of clean drinking water with great negative consequences. Many, if not all, of these environmental challenges are the result to varying degrees of the same human footprint that our species is leaving on this planet.

The road to success must include a broad set of stakeholders who help implement the ACAP. This is important because there are many issues that are beyond the simple realm of "amphibian conservation work." Addressing many of the underlying causes of this crisis will help us avert the next global environmental challenge. Helping curb unsustainable wildlife use would not only decrease some of the threats to particular amphibian species, but also help us apply these same solutions to other species. Similarly, tackling climate change, although a huge task in its own right, will make a major contribution to the continued survival of all species as well as to the sustainability of ecosystems in general.

Claude Gascon
Co-Chair IUCN/SSC Amphibian Specialist Group Secretariat
Executive Vice President, Conservation International, Virginia

James P. Collins
Co-Chair IUCN/SSC Amphibian Specialist Group Secretariat
Professor, School of Life Sciences, Arizona State University, Arizona

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Although we once again express our sincere thanks to the many individuals that contributed to the GAA below, it is also necessary here to extend particular thanks to those who helped make publication of *Threatened Amphibians of the World* a reality. Undertaking and producing a book of this scope has relied greatly on the dedicated help and willingness of a very large number of people, as borne out by the acknowledgements that follow.

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Introductory Chapters

CHAPTER 1. AN INTRODUCTION TO THE AMPHIBIANS

Neil Cox, Simon Stuart, Janice Chanson, Michael Hoffmann,
David Gower, Mark Wilkinson, Don Church and Robin Moore

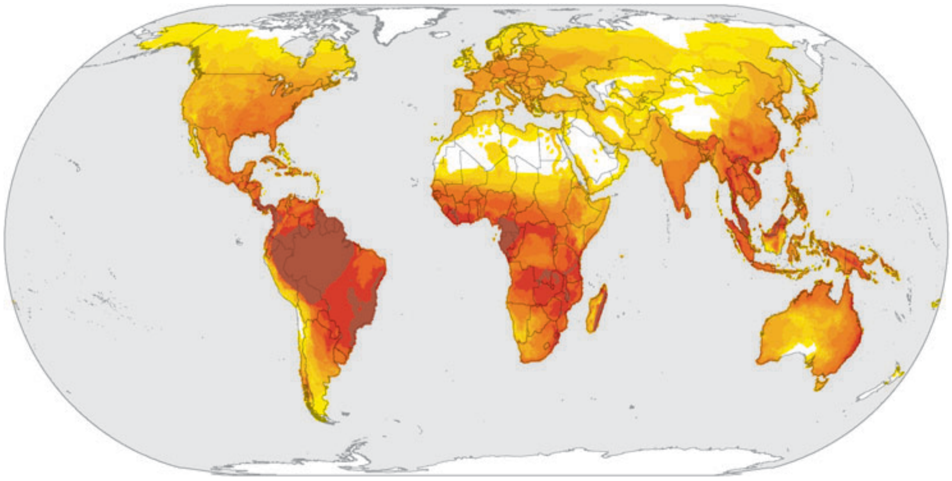


Figure 1. Species richness map for amphibians in the Order Anura, with dark red colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes. Maximum richness equals 142 species.

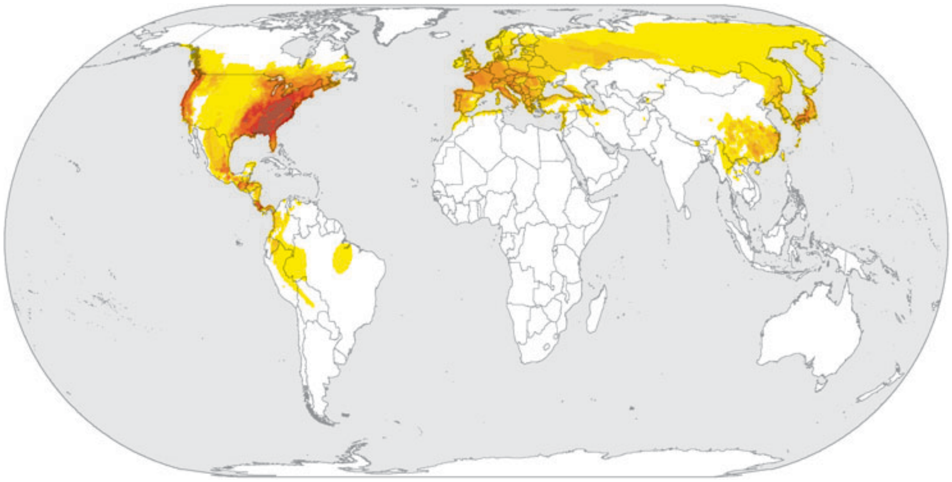


Figure 2. Species richness map for amphibians in the Order Caudata, with dark red colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes. Maximum richness equals 23 species.

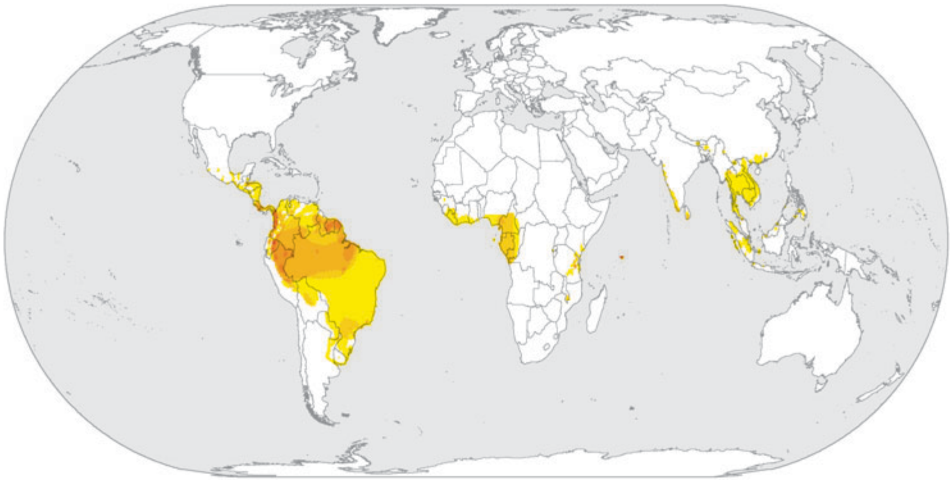


Figure 3. Species richness map for amphibians in the Order Gymnophiona, with dark red colours corresponding to regions of higher richness. Colour scale based on 8 quantile classes. Maximum richness equals 8 species.

AN OVERVIEW OF AMPHIBIAN CLASSIFICATION AND DIVERSITY

Amphibians are familiar to most people as frogs and toads, salamanders and newts, and to a much smaller group of people as caecilians. All amphibians are members of the tetrapod vertebrate Class Amphibia. There are more than 6,000 currently recognized species of extant amphibians, with representatives present in virtually all terrestrial and freshwater habitats, but absent from the coldest and driest regions, and from the most remote oceanic islands. The number of recognized species of amphibians has grown enormously in recent years, with a nearly 50% increase between 1985 and 2004 (Frost 1985, 2004) and an increase in species numbers of 25% in the years between 1992 and 2003 (Köhler *et al.* 2005) (and see Essay 1.1). This unprecedented growth largely reflects an increase in collecting work in previously remote locations, a significant growth of active herpetological communities in a few megadiverse countries, and the application of complementary techniques, such as molecular genetics, to support more traditional taxonomic methods. Even countries such as Sri Lanka, in which biodiversity inventories were deemed to be relatively complete (see Essay 1.2), are revealing startling levels of previously undocumented and unsuspected diversity. Unfortunately, as this book demonstrates, our rapid increase in the knowledge of amphibian species diversity and biology is coincident with a massive global decline in amphibian populations.

Frogs, Salamanders and Caecilians – the Amphibian Orders

The Amphibians are divided between three higher-level ranks or Orders: Gymnophiona, Anura and Caudata, with Anura and Caudata being more closely related to each other than either is to the Gymnophiona.

Anura is comprised of the frogs (and their subgroup, the toads), and is by far the largest Order, with 5,208 living species currently recognized[1]. Anurans are globally distributed, being found on every continent with the exception of Antarctica (Figure 1). While tropical habitats are richest in anuran diversity, frogs and toads may be encountered in many different environments ranging from dry deserts, through tropical and temperate regions to areas as far north as the Arctic Circle and as far south as Tierra del Fuego at the tip of South America. The elevation at which frogs have been recorded ranges from sea level (or even below it in some cases) to as high as 5,244m asl in the Peruvian Andes (Seimon *et al.* 2006). Although anurans have a wide variety of body shapes, adult frogs and toads are always tailless and have four limbs. The have a constrained and specialized body form including a very short body, an elongated pelvis, relatively large head, and two well-developed hind legs used for jumping and/or swimming. The frogs and toads range greatly in size. The giant Goliath Frog *Conraua goliath* of West Africa may grow to over 30cm (snout-vent length), while mature adults of the Flea-frog *Brachycephalus didactylus* of south-eastern Brazil and *Eleutherodactylus iberia* and *E. limbatus* of Cuba may be less than 1cm (snout-vent length). Virtually all species have external fertilization and most have aquatic larvae (tadpoles).

The Caudata (salamanders and newts) contains 535 described living species and is the second largest of the three amphibian Orders, although representing only about 10% of the number of species as frogs. Salamanders and newts are less widely distributed than the frogs and toads, with families mostly concentrated in the north temperate regions (Figure 2); but about 40% of the species occur in the New World tropics. There are no salamander or newt species in Sub-Saharan Africa, Madagascar, the Indian Subcontinent south of the Himalayas, insular Southeast Asia, and Australasia, and only a few in South America and mainland Southeast Asia. The southern Appalachian Mountains of the eastern United States is the centre of species diversity for the Caudata (see Essay 8.1). Around 60 species of the family Plethodontidae (lungless salamanders) are found in this mountain range, including many locally restricted species. Most salamanders and newts have the primitive tetrapod body shape, with four limbs and a long flattened tail, but there is also a tendency for body elongation and limb reduction or loss. They generally move over land by walking and aquatic species use their long tail for rapid swimming in water. Within the Caudata there are many well-known paedomorphic forms (sexually mature animals retaining juvenile characteristics). The highly threatened Axolotl *Ambystoma mexicanum* of the Valley of Mexico is probably the most familiar paedomorphic species. The largest of the Caudata, and indeed of modern amphibians, is the rapidly declining Chinese Giant Salamander *Andrias davidianus*, which may grow to around 200cm in total length; the smallest may be the salamander *Thorius arboreus* of Mexico, which has an average total length of only around 1.7cm. Most salamanders have internal fertilization via a spermatophore and aquatic larvae, but direct development of terrestrial eggs without an aquatic life-stage whatsoever is also common.

The Gymnophiona (caecilians) occur in the tropics of the Americas, Africa and Asia (Figure 3). In addition, caecilians are present on the Seychelles, but absent from Madagascar, New Guinea and Australasia; their apparent absence from much of the Congo Basin may be due to lack of survey effort. With only 172 described species, this is the smallest of the three amphibian Orders, even though the group is at least as old as all of the diversity of salamanders and frogs taken together. Because they tend to be rare animals in collections, the taxonomic status of many caecilian species is uncertain. According to our current understanding of caecilian taxonomy, the two most species-rich genera are *Ichthyophis* (34 species) of South and Southeast Asia, and *Caecilia* (33 species) occurring mainly in South America. Caecilians are elongated and limbless, and they are sometimes mistaken for snakes, eels or earthworms. The largest of the caecilians is the poorly known *Caecilia thompsoni* of Colombia, which may exceed 150cm in length. The smallest caecilian is probably the threatened *Grandisonia brevis* of the Seychelles Islands, which grows little larger than 11cm. In general, caecilians are 'burrowing' species and are most often encountered in leaf-litter or under soil. A few are aquatic species (such as the Rubber Eel *Typhlonectes natans*). Caecilian species show a relatively wide range of reproductive modes. All species seem to have internal fertilization and at least 31 of the known species are live-bearing. Oviparous caecilians lay their eggs on land have either direct development or an aquatic larva (and see Essay 1.3).

Amphibian classification at the family level

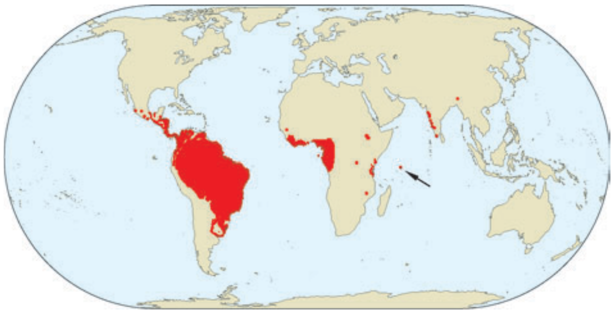
At a slightly finer taxonomic level, amphibians are divided up among 48 families, some of which, like the recently named Nasikabatrachidae (Biju and Bossuyt 2003), are monotypic (including only a single species), whereas others, particularly the Hylidae and Leptodactylidae, are represented by hundreds of species, the latter including the genus *Eleutherodactylus*, the most speciose vertebrate genus with more than 600 species (see Essay 1.4). Amphibian classification was relatively stable for much of the 20th century, but the very roots of the amphibian tree have been shaken by a new classification proposed by Frost *et al.* (2006). Frost and associates showed that a number of traditionally recognized groups (including entire families) are para- or polyphyletic (in other words, they are not natural groups in terms of evolutionary history). The new classification proposed by Frost *et al.* (2006) appeared while this book was in preparation. Thus, we use the traditional classification of amphibian families (following Frost 2004). However, in this chapter, we outline the new classification of Frost *et al.* (2006), as amended by Grant *et al.* (2006) and Glaw and Vences (2006), to show some of the major taxonomic changes that are now under discussion. We also discuss the implications of Frost *et al.* (2006) in the regional introductory chapters.

The Traditional View of Amphibian Families

This section presents the traditionally recognized amphibian families, alphabetically within each order.

Caecilians – Gymnophiona

Caeciliidae. This is the largest of the caecilian families, containing 113 species, distributed within 21 genera. Many of these species are known from fewer than 10 specimens and little is known of species ranges and biological attributes. In this treatment, the semi-aquatic to aquatic species of South America, often recognized as the Family Typhlonectidae, are included in the Caeciliidae. Representatives are widely, but disjunctly, distributed throughout much of the tropics, being found in South and Central America, West and East Africa, on the Indian Subcontinent and also on the Seychelles Islands (uniquely, there are more caecilian species in the Seychelles than there are frogs). Although the breeding biology of most caeciliid species remains poorly known at present, larval-developing, direct-developing and live-bearing species have all been recorded.

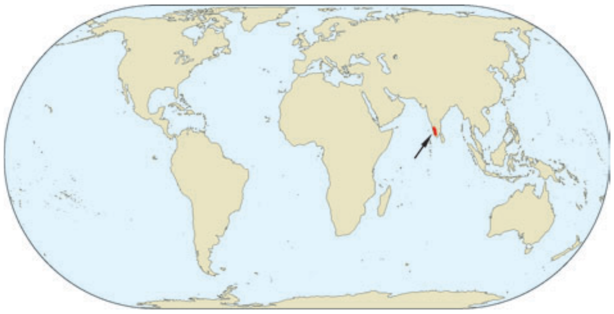


Ichthyophiidae. This poorly known family of caecilians is widely distributed in South Asia and Southeast Asia. The 39 recognized species are divided between the two very poorly delimited genera *Ichthyophis* and *Caudacaecilia*. However, many of the currently named species are poorly circumscribed and require taxonomic confirmation. All taxa are egg-layers. The eggs are deposited in underground chambers and they are guarded by the mother at least until hatching. The larvae may be encountered in waterlogged soil, streams, ponds and other waterbodies.

Rhinatrematidae. This poorly known family of caecilians is restricted to northern South America, with most species known from the tropical Andes. The genus *Epicrionops* has eight species and *Rhinatrema* one. All species are presumed to lay eggs on land, with the larvae living in waterbodies.

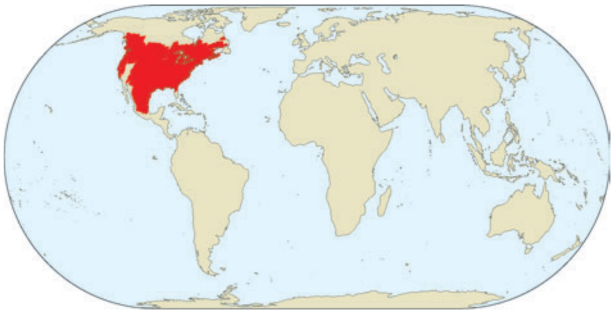
Scolecomorphidae. This poorly known family of caecilians comprises two genera, the West African *Crotaphatrema* and East African *Scolecomorphus*, with three species in each. We know very little about *Crotaphatrema*, as only seven individuals have ever been seen, all from western Cameroon. The diversity of the genus *Scolecomorphus* is centred on eastern Tanzania. Two of the species are known to be live-bearing, and the third is presumed to be so.

Uraeotyphlidae. This small family of caecilians contains only five species all of which are in the genus *Uraeotyphlus*. The family is entirely restricted to the Western Ghats and surrounding parts of southern India. The breeding biology of the family is poorly known, but they are probably all oviparous species with terrestrial eggs and aquatic larvae.



Salamanders and Newts – Caudata

Ambystomatidae – Mole Salamanders. This family of 30 species (all within the genus *Ambystoma*) is strictly North American (occurring south to central Mexico), where they range widely throughout much of the continent. Animals are largely terrestrial and breed in slow or still waters but some are stream-dwellers; all species undergo larval development. The family includes a number of paedomorphic species that retain larval characteristics (such as gills) as adults, including the famous Axolotl *Ambystoma mexicanum*.

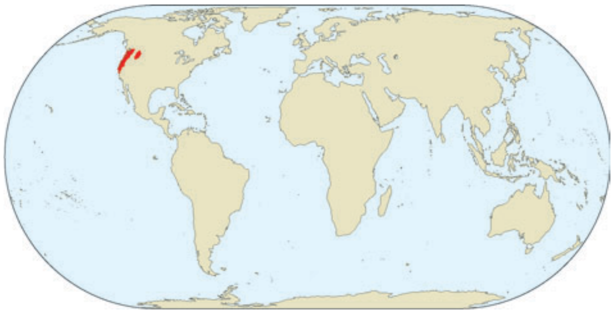


Amphiumidae – Amphiumas. This family contains three species, all in the genus *Amphiuma*, and is endemic to the coastal plain of the eastern and south-eastern United States. These are relatively large, eel-like salamanders, which are specialized for a mostly aquatic lifestyle. The eggs of these species are laid in a moist cavity on land close to the water; the female guards the nest until the larvae hatch and are washed into the adjacent water. An interesting feature of the larvae is their external gills, which disappear once the lungs develop.

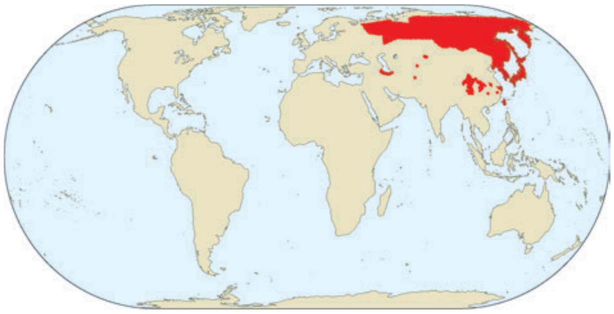
The Pickerel Frog Rana palustris *(Least Concern), found over much of eastern North America, is a typical representative of the very diverse amphibian Order Anura, which includes the frogs and toads. © Don Church*

Cryptobranchidae – Giant Salamanders. This small family is entirely aquatic. Cryptobranchidae are very large salamanders placed in three species in two genera (*Andrias* and *Cryptobranchus*). The family has a disjunct distribution with species present only in East Asia and the eastern United States. The species undergo larval development, with paired strings of externally fertilized eggs deposited under stones or between rocks within streams and other waterbodies. This family contains the largest (~200cm) and the heaviest (~50kg) of the modern day amphibians, the Chinese Giant Salamander *Andrias davidianus.*

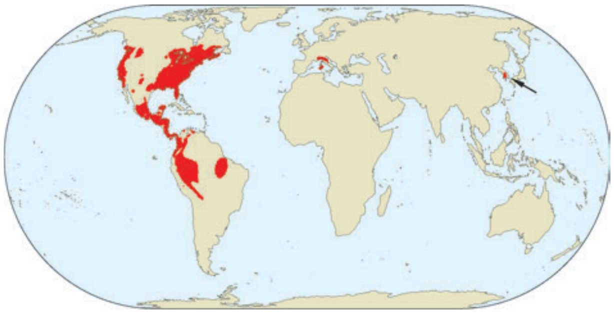
Dicamptodontidae – Pacific Mole Salamanders. This small family of relatively large, larval-developing salamanders is restricted to western parts of the United States, with one species occurring marginally in Canada. All four members are in the single genus *Dicamptodon.* The eggs are deposited in clear streams, where they are attached singly to rocks and other cover. The stream-adapted larvae take between 2 and 4.5 years to reach metamorphosis and may achieve sexual maturity without metamorphosing. One species, *Dicamptodon copei*, is exclusively paedomorphic.



Hynobiidae – Asian Salamanders. These salamanders are Asian with a centre of diversity in Japan, with only the very widespread Siberian Salamander *Salamandrella keyserlingii* also present in extreme eastern Europe. There are 46 species divided between the seven genera, with *Hynobius* being the most speciose (27 species; see Essay 10.1). The salamanders of this family are highly aquatic, living mostly in streams and pools, and have external fertilization, and the eggs are laid in two egg-sacs attached to rocks or submerged vegetation. In some species, the male is known to guard the eggs.

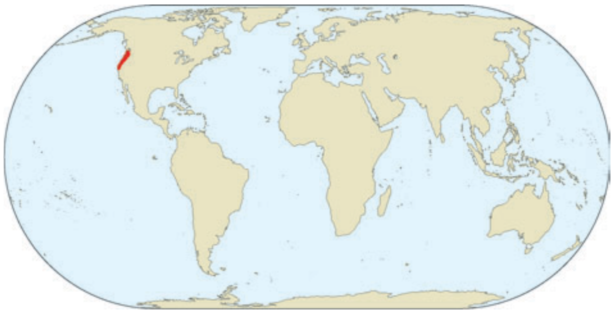


Plethodontidae – the Lungless Salamanders. This is the largest of the salamander families, with the vast majority of the 365 species being found in the New World (see Essay 9.3). Outside of this region there are seven species known from Europe, and a single, recently discovered Asian species (*Karsenia koreana*) currently known only from the middle of the Korean Peninsula. Plethodontids are the only salamanders that have a substantial presence in the New World tropics, where more than 60% of the species are found, most of them in Central America. The family is generally present in a wide variety of habitats including damp terrestrial areas, waterbodies (both stagnant and flowing), cave and similar habitats, and arboreal sites (such as within bromeiliads). Most of the species have direct development, unique to this family among salamanders; however, at least 50 species undergo larval development.

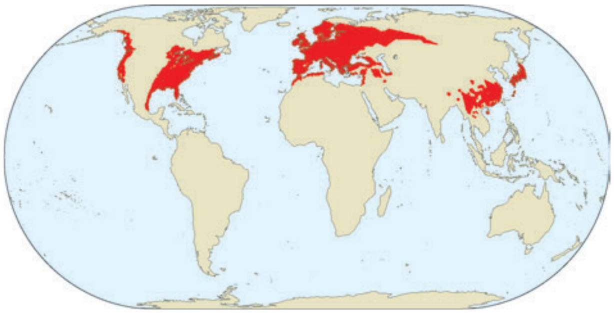


Proteidae – Mudpuppies and Waterdogs. This small family of salamanders comprises five species in the genus *Necturus,* found in the streams of eastern North America, and the single strange species, the Olm *Proteus anguinus*, which is restricted to subterranean aquatic habitats within the Dinaric Alps of south-eastern Europe. All of the species are both aquatic and paedomorphic. The breeding biology of this family is poorly known; however, female Olms have been recorded laying ~70 eggs on rocks, and, in addition, the species is occasionally live-bearing with fully formed young born after a period of about two years.

Rhyacotritonidae – Torrent Salamanders. This small family of four species, all in the genus *Rhyacotriton*, is endemic to the Coastal and Cascade Ranges of the western United States. Populations of these salamanders are usually closely associated with cold streams in old-growth coniferous forest. All four species undergo larval development.



Salamandridae – Newts and Relatives. This family is widespread with representatives present in Europe, North Africa, Asia and North America. Most of the species within Salamandridae are aquatic breeders, laying eggs in ponds, streams and other suitable waterbodies. A small number of the species, including the well-known Fire Salamander *Salamandra salamandra*, are live-bearing.



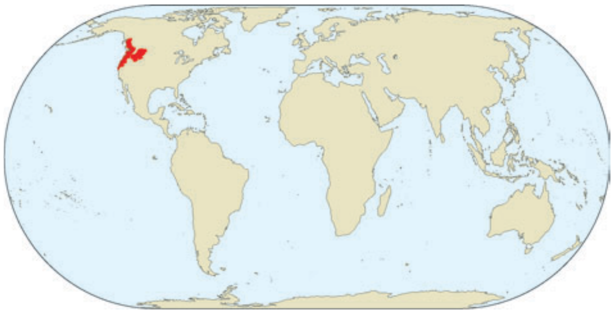
Sirenidae – the Sirens. This small family has two genera (*Siren* and *Pseudobranchus*) with four species, and is restricted to the south-eastern United States and northern Mexico. Animals are mostly aquatic; the eggs are deposited singly or in small numbers, and are attached to submerged vegetation.

Frogs and Toads – Anura

Allophrynidae. This monotypic family is generally widespread in northern South America, where it ranges from Venezuela, through much of the Guiana region and into north and eastern Brazil[2]. The single species is largely associated with water bodies, where explosive breeding and larval development take place. The classification of the family, and the single recognized species, *Allophryne ruthveni*, has been problematic. *Allophryne* has previously been assigned to a number of families, including Allophrynidae, Bufonidae, Centrolenidae, Hylidae and Leptodactylidae.

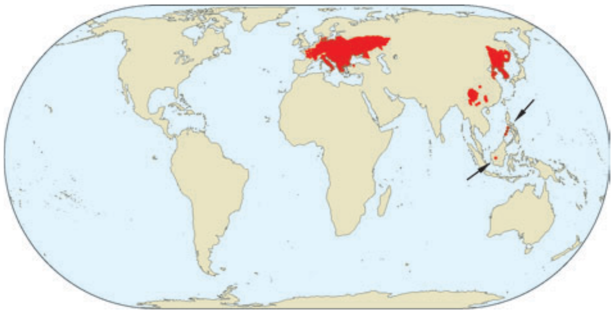
Arthroleptidae – Squeakers or Screaming Frogs. This family is dominated by the direct-developing genus *Arthroleptis* (34 species), which is widely distributed in more mesic environments of the African mainland. Together with *Schoutedenella*, it is one of the most taxonomically confused groups of frogs in the world, with many species in Sub-Saharan Africa being of uncertain identity, and with large numbers of species remaining to be described. The third genus in the family, *Cardioglossa* (16 species), is represented by stream-associated, larval-developing frogs in West and Central Africa, with the centre of known diversity in Cameroon.

Ascaphidae – Tailed Frogs. The small family Ascaphidae contains only two species, both in the genus *Ascaphus*. The family exhibits a number of primitive characteristics, and is unique among the frogs and toads in that animals posses a copulatory organ (the eponymous "tail") that allows internal fertilization to take place in the fast-flowing streams they inhabit. The unpigmented eggs are attached as strings to the underside of rocks within the stream; the larvae also develop within this environment. The family is endemic to North America, where it is distributed in the north-western USA and south-western Canada.



Astylosternidae. This family of stream-associated, larval-developing frogs has its centre of diversity in Cameroon, with a few species occurring more widely within the equatorial forest belt. Two genera, *Astylosternus* (11 species) and *Leptodactylodon* (15 species) dominate the family, with three monotypic genera, one of which, *Trichobatrachus*, is the famous Hairy Frog.

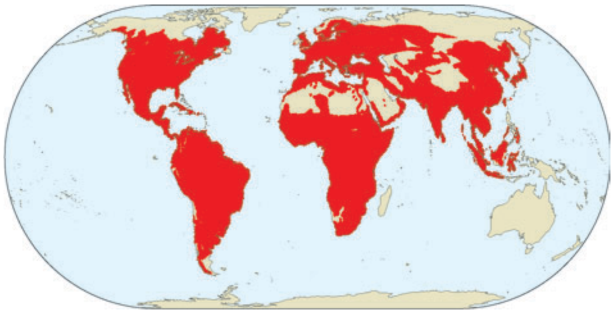
Bombinatoridae – Fire-bellied Toads. This small family of only 10, often colourful, species is widely distributed in Europe and Asia. There are two genera, *Bombina* (eight species), which mostly ranges from Western Europe into East Asia, and the poorly known genus *Barbourula*, that has only two known species, one present in the Philippines and one in Borneo. *Bombina* are all believed to undergo larval development; the reproductive mode of *Barbourula* is currently unknown, but they are suspected to be direct-developing species.



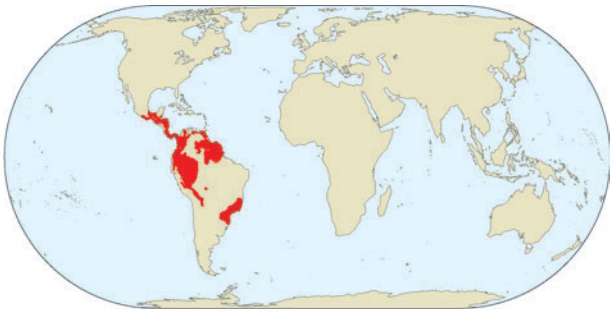
Brachycephalidae – Saddle-back Toads or Pumpkin Toadlets. This small family of toads is restricted to the humid forests of the Atlantic coast of south-eastern Brazil. There is a single genus, *Brachycephalus*, containing the eight known species[3] - five of these having been described since 1998. These small toads live in leaf litter on the forest floor, and are all believed to deposit a few large, terrestrial eggs and to undergo direct development.

This Spotted Salamander Hynobius naevius *(Least Concern) is one of sixteen* Hynobius *salamander species found only in Japan. The only other representatives of the Family Hynobiidae are found in mainland China (six species), the island of Taiwan (three), and the Korean Peninsula (three). © Henk Wallays*

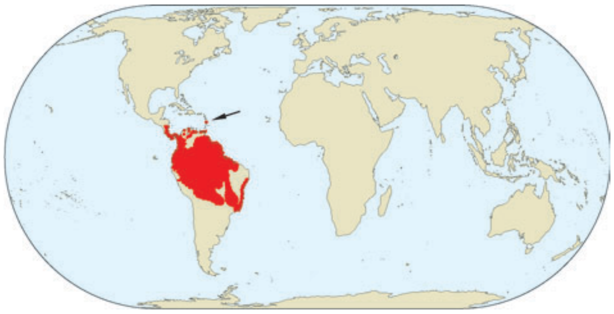
Bufonidae – True Toads. Members of the Bufonidae are near global in occurrence, being absent naturally from Madagascar, New Guinea, Australia and surrounding islands. Species occupy a wide variety of habitats, from very arid conditions to humid tropical rainforest. It is a speciose family and although the vast majority of the species have larval development, there are some direct-developing and live-bearing species. The genus *Nimbaphrynoides* (two species), includes the only fully viviparous frog species (with the embryos being nourished internally by the female).



Centrolenidae – Glass Frogs. This speciose Neotropical family ranges from southern Mexico to Bolivia and north-eastern Argentina. The family is overwhelmingly concentrated in the tropical Andean countries (Colombia, Ecuador, Peru and Venezuela), where 124 species (90% of the total) occur. Most species are arboreal to some degree, and typically lay small clutches of eggs on vegetation or rocks overhanging water. On hatching, the larvae fall into the water below and complete their development. Members of this family are unusual, in that the dorsal part of the body is commonly a shade of green, whereas the ventral side is often transparent, allowing many of the internal organs to be seen.



Dendrobatidae – Poison Frogs. The dendrobatids are almost exclusively confined to the tropics of Central and South America. The greatest diversity is in the tropical Andean countries, where 190 species (81% of the total) occur. A single species occurs in the Lesser Antilles (on Martinique). Only a few species are the familiar brightly coloured animals often seen in the pet trade (especially in the genera *Dendrobates*, *Epipedobates* and *Phyllobates*); the majority are less colourful, including most species of the largest genus *Colostethus* (131 species). Nearly all species have a larval phase. In some species an adult guards the eggs at the deposition site (such as a bromeliad), before carrying the hatched larvae on its back to water (usually a stream) where development is completed.

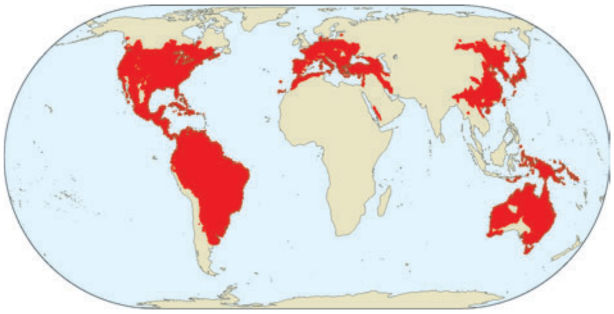


Discoglossidae – Painted Frogs and Midwife Toads. This small family has its distribution centred on the western Mediterranean Basin, with one species extending as far north as northern Germany, and a single species known from Israel (the now extinct Hula Painted Frog *Discoglossus nigriventer*). The 12 species are divided between two genera, *Alytes* and *Discoglossus*. Frogs of both genera undergo larval development in suitable waterbodies. The breeding behaviour of the genus *Alytes* is notable in that the males carry the strings of eggs wrapped around their back legs, taking them to the water when they are ready to hatch.

Heleophrynidae – Ghost Frogs. This small relict family of stream-associated, larval-developing frogs is endemic to southern Africa. All members are in the genus *Heleophryne*. These frogs are dependent on permanent streams because their tadpoles require two years to develop.

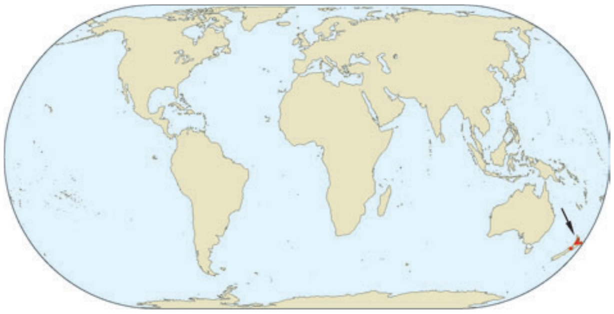
Hemisotidae – Snout-burrowers. This small family is widespread through much of the Sub-Saharan African mainland. All members are in the genus *Hemisus*. Eggs are laid underground in a nest cavity, and the tadpoles subsequently move into water where they complete their development (the females sometimes digging channels for them to move from the nest to water).

Hylidae – True Treefrogs. This family is the second largest clade of amphibians and consists of three subfamilies: Hylinae (Americas and northern Eurasia); Phyllomedusinae (tropical Americas); and Pelodryadinae (Australia, New Guinea and other islands). The family is particularly diverse in the New World, with only a few hylid genera occurring elsewhere (see Essay 1.5). Hylids occur throughout the Americas (with the exception of the extreme north and south), and are also widespread in Australia and New Guinea. Elsewhere, there are a few species in Europe and northern Asia, but the family is absent from most of tropical Asia, and all of Sub-Saharan Africa and Madagascar. Many species are arboreal, although there are exceptions, with terrestrial and aquatic species also. The vast majority of species undergo larval development. The subfamily Hemiphractinae, which included only species that undergo direct development, was recently shifted to the family Leptodactylidae (Faivovich *et al.* 2005).



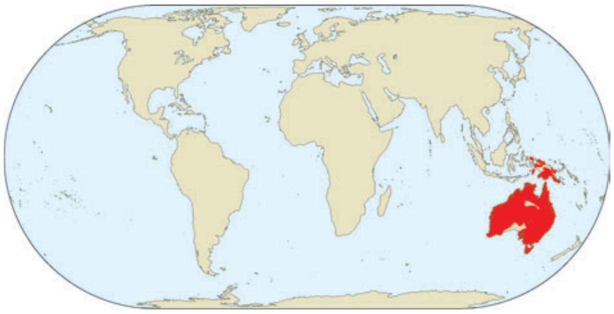
Hyperoliidae – African Treefrogs and Reed Frogs. This large family comprises 18 genera, including *Hyperolius* (125 species), *Leptopelis* (51 species), *Afrixalus* (32 species) and *Kassina* (13 species). Hyperoliids can be found in most habitats throughout the Afrotropical region, including Madagascar and the Seychelles Islands. Nearly all the members of the family undergo larval development, but a wide variety of reproductive strategies occur within the family. Under certain conditions, females of at least one species, *Hyperolius viridiflavus*, can change into fully functional males (Grafe and Linsenmair 1989). Hyperoliids are closely related to arthroleptids and astylosternids (with some authors suggesting that *Leptopelis* is, in fact, closer to these groups than to other hyperoliids), sharing many characteristics with them.

Leiopelmatidae – New Zealand Frogs. This endemic New Zealand family comprises four largely terrestrial species in the single genus *Leiopelma*. The female lays large unpigmented eggs in damp locations on the ground, which undergo direct development. The males of three of the species (*Leiopelma archeyi*, *L. hamiltoni* and *L. pakeka*) actively guard the eggs and transport the developing young. Leiopelmatidae is particularly interesting in the apparent retention of a number of primitive characteristics for frogs (see Essay 6.2), mostly shared with Ascaphidae.



Leptodactylidae – the Southern Frogs. This is by far the most speciose of all the amphibian families, with the genus *Eleutherodactylus* alone containing 610 species (and see Essay 1.4). The Leptodactylidae are found throughout South and Central America, with a few species ranging as far north as the southern United States. The family is diverse morphologically, with some species exclusively adapted to terrestrial, arboreal or aquatic lifestyles. Even though the largest group in the family (Eleutherodactylinae) breed by direct development, many are larval developing and at least one species, the Critically Endangered Golden Coqui *Eleutherodactylus jasperi*, is live-bearing.

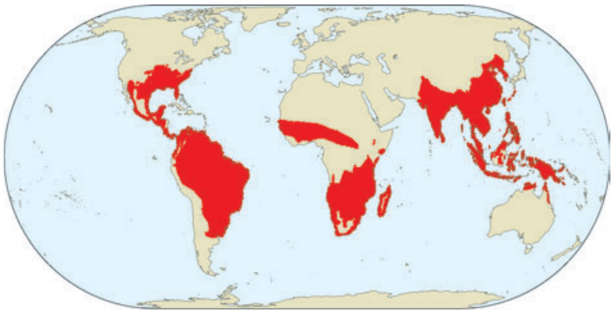
Limnodynastidae. This family of 50 species is distributed from the Aru Islands of Indonesia, through New Guinea and much of Australia, to the island of Tasmania. Five genera (*Adelotus*, *Heleiporus*, *Neobatrachus*, *Notaden* and *Philoria*) are endemic to Australia, and only five species occur outside of Australia, with four endemic to New Guinea. All of the eight genera are larval developing, with some genera (such as *Limnodynastes*) depositing eggs in floating foam nests. The Tusked Frog, *Adelotus brevis*, is unusual in that adults have small tusk-like teeth sticking up from the bottom jaw; these might possibly be used in defence of the nest (Duellman and Trueb 1994).



Mantellidae. This family is endemic to Madagascar, and is dominated by the genera *Mantidactylus* (86 species) and *Boophis* (53 species). However, by far the best-known members of the family are the brightly coloured Madagascar poison frogs of the genus *Mantella* (15 species). There are two other smaller genera. The family includes both larval- and direct-developing species.

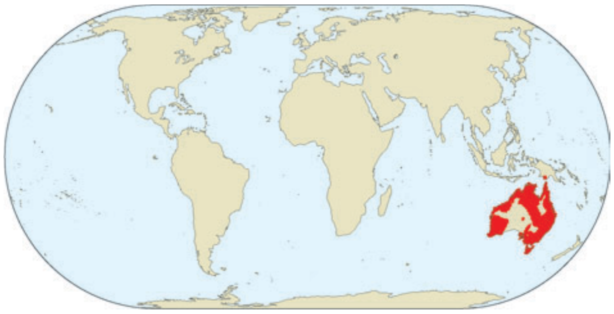
Megophryidae – Asian Spadefoots. These often-large Asian frogs range from India and Pakistan through much of Southeast Asia, to the Philippines, Borneo and the Sunda Islands. The family is quite diverse with 10 genera, the most species-rich of these being *Xenophrys* (31 species). All of the species undergo larval development in streams or similar habitats.

Microhylidae – Narrow-mouthed Toads. This diverse, large Anuran family is globally widely distributed, and may be encountered in many different habitats. The 69 recognized genera include many highly specialized forms, with a number of species adapted to either a largely fossorial or arboreal lifestyle. Both larval-developing and direct-development reproductive modes have been recorded. Although many of the direct-developing species are found on New Guinea, there are direct-developing genera outside of this region such as *Breviceps* in Africa and *Myersiella* in Brazil.

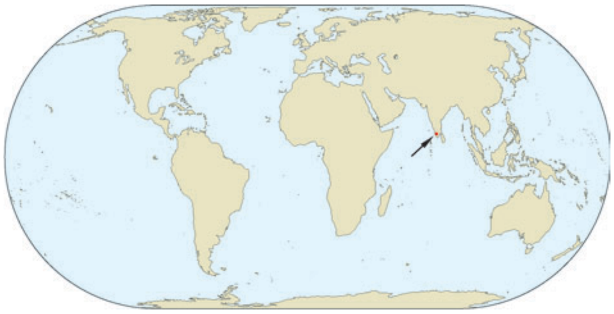


Hemiphractus fasciatus *(Near Threatened) from Panama, Colombia and Ecuador, is one of six species contained within in the newly proposed Family Hemiphractidae (currently included in Leptodactylidae). All species are highly specialized treefrogs from primary rainforest that feed only on other frog species. © Edgargo Griffith*

Myobatrachidae. This family is distributed in southern New Guinea and much of Australia, including the island of Tasmania. The family comprises 71 species and 11 genera, with the three largest genera being *Uperoleia* (24 species), *Crinia* (15 species) and *Pseudophryne* (13 species). All species are endemic to Australia except for *Crinia remota*, which is found in northern Australia as well as the southern lowlands of New Guinea (both Indonesia and Papua New Guinea), and *Uperoleia lithomoda* which occurs in northern Australia as well as the southern lowlands of Papua New Guinea. Members are for the most part terrestrial, with a number of burrowing species (e.g., *Arenophryne*). There are both larval-developing and direct-developing species within the family. The monotypic genus *Assa* is unusual in that the hatching larvae are carried in brood pouches on the hips of the male.



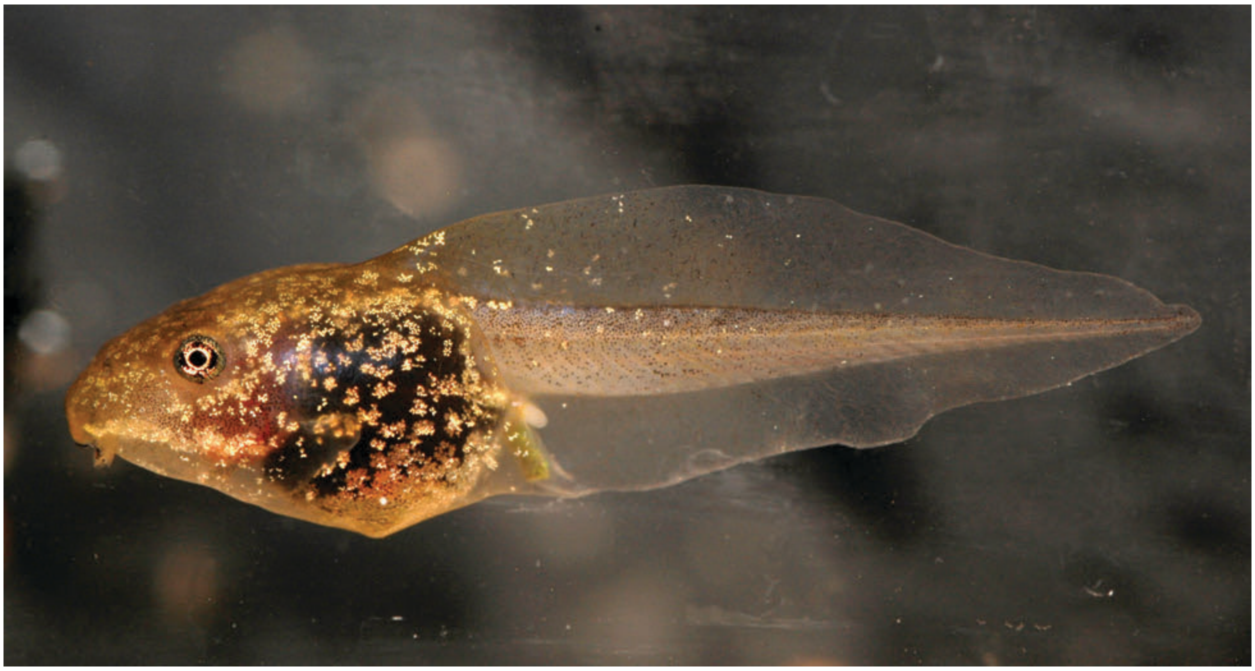
Nasikabatrachidae – Indian Burrowing Frog. This recently described, currently monotypic, family is known only from a few localities in the Western Ghats of southern India. For much of the year animals are fossorial, living up to 3.7m below ground. The species undergoes larval development, with the adults coming to the surface for a few weeks each year to breed and deposit their eggs in both temporary and permanent waterbodies. This new family appears to be most closely related to the Sooglossidae of the Seychelles Islands.



Pelobatidae – Western Palaearctic Spadefoots. This small family consists of only four species, all in the genus *Pelobates*, ranging from Morocco and Iberia in the west, through Europe, Southwest Asia and the Caucasus Mountains to western Kazakhstan. All four species are larval developing, with adults generally spawning in stagnant temporary waterbodies. The adults are adapted to digging in soil, spending much of the year underground, and generally require uncultivated sandy habitats.

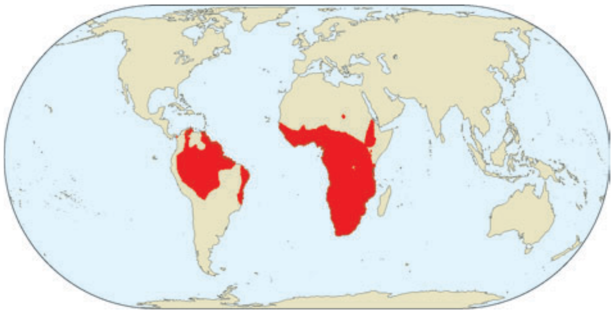
Pelodytidae – Parsley Frogs. This small family, consisting of three species all in the single genus *Pelodytes*, has a disjunct distribution in south-western Europe and the Caucasus Mountains. All species undergo larval development, with eggs laid in short strings.

Petropedetidae. This family is widespread in Africa, and is dominated by the puddle frogs of the genus *Phrynobatrachus* (66 species). There are 13 genera in total, eight of which are monotypic. Other genera are *Cacosternum* (10 species), *Arthroleptella* (7 species), *Petropedetes* (7 species) and *Arthroleptides* (3 species). The family exhibits a wide range of reproductive modes, although the great majority are larval developers.

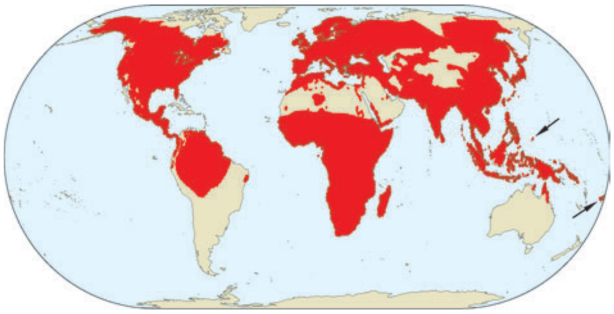


The most familiar of amphibian larvae are the free-swimming 'tadpoles' of the frogs and toads. The body shape is roughly ovoid, with a long laterally compressed tail used for swimming. Pictured here is a larval Wood Frog Rana sylvatica *(Least Concern). © Twan Leenders*

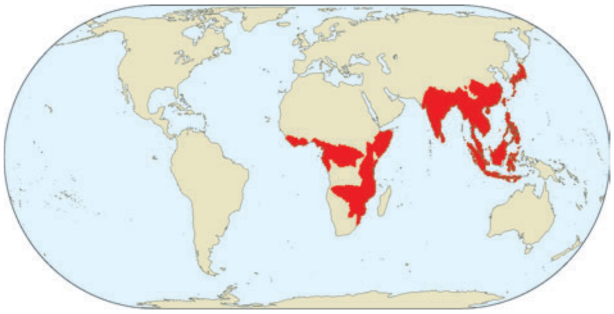
Pipidae – Tongueless Frogs. This small, distinct family of highly aquatic frogs is restricted to South America and Sub-Saharan Africa. The Pipidae is unique among frogs in that species do not have a tongue. In African genera, such as *Xenopus*, small pigmented eggs are laid in water and undergo larval development. In the South American genus *Pipa*, the eggs are laid into the females back and in some cases (such as in the Surinam Toad *Pipa pipa*) these eggs develop directly into frogs without a larval stage.



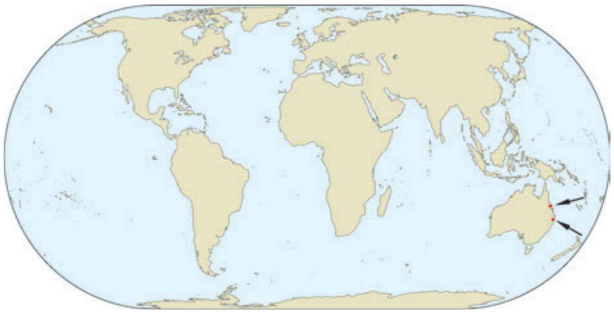
Ranidae – True Frogs. This is the third largest Anuran family, and with a few exceptions, for instance most of Australia and New Zealand, it has a very cosmopolitan distribution. Members of this family may be found in a wide variety of arid, temperate and humid tropical habitat types. While most reproduce through larval development, there are a number of direct-developing genera such as *Platymantis*. The Ranidae contains the largest living anuran, the Goliath Frog *Conraua goliath*, which can grow to over 30cm and weigh over 3kg.



Rhacophoridae – Asian Treefrogs. This large family of mostly arboreal frogs is widely distributed in Asia and Africa. Of the nine genera, the most species-rich are *Philautus* (146 species) and *Rhacophorus* (64 species), both of which are restricted to Asia. The family includes a diversity of both larval- and direct-developing species. Some species of the genus *Rhacophorus* have extensively webbed toes that enable them to glide between trees.



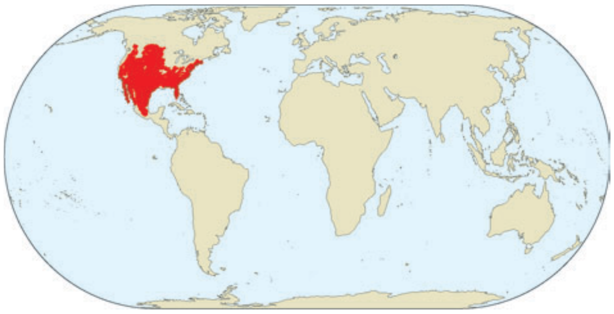
Rheobatrachidae – Gastric-brooding Frogs. This family was restricted to eastern Queensland, Australia, and is now considered to be extinct. There were only two species in the family, *Rheobatrachus silus* and *R. vitellinus*, both of which shared a unique reproductive mode. The eggs and larvae were brooded within the stomach of the female, with the larvae feeding off of the egg yolk before emerging from their mother's mouth as fully formed frogs (see Essay 6.1). The status of this family has long been controversial, with a number of authors including it as a subfamily within either the Limnodynastidae or the Myobatrachidae.



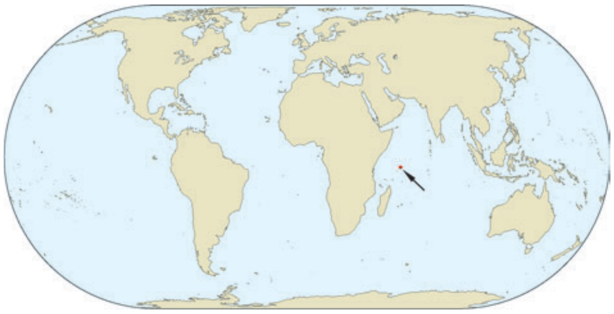
Rhinodermatidae – Darwin's Frogs. This small terrestrial family from the temperate forests of Chile and neighbouring southern Argentina contains only two species, both within the genus *Rhinoderma*. The small clutches of unpigmented eggs are laid in leaf litter. In *Rhinoderma rufum*, the male takes up the hatching larvae in its mouth and transfers them to water to complete their development. In Darwin's Frog, *Rhinoderma darwinii*, the male not only takes the larvae into its mouth, but also broods the larvae in the vocal sacs until development into froglets is completed.

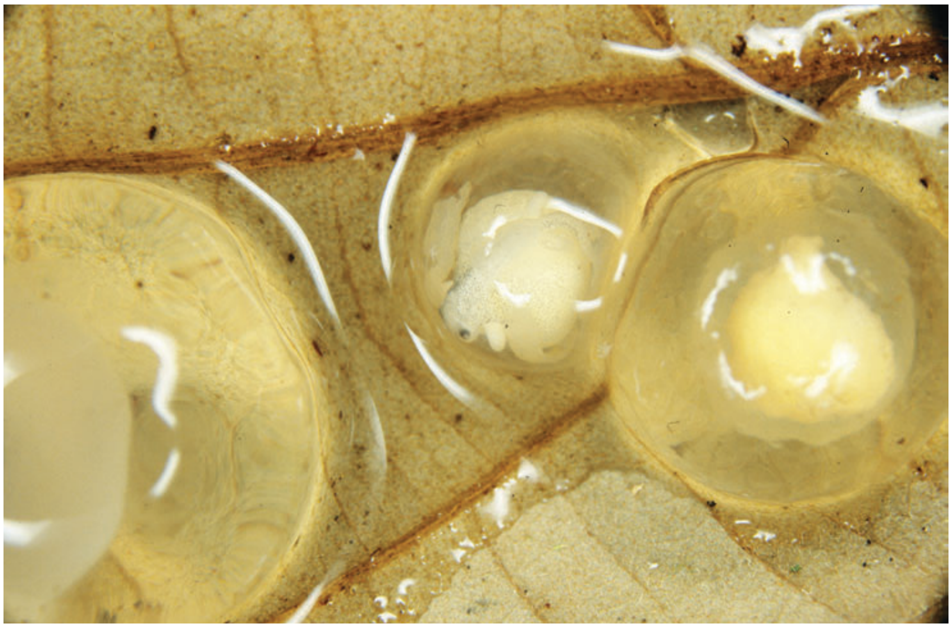
Rhinophrynidae – Burrowing Toad. This monotypic family is largely restricted to the coastal lowlands of Central America. The single species, *Rhinophrynus dorsalis*, is for the most part fossorial, coming only to the surface to mate during the rainy season; the eggs and larvae develop in temporary pools formed by heavy rains.

Scaphiopodidae – North American Spadefoots. This small family of seven species, divided between the two genera *Scaphiopus* and *Spea*, has been included by some authors in the family Pelobatidae. All of the species tend to burrow in loose soil, with adults emerging to breed in temporary pools during the rainy season. In general, the larvae develop quickly before the seasonal desiccation of their habitat.



Sooglossidae – Seychelles Frogs. This family is endemic to the Seychelles Islands, and comprises four species in two genera. Three species breed by direct development, and in one the larvae are carried on the adults' backs.





Direct development is one of the three basic amphibian breeding strategies. In this photograph, the young of the Bornean shrub-frog Philautus amoenus *(Vulnerable) can be seen developing into frogs without undergoing a free-living larval stage. © Andreas & Christel Nöllert*

The Proposed Revisions to Amphibian Families

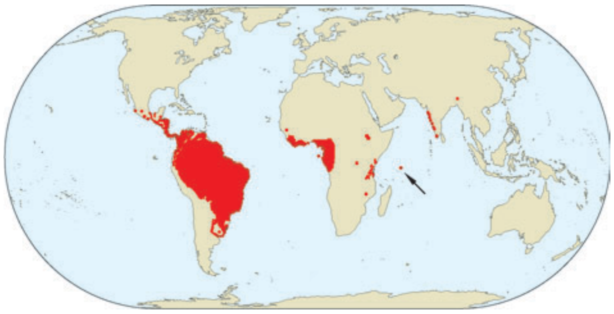
For some time it has been recognized that the traditional classification of amphibian families, especially among the frogs, does not reflect their evolutionary relationships (e.g., Darst and Cannatella 2004; Faivovich *et al.* 2005; Grant *et al.* 2006). Frost *et al.* (2006) proposed a new taxonomy of living amphibians, based on analysis of the interrelationships of 522 species selected to the best of their ability to reflect the entire amphibian tree, using molecular genetic data and also taking into account anatomical features, especially of larvae, following Haas (2003). The hypothesized evolutionary tree of amphibians, which was modified somewhat by Grant *et al.* (2006) is summarized to the level of families in Essay 1.6. The merits and demerits of this new taxonomy are currently the subject of considerable debate among herpetologists. One group (e.g., Frost *et al.* 2006) emphasizes the need to move to a monophyletic taxonomy but retain traditional nomenclature which has been more-or-less universally employed for 250 years. The other group (e.g., Cannatella and Hillis 2004; Hillis 2007) emphasize the need for a monophyletic taxonomy, but promote abandoning traditional nomenclature for a new approach that they argue better reflects understanding of phylogeny, while simultaneously arguing that caution is needed before adopting any changes prior to more thorough investigation. Frost *et al.* (2006) acknowledge that their proposal will be subject to changes as more information becomes available, as has already happened in the case of Grant *et al.* (2006). In addition, there are differences of opinion among authors regarding how data are to be analysed, probably the most serious issue at hand. Although this will be a period of intense instability, the end result should be a much improved understanding of amphibian evolutionary relationships and a taxonomy that reflects this. Whatever the outcome of this debate, it is clear that: a) the traditional classification of amphibian families, which forms the basis of the analysis in this book, will not survive; and b) although there will certainly be some changes to our understanding of the amphibian tree in coming years, much of what is proposed by Frost *et al.* (2006) is likely to be adopted.

Much of the current debate concerning Frost *et al.* (2006) is focused on the generic, rather than the family level. This debate focuses in particular on the splitting up of three large genera, *Eleutherodactylus*, *Bufo* and *Rana*, but we do not discuss this further. It should be noted that the genus *Craugastor* was separated from *Eleutherodactylus* by Crawford and Smith (2005), and we do follow this change. In addition, the formerly large genus *Hyla* was split by Faivovich *et al.* (2005), a change that we have included.

Below, we go through the Frost *et al.* (2006) proposed new family structure for amphibians, as amended by Grant *et al.* (2006), in the order of the amphibian tree (Essay 1.6). Although there are many changes at the family level, the most far-reaching and complex have to do with the splitting up the Leptodactylidae and Ranidae, and the changes to these two families also impact several families that were previously recognized.

Caecilians – Gymnophiona

Caeciliidae. Frost *et al.* (2006) include the Scolecomorphidae in this pantropical family, but its content is otherwise unchanged.



Ichthyophiidae. Frost *et al.* (2006) include the Uraeotyphlidae in this Indomalayan family, but its content is otherwise unchanged.

Rhinatrematidae. This family remains unchanged.

Salamanders and Newts – Caudata

Cryptobranchidae. This family remains unchanged.

Hynobiidae. This family remains unchanged.

Rhyacotritonidae. This family remains unchanged.

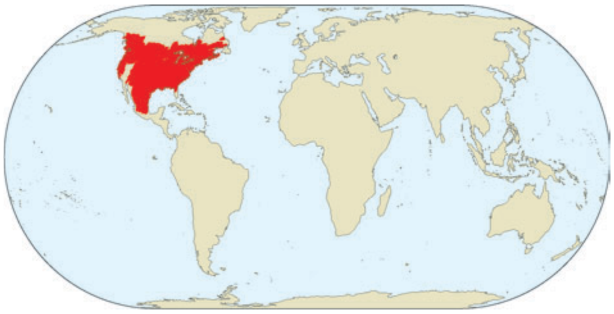
Amphiumidae. This family remains unchanged.

Plethodontidae. This family remains unchanged.

Proteidae. This family remains unchanged.

Sirenidae. This family remains unchanged.

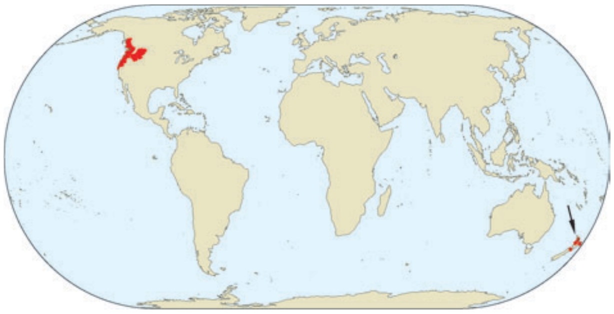
Ambystomatidae. Frost *et al.* (2006) include the Dicamptodontidae in this North American family, but its content is otherwise unchanged.



Salamandridae. This family remains unchanged.

Frogs and Toads – Anura

Leiopelmatidae. Frost *et al.* (2006) include the Ascaphidae in this family, returning to the taxonomy prior to Ford and Cannatella (1993), but its content is otherwise unchanged. As a result, this family now contains six species, and its distribution is in New Zealand and the Pacific Northwest of North America, with the New Zealand species breeding by direct development, and the North American ones by larval development.



Pipidae. This family remains unchanged.

Rhinophrynidae. This family remains unchanged.

Alytidae. This is the revised name for the family Discoglossidae, the content of which otherwise remains unchanged.

Bombinatoridae. This family remains unchanged.

Megophryidae. This family remains unchanged.

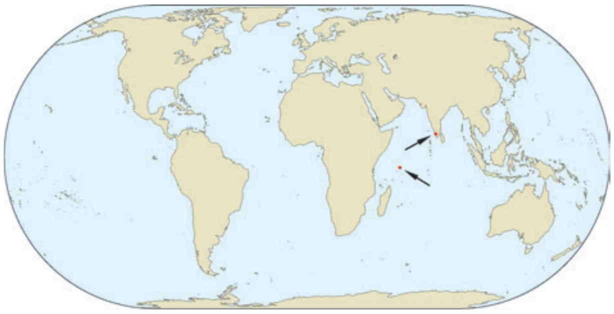
Pelobatidae. This family remains unchanged.

Pelodytidae. This family remains unchanged.

Scaphiopodidae. This family remains unchanged.

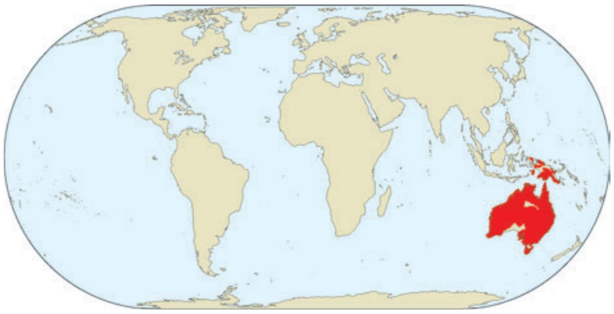
Heleophrynidae. This family remains unchanged.

Sooglossidae. Frost *et al*. (2006) include the Nasikabatrachidae in this family, consistent with the phylogenetic placement of this taxon by Biju and Bossuyt (2003), but its content is otherwise unchanged. As a result, this primitive family now contains five species, and its distribution is in the Seychelles Islands and the Western Ghats of southern India.

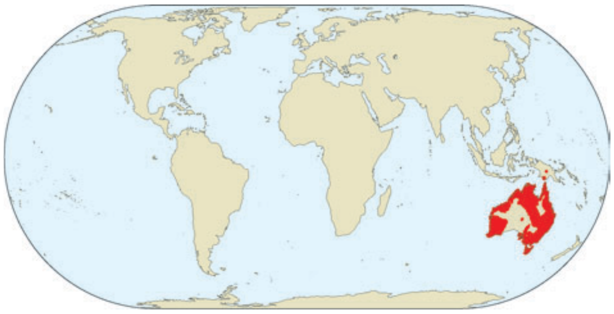


Batrachophrynidae. Frost *et al*. (2006) separate this family from the Leptodactylidae (consistent with work by San Mauro *et al*. 2005). It consists of three small genera (collectively comprising just six species), *Batrachophrynus*, *Caudiverbera* and *Telmatobufo*, from southern Chile and north into southern Andean Peru and Bolivia. These species are highly aquatic and breed by larval development. Frost *et al*. (2006) suggested that *Batrachophrynus* might not be in this group; should *Batrachophrynus* be found to be close to *Telmatobius*, the name for this family will become Calyptocephalellidae.

Limnodynastidae. Frost *et al*. (2006) transfer the genus *Mixophyes* from this family to the Myobatrachidae, but otherwise this family is unchanged. There are about 45 described species from Australia and New Guinea.

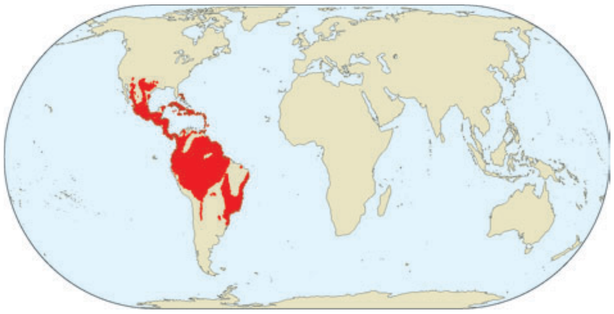


Myobatrachidae. Frost *et al*. (2006) include the Rheobatrachidae in this family, and transfer the genus *Mixophyes* to this family from the Limnodynastidae. There are almost 80 described species from Australia and New Guinea.



Hemiphractidae. Frost *et al*. (2006) separate this family from the Leptodactylidae and partitioned it further to address its non-monophyly as also suggested by Darst and Cannatella (2004). It consists of one small genus, *Hemiphractus* (comprising six species), ranging from Panama to the upper Amazon Basin. These species are highly specialized treefrogs from primary rainforest that feed only on other species of frog. They breed by direct development, with the eggs being carried on the female's back.

Brachycephalidae. The nomenclatural effect of Frost *et al*. (2006) showing that *Brachycephalus* (Brachycephalidae) is imbedded within the Eleutherodactylinae (genera *Adelophryne*, *Atopophrynus*, *Barycholos*, *Dischidodactylus*, *Craugastor*, *Eleutherodactylus*, *Euparkerella*, *Geobatrachus*, *Holoaden*, *Ischnocnema*, *Phrynopus*, *Phyllonastes* and *Phyzelaphryne)* is that the name of the combined large group becomes Brachycephalidae, a new grouping of nearly 800 species covering all of South and Central America (except Chile and most of Argentina, Paraguay and Uruguay) and the Caribbean islands, with a few species ranging as far north as the southern United States. With the exception of *Eleutherodactylus jasperi*, which is live-bearing, all members of this family so far examined lay eggs that develop directly without a larval stage.



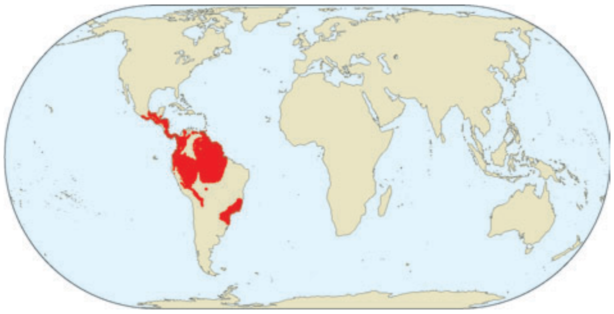
Cryptobatrachidae. Frost *et al*. (2006) separate this family from the Leptodactylidae. It consists of two genera (collectively comprising 21 species), *Cryptobatrachus* and *Stefania* confined to moderate to high elevations in northern South America (the Colombian Andes, the Sierra Nevada de Santa Marta, and the Guianan Shield in Guyana, Venezuela and northern Brazil). They exhibit direct development, with the eggs being carried on the female's back.

Oreophryne wapoga (Data Deficient) is a microhylid frog from New Guinea in which the eggs develop directly without a free-living larval stage. The male parent guards the eggs on the ground, and transports the juveniles on its back, as shown here. © Rainer Günther

Amphignathodontidae. Frost *et al.* (2006) separated this family from the Hemiphractidae. It consists of two genera, *Flectonotus* and *Gastrotheca* (collectively comprising around 60 species), ranging from Costa Rica south to northern Argentina, southern Brazil, and Trinidad and Tobago. These species, collectively termed marsupial frogs, possess a dorsal pouch for brooding their eggs (which can develop with or without a free-living larval stage, depending on the species).

Hylidae. This family remains unchanged.

Centrolenidae. Frost *et al.* (2006) include the Allophrynidae in this family, but its content and overall distribution is otherwise unchanged.



Ceratophryidae. Frost *et al.* (2006) separate this family from the Leptodactylidae. It consists of seven genera (collectively comprising around 80 species), namely *Atelognathus*, *Batrachyla*, *Ceratophrys*, *Chacophrys*, *Insuetophrynus*, *Lepidobatrachus*, and *Telmatobius*, ranging from Colombia south to Chile and Argentina. They breed by larval development.

Leptodactylidae[4]. Frost *et al.* (2006) split the Leptodactylidae into nine families (also comprising the traditionally recognized Brachycephalidae and Rhinodermatidae). These nine families are: Amphignathodontidae; Batrachophrynidae; Brachycephalidae; Ceratophryidae; Cryptobatrachidae; Cycloramphidae; Hemiphractidae; Leptodactylidae; and Thoropidae. However, Grant *et al.* (2006) merged the Thoropidae into the Cycloramphidae, split the Hylodidae out of the Cycloramphidae, and split the remaining Leptodactylidae into Leptodactylidae and Leiuperidae. Under this arrangement, the Leptodactylidae contains just four genera (*Hydrolaetare*, *Leptodactylus* [including former *Adenomera* and *Lithodytes*], *Paratelmatobius* and *Scythrophrys*) and about 75 species that breed in water with larval development (with some species building foam nests). The family ranges widely in South and Central America and the Caribbean islands, north to the southern United States, but is absent from Cuba, Chile and southern Argentina.

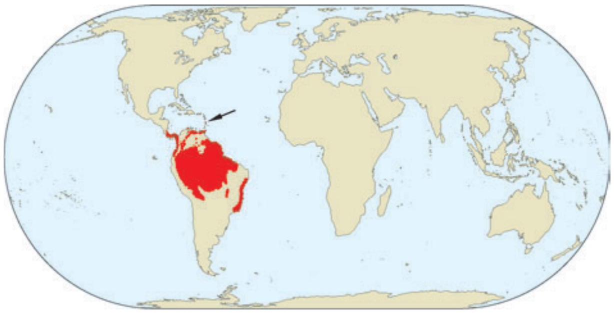
Cycloramphidae. Frost *et al.* (2006) separate this family from the Leptodactylidae, and to render it monophyletic included the traditionally recognized Rhinodermatidae within it. Subsequently, Grant *et al.* (2006) added the genus *Thoropa* to this family, but removed the genera *Crossodactylus*, *Hylodes*, and *Megaelosia* to the family Hylodidae. With these changes, the Cycloramphidae consists of 12 genera (collectively comprising around 90 species), *Alsodes*, *Crossodactylodes*, *Cycloramphus*, *Eupsophus*, *Hylorina*, *Limnomedusa*, *Macrogenioglottus*, *Odontophrynus*, *Proceratophrys*, *Rhinoderma*, *Thoropa* and *Zachaenus*, occurring in southern tropical and temperate South America. Most species breed by larval development, though in some cases the larvae are terrestrial, or live in the splash zones of waterfalls.

Leiuperidae. Grant *et al.* (2006) separate this family from the Leptodactylidae. It consists of five genera (collectively comprising around 70 species), *Edalorhina*, *Physalaemus*, *Pleurodema*, *Pseudopaludicola* and *Somuncuria*, ranging from Mexico south to Argentina. They breed by larval development, and some species make foam nests.

Bufonidae. This family remains unchanged.

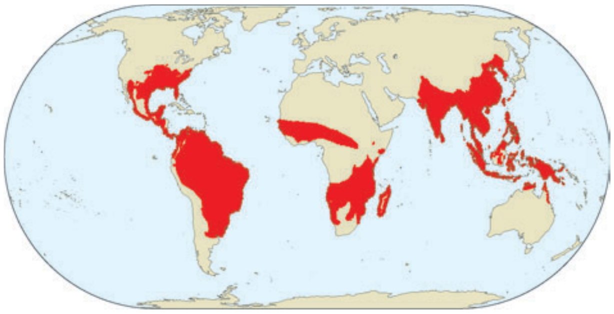
Hylodidae. Grant *et al.* (2006) separate this family from the Cycloramphidae. It consists of three genera (collectively comprising nearly 40 species), *Crossodactylus*, *Hylodes*, and *Megaelosia*, mainly restricted to southern Brazil, but ranging into nearby Argentina and Paraguay. They undergo larval development.

Aromobatidae. Grant *et al.* (2006) separate this family from the Dendrobatidae. Grant *et al.*'s revision of the Dendrobatidae and Aromobatidae results in great changes in the allocation of species to the traditionally recognized genera. The Aromobatidae consists of nearly 90 species in five genera and three subfamilies, occurring in tropical South America, north to Nicaragua, with one species on Martinique in the Lesser Antilles. The reproductive modes of these species are the same as described for the traditionally recognized Dendrobatidae above.



Dendrobatidae. Grant *et al.* (2006) separate the Aromobatidae from this family, leaving nearly 160 species in 11 genera and three subfamilies, occurring widely in tropical South America, north to Nicaragua. The reproductive strategies of these species are the same as described for the traditionally recognized Dendrobatidae above.

Microhylidae. Frost *et al.* (2006) removed the African family, Brevicipitidae, from this family, but otherwise its content remains unchanged, though it is now much less diverse in Africa. The Microhylidae consists of at least seven very distinct subfamilies: Asterophryninae (southern Philippines and Sulawesi to northern Australia; direct developing); Cophylinae (Madagascar; non-feeding larvae); Dyscophinae (Madagascar; larval developing); Gastrophryninae (the Americas; larval developing); Melanobatrachinae (Eastern Arc Mountains of Tanzania and the Western Ghats of India; larval developing); Microhylinae (South, Southeast and East Asia; larval developing); Scaphiophryninae (Madagascar; larval developing), with several genera still unassigned in Africa and Asia.



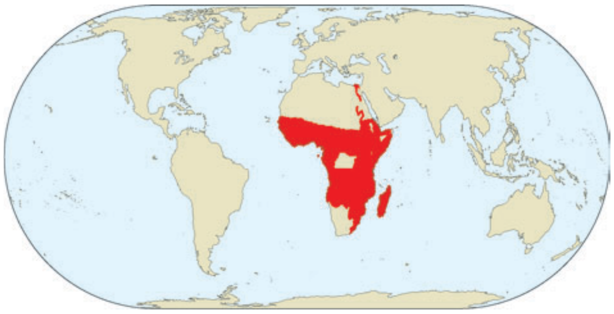
Arthroleptidae. Frost *et al.* (2006) merge the Astylosternidae into this family, and also transfer the genus *Leptopelis* from the Hyperoliidae to this family, which consists of around 130 species, widely distributed in Sub-Saharan Africa. It includes both direct- and larval-developing species.

Hyperoliidae. Frost *et al.* (2006) remove the genus *Leptopelis* from this family from Africa, Madagascar and the Seychelles, but its content is otherwise unchanged.

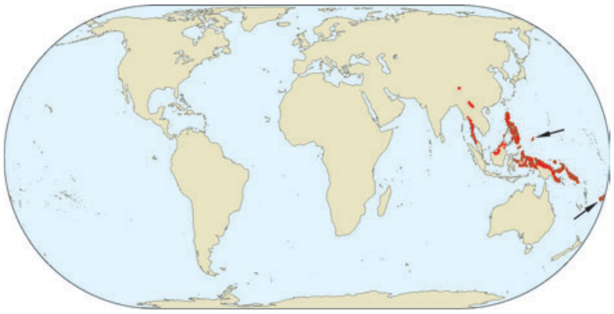
Brevicipitidae. Frost *et al.* (2006) separate this family from the Microhylidae, following Loader *et al.* (2004). There are five genera (*Balebreviceps, Breviceps, Callulina, Probreviceps*, and *Spelaeophryne*) and 24 species occurring in eastern and southern Africa, from Ethiopia south to South Africa. Where known, all species breed by direct development.

Hemisotidae. This family remains unchanged.

Ptychadenidae. Frost *et al.* (2006) separate this family from the Ranidae. There are three genera (*Hildebrandtia*, *Lanzarana*, *Ptychadena*) and 51 species occurring widely in Sub-Saharan Africa and Madagascar. All species reproduce by larval development in water.



Ceratobatrachidae. Frost *et al.* (2006) separate this family from the Ranidae as phylogenetically distinct. There are six genera (*Batrachylodes*, *Ceratobatrachus*, *Discodeles*, *Ingerana*, *Palmatorappia*, *Platymantis*) and almost 80 species occurring from southern China, though Myanmar, adjacent Thailand, Peninsular Malaysia, northern Borneo, the Philippines, New Guinea, the Admiralty and Bismarck Archipelagos, the Solomon Islands, Fiji and Palau. All species breed by direct development.

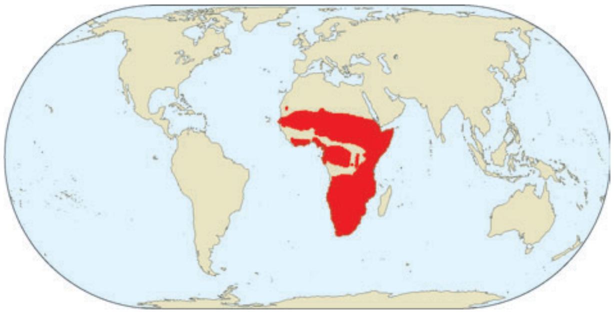


Micrixalidae. Frost *et al.* (2006) separate this family from the Ranidae. There is a single genus (*Micrixalus*) and 11 species restricted to the Western Ghats of southern India. All species exhibit larval development.

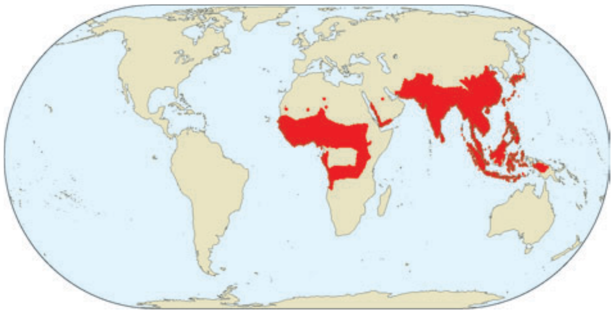
Phrynobatrachidae. Frost *et al.* (2006) separate this family from the Petropedetidae as phylogenetically distant. There is one genus *Phrynobatrachus* (including *Dimorphognathus* and *Phrynodon* and excluding *Ericabatrachus*, which Scott [2005] transferred to what is now Pyxicephalidae) and almost 70 species occurring widely in Sub-Saharan Africa. Most species breed by larval development.

Petropedetidae. Frost *et al.* (2006) make major changes to the content of this family. All the existing genera in the family, except for *Petropedetes* and *Arthroleptides*, are moved to two new families endemic to the Afrotropics, Phrynobatrachidae and Pyxicephalidae. However, two genera are transferred from Ranidae to Petropedetidae: *Conraua*, and *Indirana* (this last genus of 10 species occurring only in the Western Ghats of southern India). Under this arrangement, Petropedetidae becomes a small family of just 26 species, 16 in tropical Africa and 10 in India. All species breed by larval development, and many have larvae associated with the splash zones of waterfalls.

Pyxicephalidae. Frost *et al.* (2006) establish this new family from genera previously assigned to Petropedetidae and Ranidae, largely consistent with a monophyletic group first recognized by Van der Meijden *et al.* (2005). It comprises 13 genera (*Amietia*, *Afrana*, *Anhydrophryne*, *Arthroleptella*, *Aubria*, *Cacosternum*, *Ericabatrachus* [transferred to this group by Scott 2005], *Microbatrachella*, *Natalobatrachus*, *Nothophryne*, *Poyntonia*, *Pyxicephalus*, *Strongylopus*, and *Tomopterna*) and 61 species that are widely distributed in Sub-Saharan Africa. Most of the species breed by larval development, but some are direct developers.

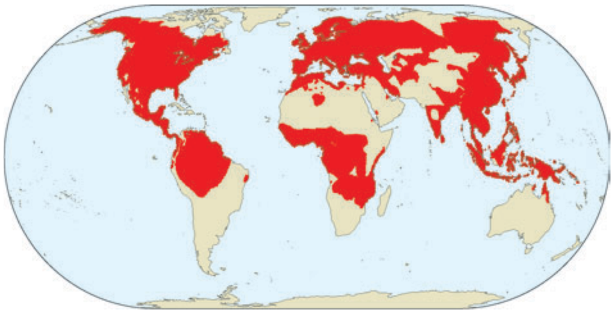


Dicroglossidae. Frost *et al.* (2006) establish this new family from genera previously assigned to Ranidae, but found to be distantly related to that group. It includes 11 genera (*Annandia*, *Eripaa*, *Euphlyctis*, *Fejervarya*, *Hoplobatrachus*, *Limnonectes*, *Minervarya*, *Nannophrys*, *Nanorana*, *Occidozyga*, *Ombrana*, *Quasipaa*, and *Sphaerotheca*) and 143 species that are widely distributed in South, East and Southeast Asia (as far east as the Philippines and the Lesser Sunda Islands), with one species in Sub-Saharan Africa and another on the Arabian Peninsula. All species breed by larval development.



Nyctibatrachidae. Frost *et al.* (2006) establish this new family from genera previously assigned to Ranidae. It is composed of two genera (*Nyctibatrachus*, *Lankanectes*) and 13 species that are endemic to Sri Lanka and the Western Ghats of southern India. All species breed in water with larval development.

Ranidae. Frost *et al.* (2006) split the Ranidae into eight families (also comprising the traditionally recognized Petropedetidae) to remedy the polyphyly of the Ranidae as traditionally recognized. These eight families are: Ceratobatrachidae; Dicroglossidae; Micrixalidae; Nyctibatrachidae; Petropedetidae; Ptychadenidae; Pyxicephalidae; and Ranidae. Under this arrangement, the Ranidae contains just eight genera (*Amnirana*, *Amolops*, *Huia*, *Meristogenys*, *Pseudoamolops*, *Pterorana*, *Rana* and *Staurois*, though Frost *et al.* [2006] redelimited and recognized several new genera) and 310 species that breed in water with larval development. The family ranges widely throughout Eurasia and tropical Asia, to northern Australia and the Solomon Islands, throughout North America south to northern South America, and also in tropical Africa. It is absent from the Caribbean islands, Madagascar and New Zealand, and from most of southern Africa, Australia and most of South America south of the Amazon basin.



Mantellidae. This family remains unchanged, although Glaw and Vences (2006) have recently provided a completely revised taxonomy that bears little resemblance to what preceded it.

Rhacophoridae. This family remains unchanged.

In summary, under the revisions of Frost *et al.* (2006) and Grant *et al.* (2006), nine traditionally recognized families disappear (Scolecomorphidae, Uraeotyphlidae, Dicamptodontidae, Ascaphidae, Nasikabatrachidae, Rheobatrachidae, Allophrynidae, Rhinodermatidae, Astylosternidae), and 17 new families are established (Batrachophrynidae, Hemiphractidae, Cryptobatrachidae, Amphignathodontidae, Ceratophryidae, Cycloramphidae, Leiuperidae, Hylodidae, Aromobatidae, Brevicipitidae, Ptychadenidae, Ceratobatrachidae, Micrixalidae, Phrynobatrachidae, Pyxicephalidae, Dicroglossidae, Nyctibatrachidae). The number of amphibian families increases from 48 to 56.

Reproduction, Parental Care, and Metamorphosis

The characteristic most closely associated with amphibians is their ability to live in both terrestrial and freshwater environments – they are amphibious. Movement of amphibians between land and water is commonly linked to breeding activity. Adults move from terrestrial habitats to spawn in water, the resulting free-living larvae are aquatic, and fully developed young return to land following the process of metamorphosis. However, there are many exceptions to this lifestyle, including species that complete their entire live cycles in terrestrial habitats (such as many caecilians and the Puerto Rican Coqui Frog *Eleutherodactylus coqui*); species that are wholly aquatic (e.g., frogs of the genus *Pipa*); and many species that undergo direct development or are live-bearing, bypassing the free-living larval stage.

Amphibians use either internal or external fertilization. With very few exceptions, the fertilization of eggs in frogs and toads is external, while the vast majority of salamanders and newts, and probably all caecilians, have internal fertilization. Among the frogs and toads, the only species known to exhibit forms of internal fertilization are members of the family Ascaphidae, the live-bearing African toad genera *Nimbaphrynoides* and *Nectophrynoides*, the African toad species *Mertensophryne micranotis* and the live-bearing frog from Puerto Rico *Eleutherodactylus jasperi*. Within the salamanders and newts, the families Hynobiidae, Cryptobranchidae, and possibly the Sirenidae, have external fertilization (Duellman and Trueb 1994).

The eggs of amphibians are commonly formed of one or several semi-permeable gelatinous membranes surrounding the ovum. These membranes allow gasses and water to pass freely through the egg and also protect the egg against damage, desiccation, infection and predation. Eggs are most often deposited (oviposition) in water bodies or in damp sites (such as underneath moist leaf-litter) where desiccation is unlikely to prevent successful development.

The most familiar of amphibian larvae are the free-swimming 'tadpoles' of frogs and toads. The body shape of most anuran larvae is roughly ovoid, with a long laterally compressed tail used for swimming. The mouthparts are generally formed of upper and lower horny beak-like jaws, with surrounding oral papillae. Anuran larvae are commonly herbivorous with a gut that is often quite long in order to process plant matter. The larvae of salamanders and newts tend to have a very similar morphology to that of the adults, with noticeable external differences being their smaller size, external filamentous gills, flattened tail fin, and the lack of a true tongue. The young of larval-developing caecilians are eel-like and superficially similar in form to the adult animals. Caecilian larvae differ from the adults in having a tail fin, a spiracle and gill slits, lateral line organs and expanded lips for suction feeding. While some caecilians hatch with external gills, these are generally reabsorbed into the body or shed within a few days.

Reproductive modes

While most amphibian species lay eggs (oviparous), there are in general three main breeding modes: those that lay eggs and have a free-living larval stage; those that lay eggs and undergo direct development, circumventing the larval stage; and the non-egg laying live-bearing (viviparous and ovoviviparous) species, in which the young develop completely, or to some large degree, within the female.

Having a larval stage is by far the most common, and perhaps the most familiar, amphibian reproductive mode. This mode of reproduction has been recorded in more than two-thirds of the world's ~6,000 amphibian species (see Chapter 4), perhaps being completely absent only from the families Brachycephalidae, Leiopelmatidae, Typhlonectidae and Scolecomorphidae (though in several families, such as Arthroleptidae, Leptodactylidae, Microhylidae, Plethodontidae and Rhacophoridae, many species do not have a larval stage). In the majority of species, the eggs are laid within a suitable water-body, which may range in size from a leaf-axil to a large lake, and hatch into free-living aquatic larvae (tadpoles) that complete their development and undergo metamorphosis before leaving the water.

In the majority of direct-developing species, a reproductive mode that is particularly common within the families Arthroleptidae, Caeciliidae, Leptodactylidae, Microhylidae, Plethodontidae and Rhacophoridae, the eggs are deposited in a damp or moist terrestrial site (such as underneath leaf-litter, bark or rocks), where they complete development, sometimes under the umbrella of paternal care, and hatch as fully formed young. Advantages to a direct-development strategy include reduced vulnerability to aquatic predators and to drying up of wetlands.

A very few amphibian species (less than 2% of all species) have a live-bearing reproductive mode. Ovoviviparous species include all species in which the young undergo development within the female obtaining nourishment from the yolk alone. In viviparous species the developing young obtain additional nourishment from the female. In most ovoviviparous or viviparous species very few well-developed young are born. Many of the known live-bearing amphibian species are caecilians of the families Caeciliidae (28 species) and Scolecomorphidae (three species). Within the salamanders and newts there are 12 live-bearing species in the genera *Salamandra* and *Lyciasalamandra* (some species of *Salamandra* give birth to free-living larvae that complete their development in water). There are few known live-bearing frog and toad species (14 species in total), relative to the diversity of the Order as a whole. Most of these species, such as the Critically Endangered Kihansi Spray Toad *Nectophrynoides asperginis* and Golden Coqui *Eleutherodactylus jasperi* are ovoviviparous, with the equally highly threatened *Nimbaphrynoides liberiensis* and *Nimbaphrynoides occidentalis* being the only known truly viviparous frogs.

For the purposes of analysis in this book, amphibian reproductive modes have been combined into three general groups: *larval developing* - species that lay eggs, from which free-living larvae hatch; *direct developing* – species that lay eggs in which the young develop into the adult form, and undergo any metamorphosis prior to hatching; and *live-bearing* – species that do not lay eggs, and give birth to young animals.

Parental Care

While most amphibian species show very little or no parental care after initial egg deposition, there are a number of instances where the care of both eggs and larvae is highly developed. Parental care can include the production of foam nests in which the eggs develop (Anura), driving away predators (including conspecifics), moistening and aeration of the eggs, oscillation (or turning) of eggs, the removal of damaged or infected eggs from the clutch, and possibly the application of protective skin secretions to prevent pathogen growth (Duellman and Trueb 1994; Stebbins and Cohen 1995). Some well-known examples of protection include: the African Bullfrog *Pyxicephalus adspersus* that will attack much larger animals and people that come close to the nest site; the construction and guarding of shallow nesting basins by males of the frog *Hypsiboas rosenbergi*; the large aquatic Hellbender Salamander *Cryptobranchus alleganiensis* that defends eggs against predation; and, where known, the terrestrial eggs of oviparous caecilians are attended by the female until they hatch into aquatic larvae (Duellman and Trueb 1994; Stebbins and Cohen 1995).

In some instances the eggs or larvae are actively transported by one of the adults. Following amplexus, the strings of eggs of midwife toads (*Alytes* spp.) are collected on the hind legs of the male, which are carried (with periodic moistening in water) until the larvae begin to hatch. The male then transports them to water where they hatch and complete their development. Many of the species of dendrobatid frogs from the Neotropics (including a number of the well-known Poison Frogs) show quite advanced parental care. In addition to the adults guarding the terrestrial site of egg deposition, the larvae upon hatching are typically transported on the back of one of the adults to a stream or water-filled bromeliad where development is completed. Similar behaviour has also been recorded in two ranid frogs (*Limnonectes finchi* and *L. palavanensis*) from Borneo, the sooglossid *Sooglossus seychellensis* (in which larval development is completed on the adults' back), in the Leiopelmatidae (in which the males of *Leiopelma archeyi*, *L. hamiltoni* and *L. pakeka* transport the young on their back), and most recently in the New Guinea microhylids *Liophryne schlaginhaufeni*, *Sphenophryne cornuta*, *Oreophryne* cf. *wapoga* and the newly described *Callulops pullifer* (Inger *et al.* 1986; Inger and Voris 1988; Duellman and Trueb 1994; Stebbins and Cohen 1995; Günther *et al.* 2001; Bickford 2002; Günther 2006).

The young of the caecilian Boulengerula taitana *(Least Concern) have been found to nourish themselves by stripping and eating the outer layer of the mother's skin. © Alexander Kupfer*

Forms of brooding developing eggs within pouches or body cavities have evolved in a number of amphibian species. For example, the eggs of the well-known aquatic toads of the genus *Pipa* develop on the back of the female, with either larvae or toadlets emerging from under the skin. Several leptodactylid genera (*Hemiphractus, Gastrotheca, Flectonotus, Stefania*) contain species in which the eggs are carried in pouches, or are glued to the back of the adult. Depending on the species, the eggs either develop directly into froglets, or are released from the adult as well-developed non-feeding larvae. The hatching larvae of the monotypic Australian genus *Assa* climb into hip pouches on the male, where they may remain for around two months feeding on the yolk sac before emerging as fully developed froglets.

The two species of the genus *Rhinoderma* from southern Argentina and Chile are the only known examples of vocal sac brooding amphibians. The male Darwin's Frog *Rhinoderma darwinii* collects recently hatched larvae into the vocal sac where they complete their development, eventually emerging from the male's mouth as froglets. Similarly, the two, now extinct gastric-brooding species of *Rheobatrachus* from eastern Australia were unique in that the female picked up the eggs that then completed their development to froglets entirely within the female's stomach (see Essay 6.1). As with Darwin's Frog, *Rheobatrachus* froglets emerged from the mouth once fully developed.

There are a few instances known of amphibians actively providing nourishment to the developing larvae. Females of a number of species in the genus *Dendrobates* regularly lay unfertilized eggs into the bromeliads and leaf axils in which their larvae are developing. The larvae rely on these eggs as a source of nutrition, and may not survive if the eggs are not deposited. The developing larvae of the Critically Endangered Mountain Chicken *Leptodactylus fallax* feed exclusively on unfertilized eggs provided by the female; with as many as 10,000 to 25,000 unfertilized eggs deposited in total (Gibson and Ley 2004). The young of the caecilian *Boulengerula taitana* have recently been found to nourish themselves by stripping and eating the outer layer of their mother's skin. This form of parental care might be common in direct-developing caecilians, but is not known from other amphibians (Kupfer *et al.* 2006).

Metamorphosis

The process of metamorphosis from the larval stage to adult form is often dramatic in amphibians. In general, an internal release of the hormone thyroxine prepares the organs and tissues of the larval amphibian for metamorphosis. The timing of the thyroxine release is largely determined by both environmental factors (such as overcrowding or predation levels) and chemical factors, including a reduction in the corticoid hormones that inhibit thyroxine release (Zug *et al.* 2001).

The transformation is most striking in the frogs and toads. During metamorphosis, the larvae begin to develop all their limbs (including the strong hind legs), larval mouthparts are replaced by true jaws and teeth, the tail is reabsorbed, the glandular outer skin of the adult develops, the gut changes to process a more carnivorous diet, the lungs continue their development, and the skeleton hardens. As salamander young often closely resemble the adults, metamorphosis appears to be less remarkable. However, significant changes do take place, including the reabsorbtion of the external gills and the tail fin, and the development of a true tongue. In some salamanders and newts, adults may retain juvenile characteristics (such as external gills); this phenomenon is termed paedomorphism. Caecilian larvae are superficially similar to adult animals, but metamorphic changes may be substantial including

This image of a larval Marbled Salamander Ambystoma opacum *(Least Concern) shows clearly the large filamentous gills used for respiration. © Henk Wallays*

a thickening of the skin and development of scales, changes in the cranium and glossal skeleton and associated musculature, loss of labial folds and gill slits, and the growth of sensory tentacles.

Skin, Respiration and Thermoregulation

The distinctive semi-permeable skin of amphibians performs a number of important biological functions. The outer skin (epidermis) is covered with mucous glands and serous granular glands. The mucous glands help to keep the skin moist and slippery by secreting mucus. The granular glands secrete alkaloids or other chemicals that are often toxic to potential predators. The skin helps to protect the animal against physical damage (such as abrasion), and antimicrobial peptides covering the skin prevent infection by pathogens (further details of the possible values of these skin secretions are discussed in Chapter 2).

Amphibians occur in a wide variety of colours, ranging from the subtle shades of green, brown and black used to camouflage animals, to the bright warning colours of the familiar posion frogs. Pigmentation cells within the skin largely determine colour and shading. Pigments may be dispersed or concentrated through hormonal action, allowing skin colour and patterns to quickly change in response to the animal's environment.

The skin can be an important respiratory organ. Most amphibians have a semi-permeable skin with both a low level of keratinization, and an extensive network of below-skin blood capillaries adapted to cutaneous gas exchange (oxygen absorption through the skin). The importance of this varies between species, but for some groups, such as the lungless plethodontid salamanders, cutaneous gas exchange may account for 85-90% of total gas exchange (Duellman and Trueb 1994; Stebbins and Cohen 1995). Some amphibians, such as the giant salamanders of China and Japan (*Andrias* spp.), have evolved skin folds that may enhance gas exchange through an increased skin surface area. Hair-like filaments develop on the body of male Hairy Frogs *Trichobatrachus robustus* during the breeding season, and these may aid oxygen uptake during times of increased demand. A single species of caecilian is entirely lungless; the enigmatic *Atretochoana eiselti* is a giant aquatic species known from only two specimens.

Most amphibians at some point in their development use gills for gas exchange. Larval amphibians often have filamentous gills that are the primary means of respiration. These gills are usually reabsorbed into the body during metamorphosis, while the adult lungs develop. The lungs of amphibian species are ventilated by a buccopharyngeal pump accompanied by exaggerated 'gulping' movements of the floor of the mouth. Lungs vary greatly in size and structure, and this variation may be related to a number of factors including the importance of other respiratory organs (such as the skin), thermal characteristics, activity, and habitat and evolutionary characteristics (Stebbins and Cohen 1995). In general, amphibians inhabiting well-oxygenated cold environments (for instance, mountain streams) are more likely to have smaller or reduced lungs; species from warmer habitats with low oxygen levels more commonly have larger lungs with a more complex structure. Some aquatic caecilians have very well-developed lungs extending almost the entire length of their bodies that may be important in buoyancy as well as in respiration. Gas exchange across the lining of the buccal cavity and pharynx (mouth and throat) appears to be particularly important to a number of salamanders, most especially the lungless species.

Unlike 'warm-blooded' birds and mammals (endotherms), amphibians are ectotherms or 'cold-blooded' animals, with the outside environment largely determining body temperature. Both behavioural and physiological mechanisms regulate body temperature. Behavioural mechanisms are mostly associated with movements to warmer or cooler sites, or microhabitats, within the animal's environment. This includes moving to basking sites where the animal can raise its body temperature through exposure to the sun, or movements to shaded areas away from the heat. Physiological adaptations include increasing or decreasing evaporative cooling through the skin; changes in skin pigmentation in response to UV exposure; and possibly changes in the amount of blood flow to the skin. While very few amphibians can persist at temperatures above 43ºC (110ºF), several species, such as the North American Wood Frog *Rana sylvatica*, can tolerate freezing conditions through conversion of liver glycogen to glucose in response to extracellular ice formation. Animals recover when milder temperatures arrive by greatly increasing blood glucose levels (Stebbins and Cohen 1995).

As with thermoregulation, body water regulation in amphibians is controlled by both behavioural and physiological mechanisms. The generally highly water permeable skin of amphibians allows movement of water both into the body through osmosis when the animal enters the water or is exposed to a moist surface, and away from the body through evaporative transpiration when the animal is outside a wet or damp environment. Individual animals can control the intake of water through the skin by entering or leaving water, and many animals regularly move between terrestrial and wet or damp sites to rehydrate themselves.

Body water regulation is most commonly associated with preventing water loss, rather than coping with an excess of water. Amphibians have developed several strategies to prevent water loss, including: having a largely nocturnal lifestyle; inhabiting moist places when away from water; burrowing or undergoing periods of aestivation to avoid dry periods when desiccation is a possibility; a reduction of the body area available for evaporative transpiration; the retention of urea in plasma (especially among species from arid habitats); and, in a few species, the excretion of nitrogenous waste as up to 80% uric acid (uricotelic species). In some instances, amphibians have to adapt to excess, rather than a loss, of water. Amphibians that are largely, or wholly, aquatic in freshwater for a lengthy period tend to have modified skin and kidneys to prevent or compensate for excessive osmosis from the surrounding environment.

Because of the loss of body water through osmosis in saltwater, there are no truly marine amphibians. The frog *Fejervarya cancrivora* from Southeast Asia occurs in the brackish water of mangrove forest, and is the closest to a marine amphibian.

Diet

With few exceptions, the diet of adult amphibians consists of a wide range of freshwater and terrestrial invertebrates. Most amphibians appear to be opportunistic feeders, with the types of prey captured often dependent on availability and seasonality. While most adult amphibians only consume invertebrates, some larger amphibians, such as the African Bullfrog *Pyxicephalus adspersus*, can also catch small vertebrates such as mice, birds, reptiles or other amphibians. Amphibians have also been recorded feeding opportunistically on dead carrion, pet food, organic waste, and similar scraps. There are a few well-recorded instances of amphibians in which the adult also consumes vegetables or fruits. Adults of the treefrog *Xenohyla truncata* regularly consume small fruits, and as some of the defecated seeds germinate it seems possible that this frog may contribute to plant dispersal (da Silva *et al.* 1989).

Amphibian larvae have a greater diversity of feeding mechanisms and diet than adult amphibians. The larvae of most frogs and toads are highly specialized filter feeders, using organs called the branchial food traps and gill filters to collect food. Trapped food is transported from these traps to the oesophagus by mucal threads. Anuran larvae typically fall into two groups, those that feed on microscopic matter (microphagous), and those that feed on much larger objects (macrophagous). Microphagous larvae feed on food items such as suspended algae or protists, and tend to have large branchial food traps. Macrophagous larvae generally have both reduced branchial food traps and keratinized mouthparts adapted to scraping and biting food, including algal mats or animal prey (including other amphibian larvae). In contrast to the frogs and toads, the vast majority of salamander and newt larvae and probably all caecilian larvae are carnivorous, and feed on aquatic invertebrates.

Movement and Migration

In general, the daily movement of amphibian species is mostly restricted to the vicinity of the animals' home range. Although the home range size of most amphibian species remains unstudied or poorly known, in many cases it is believed that home range sizes are typically quite small, being a total of only a few square metres in size. However, it should be noted that amphibians have a wide range of dispersal abilities, and in some instances are known to move greater distances than previously anticipated (Smith and Green 2005). Possibly the most commonly recognized amphibian movements are the more substantial seasonal migrations of large numbers of animals from their individual home territories to and from breeding sites. The sight of mass breeding congregations of amphibians in ponds, lakes and other water bodies is generally familiar to most people, and may often be their first encounter with amphibians. Seasonal breeding migrations tend to be triggered by a number of environmental conditions; these can include changes in daylight, temperature, or in moisture and precipitation levels. For example, Gascon *et al.* (2003) mention a breeding aggregation of more than 5,000 adults of the Marbled Salamander *Ambystoma opacum* in a cluster of three ponds at the base of the Blue Ridge Mountains following the torrential rains of Hurricane Dennis in September of 1999; the breeding event gave rise to over 12,000 metamorphic salamanders that emigrated en masse from ponds in the following May. Movements most often take place at night, probably reducing the risk of predation by birds and other diurnal predators (Zug *et al.* 2001).

While many amphibians may move only relatively short distances from the surrounding terrestrial habitat to and from the breeding site, it is possible for some species to travel longer distances to their traditional breeding site. Experiments with displaced individuals of Red-bellied Newts *Taricha rivularis* have demonstrated that animals were able to locate their breeding sites from as far as eight kilometres away (Twitty *et al.* 1967).

Amphibian movements and migrations are guided by a number of homing and orientation mechanisms (Zug *et al.* 2001). Visual landmarks within the home territory or migration route help to direct individual animals, especially to familiar escape routes when disturbed. Many species are guided by olfactory cues, including the characteristic scents, smells or odours of the home territory or breeding site. The sounds of calling conspecifics provide auditory cues for frogs defending territories or trying to locate a mate. Variation in polarized light allows amphibians to differentiate between wet and dry areas; in addition, salamanders are able to orient themselves through the use of the pineal body which acts as a polarized light receptor (Zug *et al.* 2001). Many amphibians are sensitive to magnetic fields, and a number of studies into this interesting field have demonstrated that animals can orientate themselves through the use of a light sensitive magnetic compass (including Phillips 1977, 1986a,b; Sinsch 1987; Deutschlander 2000; Freake and Phillips 2005). Two magnetoreception systems have been found: the first measures spatial variation in the magnetic field and uses this information to derive a geographic map of the area, while the second system is sensitive to the horizontal alignment (azimuth) of the magnetic field and is used for compass alignment (Freake and Phillips 2005). Recent studies have confirmed the presence of orientation by magnetic fields in both the Caudata and Anura (Freake and Phillips 2005).

Communication

Amphibians generally communicate through vocal, chemical or visual means, or through a combination of these three systems. Of the three Orders of amphibian, only the frogs and toads tend to make significant vocalizations. While some species of caecilians and salamanders can produce soft clicking, squeaking or hissing sounds, in general there are very few voluntary sounds made. Although there are a few exceptions, most species of frogs and toads tend to force air from the lungs over the larynx where the vocal cords vibrate creating sound. In many cases the calls are transmitted via vocal sacs, with some external vocal sacs having a balloon-like appearance. While further research is needed into the role of the vocal sacs, these are often considered to both intensify or modify the acoustic signal and assist in radiating calls in all directions.

The volume and intensity of calls can vary greatly by species, and this often depends on whether the call is intended for nearby conspecifics or for those that are far away. Environmental conditions may also determine the volume and intensity of the call. For example, the threatened species *Amolops tormotus* from eastern China has recently been discovered to emit calls in ultrasonic frequencies; this is possibly an adaptation to the loud torrential stream habitats in which the animal lives (Feng *et al.* 2006). The Bornean frog *Metaphrynella sundana* has been shown to actively exploit the acoustic properties of partially water-filled tree cavities (Lardner and bin Lakim 2002). By tuning their vocalizations to the resonant frequency of the hole, the calling males enhance their chances of attracting a female.

Most communication between individual caecilians and salamanders appears to be largely through chemical secretions and visual signs. Perhaps the most commonly employed chemical signals are pheromones produced by courtship glands, which may be used to distinguish between species and also to locate conspecifics (Zug *et al.* 2001). Visual or tactile signals in amphibians have been observed in all three Orders and can include animals biting, nudging or butting their partner, tail-whipping (especially in some European newts), or using a foot-flagging display and colour displays especially where vocalizations may not easily be heard (Zug *et al.* 2001; Hödl 2000).

Amphibian communication methods are very diverse and have several different functions. Advisement calls and signals are used to attract a mate, to aggressively warn others of territorial boundaries, or are made in response to encountering other males. Reciprocation calls and signals are made by females willing to mate in response to the courtship of a particular male. Unreceptive females give release calls or signals during attempts at amplexus, as do males that have been mistakenly identified as females. Distress signals may be low-pitched shrieks or shrill cries, or specific movements or chemicals, which are produced by either sex in response to disturbance or fright.

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Endnotes

1 Based on the results of the Global Amphibian Assessment, as of December 2006. At the time of going to press (February 2008), there were 6,184 species recognized on *Amphibian Species of the World* (Frost 2007), including 5,453 anurans, 560 Caudata, and 171 Gymnophiona.

2 Recently also collected in Peru by Pitman *et al.* (2003).

3 During 2006 three new *Brachycephalus* species were described (*B. ferruginus*, *B. pombali*, and *B. alipioi*), increasing the number of recognized species in the family Brachycephalidae to 11 (Pombal Jr. and Gasparini 2006).

4 The enigmatic genus *Rupirana* Heyer, 1999, formerly included within the Leptodactylidae is not allocated to any family by Frost *et al.* (2006). These authors remark that they did not study it, and that its position remains to be elucidated.

Paratelmatobius lutzii *is an example of a Brazilian frog that is currently listed as Data Deficient, but which should probably be considered as Critically Endangered. It was once common in an area of a few square metres on the Alto do Itatiaia, at 2,200m asl in the Serra da Mantiqueira, on the border of the states of Minas Gerais and Rio de Janeiro. However, it has not been seen since 1978, despite suitable habitat remaining and significant survey efforts. © Ivan Sazima*

ESSAY 1.1. TRENDS IN RATES OF AMPHIBIAN SPECIES DESCRIPTIONS

Since the official implementation of zoological nomenclature by Carl von Linné in 1758 there has been a steady increase in the number of recognized extant amphibian species. However, rates of species descriptions over time have been neither constant nor decreasing – as one would expect when assuming that the number of undiscovered species decreases with a longer period of scientific investigation. Unlike other, well-known, vertebrate groups such as mammals and birds,, amphibians are a class where species numbers have increased exponentially, especially in recent decades (Glaw and Köhler 1998, AmphibiaWeb 2006).

Since the early times of amphibian classification, the major works of a few active taxonomists contributed significantly to descriptions of novel taxa, specifically Josephus N. Laurenti, François Daudin, Johann Baptist von Spix, André M. Constant Duméril and Gabriel Bibron, Albert C. L. G. Günther, Edward D. Cope, Wilhelm Peters, George A. Boulenger and Oskar Boettger. With the increasing number of researchers dealing with the classification of amphibians and the intensified exploration of tropical regions, taxonomic work on amphibians experienced its first major boost and description rates of species per period steadily increased until the end of the 19th century. For example, about 260 species of amphibians were described in the last decade of the 19th century, many of which are still considered to represent valid taxa.

Subsequently, a decrease in species description rates occurred during two periods of the last century. These periods correlate with the First and Second World Wars, respectively, with obviously low research activity (Glaw and Köhler 1998). However, the general long-term trend was still an increase in description rates.

More recently, a second major boost of new species discoveries and descriptions has been in evidence. Whereas at the end of 1992, the number of amphibians recognized stood at only 4,533 species (Duellman 1993, Glaw *et al.* 1998), as of July 2006, this total stood at 6,041 species (AmphibiaWeb 2006). This equates to an increase of more than 32% in only 13 years. The absolute number of newly described amphibian species per decade (not only the cumulative number of valid and described species) has been steadily increasing since the 1960s, with especially steep increases since the 1990s (Glaw and Köhler 1998, Köhler *et al.* 2005). No fewer than 810 amphibian species were described in the last decade of the 20th century; this is more than three times the number of species descriptions compared with the same period 100 years earlier. The average annual number of amphibians described during the 1990s was about 81 species; the number of described species in 2005 alone exceeds 200, a record that was never reached before. One factor contributing to this high rate of description was the publication of at least 35 new species from Sri Lanka (Manamendra-Arachi and Pethiyagoda 2005, Meegaskumbura and Manamendra-Arachi 2005).

New species descriptions can be attributed, in part, to known populations of described species that have been found to be genetically or bioacoustically (in frogs) distinct, and may in many cases be recognized as different species. Modern molecular and bioacoustic techniques that provide increased 'resolution' have revealed that in many cases several morphologically similar, and hence, cryptic species may be concealed within a single taxon name. However, compared with true first-hand discoveries in amphibians, removal from synonymy constitutes a relatively small portion (~14%) of newly recognized species (Köhler *et al.* 2005). Indeed, a large proportion of new species are genuine new discoveries, as exemplified by the recent spectacular findings of a new frog family, genus and species in India, the Nasikabatrachidae (Biju and Bossuyt 2003), and of a new genus and species of plethodontid salamander, *Karsenia*, in Korea – the first Asian representative of this family (Min *et al.* 2005). A case study of mantellid frogs in Madagascar indicated that newly discovered species since 1990 were as genetically divergent as those described in previous research periods. Additionally, most had not been collected previously, indicating that the increase in new amphibian species on this island of endemism is not a sign of taxonomic inflation due to exaggerated splitting approaches or different species concepts (Köhler *et al.* 2005).

If the current trend in species descriptions continues, we probably face a decade (2000-2009) in which more than 1,500 amphibian species could be described. This raises the interesting question of just how long will this trend continue and how many amphibian species are there on earth? Of course, nobody knows the final number and there is no available method to give an exact estimate. We suspect that at least several hundred new species remain to be described from throughout the tropical regions (including Madagascar, India, Sri Lanka, Indonesia, Philippines, New Guinea, and South America). For example, 223 species are officially known from Madagascar (December 2005), yet we have clear evidence (from morphology, bioacoustics and genetics) for the existence of at least 282 species and know of 45 further forms which are likely to represent new species as well, indicating that about 100 new Madagascan species still await their description at the current time.

Given this situation, and the strongly increasing description rates in many tropical areas of the world, we believe that an eventual doubling of the current number of known amphibian species to around 12,000 is not inconceivable, though this global amphibian inventory may still require an additional 50 years to be completed. In the meantime, since many of our currently recognized amphibian "species" may actually prove to represent species complexes, this will have practical relevance for conservation. Taxonomic revisions will likely have an important bearing on the Red List status of many species, particularly if formerly widespread non-threatened species complexes are actually shown to represent a number of smaller-ranged threatened species. In addition, the non-cryptic 'real' discoveries of the future are far more likely to be taxa having restricted ranges, with the result that these species are more likely to qualify as threatened. These two factors suggest that future estimates of the degree of threat among amphibians will be much higher due to factors unrelated to habitat destruction and other human-induced declines.

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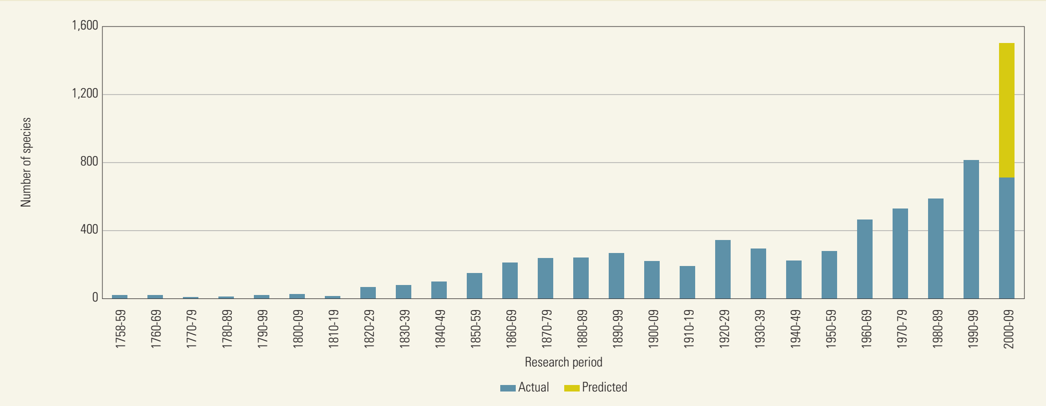

Figure 1. *Descriptions of new amphibian species per decade until July 2006 on a global scale (including taxa considered to be valid species today only). A steady increase of the numbers is recognizable since 1940. The yellow bar shows the expectation for the period 2000-2009 if the rate of 2000-2006 continues.*

ESSAY 1.2. AMPHIBIAN DIVERSITY AND THE CASE OF SRI LANKA'S BURGEONING INVENTORY

Biodiversity exploration in Sri Lanka, a 65,000-km^2 continental island situated immediately south of India, began with the arrival of Portuguese colonists in 1505. The country had, from pre-Roman times, been an important source of spices, including black pepper and cardamom. European demand for medicinal plants and spices was growing, and sporadic botanical investigations were not long in getting under way. Natural history studies gathered momentum with transfer of the island to the Netherlands in the early 17th century, the first botanic gardens being established in 1669. In 1747, Carolus Linnaeus wrote *Flora Zeylanica* (1747), his only tropical flora, on the then-known plants of the island. Inheriting the island from the Dutch in 1796, the British institutionalized biodiversity exploration by establishing a botanic garden at Peradeniya in 1822, and a natural-history museum in 1877.

By 1993, when the Wildlife Heritage Trust (WHT) – a non-profit organization dedicated to the scientific exploration and documentation of Sri Lanka's biodiversity – began a survey of the island's amphibian populations, the island's vertebrate fauna was generally regarded as well known. Every group had benefited from taxonomic reviews – Kirtisinghe (1957), the major taxonomic work on amphibians before the WHT explorations, recognized 35 species – and there was no hint in the regularly published checklists that significant novelties were to be expected. Indeed, the accretion of new amphibian species had slowed to a trickle, just four having been discovered in the previous half-century (Figure 1).

The initial purpose of the WHT survey was to identify key habitats for amphibian conservation, with the knowledge that by 1993 Sri Lanka's rapidly growing human population was causing ever-increasing expanses of forest to be converted to agriculture. However, within just a short period of time, the WHT team began uncovering many novelties, and in 1998 announced that the island's amphibian fauna could reach an unprecedented 250 species (Pethiyagoda and Manmendra-Arachchi 1998), an estimate since revised downward to ~140 by Meegaskumbura *et al.* (2002). Between 1993 and the present, 42 of these new species have been formally named (e.g., Manamendra-Arachchi and Pethiyagoda 2005; Meegaskumbura and Manamendra-Arachchi 2005) and as many as 50 more are in the process of description.

The vast majority of the novelties discovered in Sri Lanka belong to the Oriental shrub-frog genus *Philautus*. These small frogs are ubiquitous in the very humid forests of tropical Asia, and their tinkling vocalizations figure prominently in the nocturnal forest chorus. *Philautus* are direct-developing frogs: their eggs, deposited on leaves or in shallow nests excavated in the forest floor, hatch directly into near-fully metamorphosed froglets, bypassing the 'conventional' aquatic tadpole stage. Although direct-development rarely features in popular texts on amphibian biology, about 20% of the world's anuran species are reported to show this developmental mode (Thibaudeau and Altig 1999). Many Sri Lankan *Philautus* appear to have remained undiscovered for so long because they had been assumed to belong to a small number of polymorphic species. However, the WHT studies have shown that the new species were consistently distinct, not only in morphology, but also with respect to bioacoustics and genetics (Meegaskumbura and Manamendra-Arachchi 2005) (Figure 2).

The island's species count presently stands at 103, of which 19 are categorized as Extinct, 11 Critically Endangered, 35 Endangered and 6 Vulnerable. While loss of habitat is clearly the most immediate threat, habitat fragmentation combined with on-going climatic change is likely to result in many more species being considered threatened, especially those restricted to high altitudes. Although there is no evidence of Sri Lankan amphibians having been victim to the synergistic effects of climate change and disease (e.g., Pounds *et al.* 2006), on-going climatic change could stress shrub-frog populations. Bahir *et al.* (2005) showed that *Philautus* breed only during periods of sustained rainfall and continuously high relative humidity (80-100%). However, meteorological data from across Sri Lanka show clear warming and desiccation trends. For example, at Nuwara Eliya (1,800 m asl) in the central mountains, average annual temperature increased by 1.3°C and average annual precipitation decreased by ~20% in the period 1869-1995 (Schaefer 1998).

The irony of so many new amphibian species being discovered when amphibian populations worldwide are declining has not escaped attention (e.g., Hanken 1999): some 1,000 newly discovered species were described worldwide in the period 1992-2003 (Köhler *et al.* 2005; and see Essay 1.1).

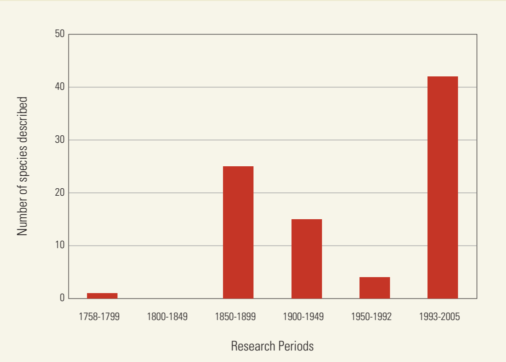

Figure 1. *Number of descriptions of new amphibian species from Sri Lanka from the time of Linnaeus to the present.*

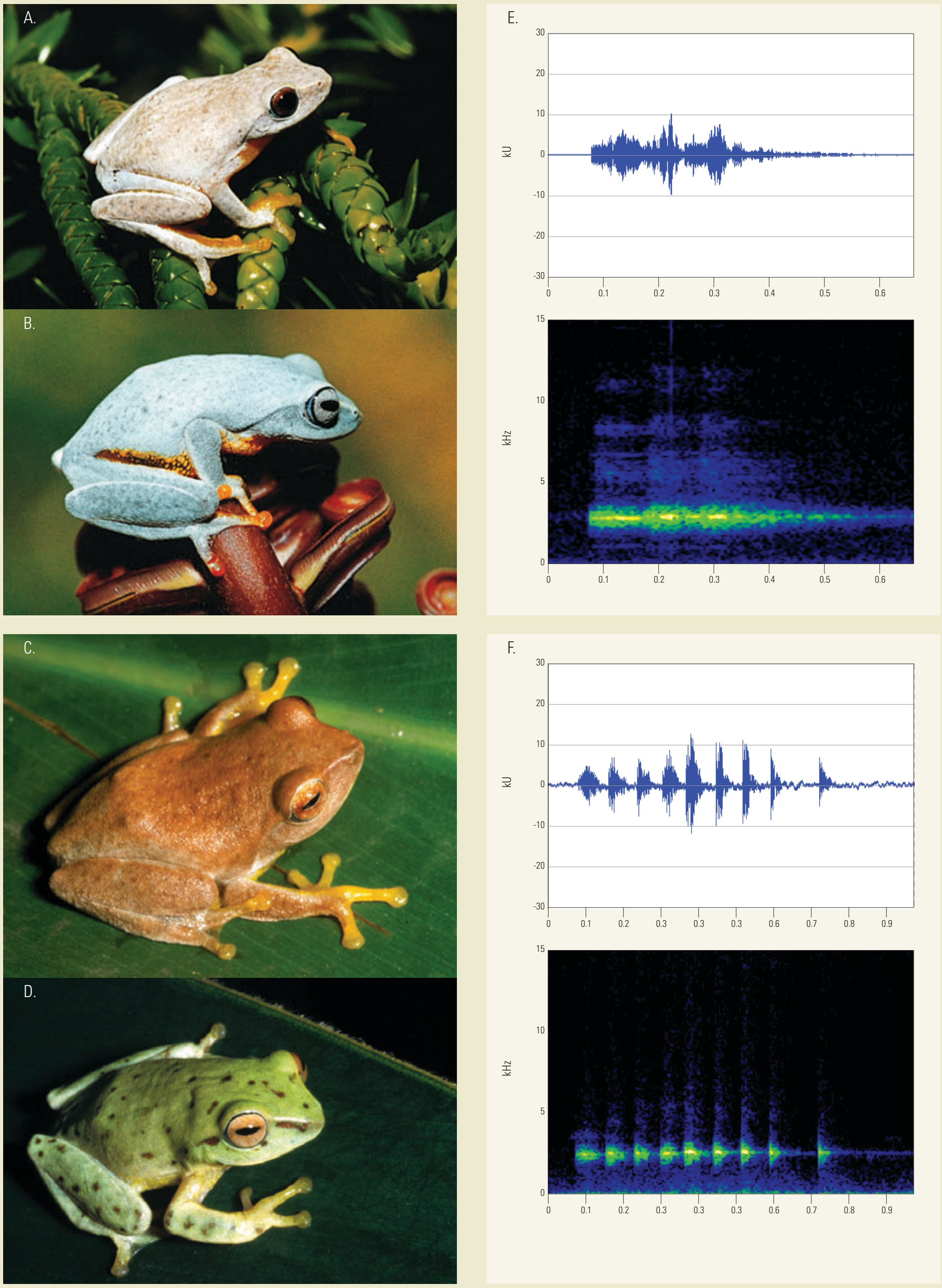

Figure 2. *Although* Philautus hoffmanni *(A,C) and* P. asankai *(B,D) are distinctively coloured, these 'sister species' are morphologically so similar that they key out as a single species.* Philautus hoffmanni *is restricted to altitudes of about 1,250m in Sri Lanka's Knuckles Hills, while* P. asankai *occurs only at altitudes of 800-1,800m in the central massif, about 100km to the south. The two populations are separated by a deep valley. Despite their superficial similarity, the species are distinguished by their vocalizations (E,F), which differ in call length, pulse rate, dominant frequency, fundamental frequency, pulse length, and the number of pulses per call. They also differ from each other by a 12S and 16S mt-DNA divergence of 1.01%, a cytochrome-b divergence of 6.04%, and a suite of subtle, but consistent, morphological characters.*

The case of Sri Lanka suggests that much amphibian diversity, which is rapidly becoming impoverished, remains to be discovered, even in those regions deemed to be historically 'well studied'. This is already evidenced by ongoing studies in other megadiverse tropical countries, such as the Philippines (e.g. Brown and Guttman 2002; and see Essay 7.3). There is an urgent need, therefore, for further exploration and survey work in under-sampled regions, re-analysis of old museum collections, the application of new taxonomic methodologies, including molecular and vocalization analyses, and for the much-needed rejuvenation of neglected taxonomic collections (and see Essay 11.10).

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ESSAY 1.3. CAECILIANS

Of the three orders of living amphibians, caecilians (Gymnophiona) are the least familiar to both amateur and professional biologists. Caecilians are found in most moist tropical regions of the world except in Madagascar and Australasia, and they extend into some adjacent subtropical areas in Indochina and South America. There are c. 170 recognized caecilian species in three, four or six families, according to alternative taxonomies. Species taxonomy is still dominated by the work of E.H. Taylor (e.g., Taylor 1968). Subsequent work relegated many of Taylor's taxa to synonyms, but also increased the rate of description of new species (e.g., Wilkinson and Nussbaum 2006). The current taxonomy of many caecilians is confused, and unpublished work indicates the need for further synonymy, but also justifies the expectation of an eventual rise in the number of caecilian species once taxonomic revisions are complete and as discoveries and descriptions of new species continue (Gower and Wilkinson 2005; Wilkinson and Nussbaum 2006).

All caecilians lack limbs and limb girdles, and tails are very short or absent. Other notable external features include annulated skin, eyes covered with skin and sometimes also bone, and a pair of, sensory tentacles in front of the eyes. The name Gymnophiona ('naked snakes') seems like a rather appropriate description given their superficial snake- (or worm-) like form and lack of external scales. However, many species produce scales in pockets associated with the skin's annulation (Zylberberg *et al.* 1980).

Despite their superficial uniformity, caecilians are intriguingly diverse in morphology and ecology, as might be expected from a group that may have its origins in the Mesozoic. For example, adult caecilians range from less than 10 cm to more than 150 cm in total length, with fewer than 70 to more than 270 vertebrae. This reflects the substantial variation in the degree of elongation of caecilians. They can be dull or vividly coloured, uniform, striped or mottled. There are also notable variations in dentition, annulation, the presence and distribution of scales, and in the structure of the skull, trunk musculature, and sensory, urogenital and cardiovascular systems. The adults of the vast majority of known caecilian species are terrestrial and burrow in soil and/or leaf litter. Some are dedicated subterranean burrowers, while others are more surface-cryptic (e.g., Gower *et al.* 2004b). In addition, there are semi-aquatic and fully aquatic forms (replete with fins for swimming), and one aquatic species, *Atretochoana eiselti* (DD), is the largest lungless tetrapod (Nussbaum and Wilkinson 1995).

Caecilian reproductive modes include terrestrial oviparity, with aquatic larvae or direct development, and viviparity. Aquatic larvae have a small tail fin, lateral-line organs, labial folds and spiracles, and they undergo substantial metamorphosis. As far as is known, all male caecilians have the cloaca modified into an eversible copulatory organ (e.g., Gower and Wilkinson 2002), fertilization is internal, and the mothers of all oviparous species guard egg clutches in subterranean chambers. Different types of viviparity have been distinguished by the degree of dependence of newborns, and the amount and type of any post-parturition maternal care (Loader *et al.* 2003). The foetuses of some viviparous species are thought to feed on the lining of their mother's oviducts (Parker 1956), while the young of some species peel and eat their mothers' specially modified skin (Kupfer *et al.* 2006).

Caecilians are generally not as well studied as frogs and salamanders. This unfortunate lack of attention is perhaps primarily a consequence of their largely tropical distribution and cryptic habits. Another impediment to progress is that the distribution of experts and active researchers in caecilian biology rarely coincides with that of their study taxa. Perhaps only in India are there more than a couple of caecilian biologists studying native taxa, and this situation has underpinned the relatively recent and rapid advancements in knowledge of this fauna (Gower *et al.* 2004a).

An astonishing two-thirds of all caecilian species are classified as Data Deficient, according to IUCN Red list categories and criteria (Gower and Wilkinson 2005). The majority of these taxa are Data Deficient by virtue of their poorly characterized taxonomy, and a lack of data on distribution, ecology, abundance, and response to threats. Caecilian ecology often demands special field techniques that are rarely employed by vertebrate biologists, but substantial progress has been made in recent years (see Gower and Wilkinson 2005; Gower *et al.* 2006). However, with a handful of notable exceptions (e.g., Kupfer *et al.* 2004, 2006; Measey 2004; Measey *et al.* 2003), there have been no detailed studies of reproductive ecology and population density - important parameters for accurate and precise conservation assessments. To underpin their scientific conservation, further studies are needed of caecilian reproduction and ecological requirements, and their response to habitat alteration and climate change. Simultaneously, remaining taxonomic problems must be resolved.

Many caecilians are thought to inhabit moist forests, and it is known that some species have a biphasic life history with aquatic larvae. Thus, these species might be thought of as vulnerable to chytridiomycosis (not yet studied in caecilians) and deforestation – factors that threaten some other amphibians. Some caecilians are known to thrive in certain agricultural landscapes, but it is likely that others are adversely affected by habitat alteration and changing land use (Gower and Wilkinson 2005).

At present, no caecilians are known to have become extinct (at least those species described in the last few hundred years), and only five species are considered threatened. The taxonomy of these five taxa seems relatively stable, and they all occur in relatively small regions (an isolated Kenyan Mountain, Sri Lanka, and the Seychelles). The extent of occurrence is an important parameter in conservation assessments, but what sets the five threatened caecilians apart from other sympatric species is that they are relatively infrequently recorded, and/or their known habitats (native forest and agricultural plots) are threatened by habitat loss or pollution. Three of the five species are believed to have larvae that are dependent on water. Although the majority of caecilians are classified as Data Deficient, there is no room for complacency, and the group as a whole is threatened by lack of knowledge.

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Typhlonectes compressicauda *(Least Concern) is a member of a South American group of aquatic and semi-aquatic caecilians. This species has a wide distribution across Amazonian Venezuela, Colombia, Peru, Brazil and the Guyanas. © Alexander Kupfer*

Ichthyophis *cf.* tricolor. *Species of the two genera (*Ichthyophis *and* Caudacaecilia*) of ichthyophiid caecilians are distributed across South and Southeast Asia, west of Wallace's Line, and are the only caecilians occurring in the latter region. Taxonomic difficulties mean that the precise identification of this specimen is unclear. As far as is known, all ichthyophiids retain the presumably ancestral caecilian reproductive mode of oviparity with aquatic larvae that metamorphose into terrestrial adults. © Ashok Captain*

Herpele squalostoma *(Least Concern) is a member of the Caeciliidae, the largest and most taxonomically confused family of caecilians. This species has its eyes covered by skin and bone, and probably spends the vast majority of its life underground.* H. squalostoma *is one of the few caecilian species to appear occasionally in the pet trade in the West. © Alexander Kupfer*

ESSAY 1.4. THE MEGADIVERSE GENUS *ELEUTHERODACTYLUS*

The genus *Eleutherodactylus*, once the most speciose radiation of vertebrates on earth, is beginning to be dismembered. The dismemberment is partially driven by new molecular data showing that some other genera are intercalated within *Eleutherodactylus sensu lato* (*Brachycephalus* and *Phrynopus* being the initial two cases). However, the urge to dismember *Eleutherodactylus* is also driven by its very large size and a desire to have smaller genera at hand. Most recently, there has been a trend to recognize the genus *Craugastor*, which is largely restricted to Middle America, contains more than 100 species, and has been viewed as monophyletic for about twenty years (confirmed by more recent molecular work; Crawford and Smith 2005; Darst and Cannatella 2004; Frost *et al.* 2006).

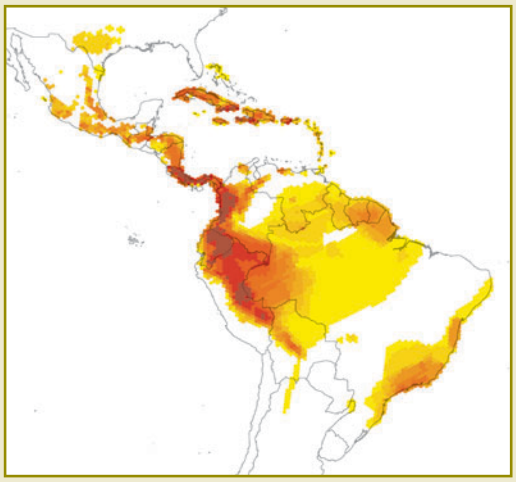

Figure 1. *Richness map of amphibian species in the genera* Eleutherodactylus *and* Craugastor*, with dark red colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes. Maximum richness equals 48 species.*

In its larger sense, *Eleutherodactylus* species are natively distributed from the south-western part of the United States (the southernmost parts of Arizona, New Mexico, and Texas) and from the Bahamas and Cuba to the south and east in an unbroken tapestry until the northernmost (both north-east and north-west) parts of Argentina. Species are known from sea level to at least 4,350m asl (in the Central Cordillera of Colombia). Some taxonomic discontinuity/ fragmentation is apparent across this broad distribution. Some species from Texas to Guatemala are assigned to the subgenus *Syrrhophus* (about 25 species of small frogs). From the south-western United States south and east to western Colombia, Ecuador, and Venezuela one finds the frogs of the genus *Craugastor*. These two generic groupings account for nearly all species of *Eleutherodactylus sensu lato* known from Middle America except for perhaps a dozen species of another group found in Lower Middle America (but better represented in South America). From the Bahamas and Cuba through all of the Greater Antilles, one finds a different group (subgenus *Euhyas*), which scarcely even enters the Lesser Antilles. Human intervention has delivered a few species of *Euhyas* onto the mainland (south-eastern United States, Mexico, Nicaragua). Another group of a half-dozen species (subgenus *Pelorius*) is restricted to Hispaniola. The third grouping in the Antilles (subgenus *Eleutherodactylus*) includes species on all of the major islands and through the Lesser Antilles. Some of these are widely introduced elsewhere (Bermuda, Hawaii, northern South America). In spite of being the most notable Neotropical radiation, few works have treated the genus (*sensu lato* or *sensu stricto*) as a whole (Lynch 1976, 2001; Lynch and Duellman 1997)

In South America, *Eleutherodactylus* species abound in the northern Andes, but barely penetrate Peru except as an assortment of species distributed along the eastern flanks of the Andes that then continues south to northern Argentina. These frogs are abundant in the western lowlands of Colombia and Ecuador, patchily in the inter-Andean valleys of Colombia, and are once again diverse in the western part of the Amazon Basin. However, east of the western fringe of the Amazon Basin, *Eleutherodactylus* becomes a scarce biological component (or even disappears entirely in the Llanos of Colombia and Venezuela as well as in the Cerrado formations of Brazil), with only a minor flare-up in the Guianas. In the once-forested Atlantic domain of eastern Brazil (and south to north-eastern Argentina) there is another focus of diversity, in sharp contrast to the situation over most of Brazil.

The South American fauna has not been fragmented with generic (or subgeneric) names as was the case for the Antilles and Middle America. Nonetheless, a number of clades are evident. The species of the Atlantic forests of Brazil, Uruguay and Argentina represent a single clade (Lynch 2001), although some species of this clade extend westward to Bolivia. Another clade, present in the north-western part of the continent, is composed of species with broad heads and chunky toad-like bodies. The remaining species are grouped into the subgenus *Eleutherodactylus*, with their distribution centered on the Andes (and immediately adjacent lowlands) of Colombia and Ecuador. This heterogeneous unit extends into Lower Central America (at least to Honduras), east to the mouth of the Amazon River, and south to Bolivia. Superimposed upon this pattern of distribution one finds some taxonomic elements that have been separated from *Eleutherodactylus sensu lato* on what could be viewed as tenuous grounds, for example, *Phrynopus* in the Andes from Colombia to Bolivia, separated because they lack digital disks.

At least in terms of Colombia and Ecuador, there is an obvious pattern to occurrence and diversity. In those areas with a negligible dry season, *Eleutherodactylus* communities achieve impressive diversities (to more than 20 sympatric species). However, as the dry season becomes more and more marked (and longer), diversity decays rapidly and only one or two species persist. When the dry season increases to three or more months duration, *Eleutherodactylus* disappear from the frog community or must retreat into enclaves (caves or phyllotemata) so as to survive the dry conditions. The cause of this pattern is almost certainly the pattern of reproduction employed by all known species (save the apparently extinct *E. jasperi*, once an ovoviviparous species). Adults, juveniles, and egg masses occupy the same ecological space and the embryos and small juveniles are especially susceptible to desiccation. Embryos and juveniles tend to occur in the leaf litter and the dry season is especially severe in that layer of the habitat (adults may retreat to phyllotemata or caves and by virtue of their smaller surface area/ volume ratio resist more effectively the harshness of the dry season than the smaller juveniles).

Members of the genus are smallish frogs. The smallest species have body-size maxima of about 10 mm and these very small species (8-18mm body size) are typically confined to the wettest parts of the landscape. The other extreme is occupied by species of *Craugastor* that reach between 100 and 130 mm body-size. Most of these occupy very wet habitats (such as the Chocó), but some occur in lands that are or appear to be dry (for example, parts of the Mexican highlands extending into the south-western part of the United States where I once collected *Craugastor augusti* amidst cactus). The generic name *Eleutherodactylus* means free toes – in allusion to the absence of inter-digital membranes (webs – and this is true for the vast majority of the species now assigned to *Eleutherodactylus*. However, a few species have apparently never read Dumeril and Bibron or Boulenger and have obviously webbed feet (for example, the Puerto Rican *E. karlschmidti* and the Colombian *E. anatipes* and *E. zygodactylus*).

For many reasons, *Eleutherodactylus* are confusing to the non-specialist. The confusion stems from several factors: (1) the sheer number of sympatric species in several areas; (2) the difficulty in distinguishing between adults and juveniles, compounded by the first factor; (3) the marked sexual dimorphism, where for most species adult males are only about 75% the length of adult females; and (4) the widespread phenomenon of pattern polymorphism, especially evident in the exposed visible parts of the animal (dorsal surfaces of the body, head and limbs). When diversity is modest (fewer than a half dozen sympatric species), even the non-specialist becomes slowly comfortable with these frogs.

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ESSAY 1.5. HYLIDAE

Hylidae, the treefrogs, is among the most species-rich family of amphibians, with more than 800 described species. These include some species quite familiar to the general public, such as common Green Treefrog *Hyla cinerea* and leaf frogs, but also an incredible diversity of less well-known groups. Hylids are found mostly in South and Central America, as well as in the Australo-Papuan Region, but some species also occur in the Caribbean, North America, and temperate Eurasia, including extreme northern Africa and the Japanese Archipelago.

Our knowledge about the relationships and composition of Hylidae has experienced dramatic changes in recent years, in part thanks to the revelations of DNA-based studies. For example, marsupial frogs, for a long time considered to be hylids, have been shown by several analyses to be quite unrelated with treefrogs, and have been shown to be unrelated to this family in recent analyses (Haas 2003; Darst and Cannatella 2004; Faivovich *et al.* 2005; Wiens *et al.* 2005; Frost *et al.* 2006)

As it stands, Hylidae is now composed of three subfamilies. Phyllomedusinae, whose species are sometimes called "monkey frogs" or "leaf frogs", includes the poster frog of the amphibian world, the Red-eyed Treefrog *Agalychnis callidryas* (LC), but also other charismatic species such as *Phyllomedusa sauvagii* (LC), and the quite uncommon, but astonishingly beautiful, *Cruziohyla craspedopus* (LC). This subfamily is distributed from the tropical areas of Mexico to northern Argentina. It currently comprises 56 species divided into seven genera. A very interesting characteristic of Phyllomedusinae is that most of its species lay eggs outside water. Eggs are most frequently adhered to leaves (sometimes even completely enveloped by them) or tree trunks, where the earlier developmental stages are spent, and the tiny larvae then fall into the water body below them (be it a pond, stream, or even the water trapped in a tree hole), where they undergo larval development as free-living feeding larvae.

The subfamily Pelodryadinae includes all the Australo-Papuan treefrogs. Among their better known representatives are *Litoria caerulea* (LC), and the White-lipped Treefrog *Litoria infrafrenata* (LC). Its more than 170 species are included in three genera: most (126) occur in the genus *Litoria*, with the remaining members included either *Cyclorana* or *Nyctimystes*^{5}. Pelodryadines are amazing in that they diversified in complete isolation, occupying an extensive range of habitats, and evolving multiple adult and tadpole morphologies that are quite reminiscent to those of the subfamily Hylinae.

The subfamily Hylinae includes the core of hylid diversity. Its more than 590 species are divided into 34 genera and four tribes. The tribe Cophomantini is restricted to the Neotropics and includes five genera. This tribe includes, among others, the "gladiator frogs", so called because males of several of its species engage in violent territorial combats, assisted by a pre-pollex (one of the bones of the hand) that is modified as a spine of variable size and shape. The tribe Dendropsophini, whose identity still requires additional research, includes seven genera restricted to the Neotropics. This tribe includes the most aquatic hylids (genera *Lysapsus* and *Pseudis*), so peculiar that for a long time they were included in a separate family (Pseudidae). It also includes the two most species-rich genera of the subfamily, the taxonomically complex *Scinax* and *Dendropsophus* (about 90 species each, and doubtless much more awaiting description), and possibly the only known frugivorous frogs (genus *Xenohyla*).

Litoria daviesae *(Vulnerable), a representative of the subfamily Pelodryadinae, is distributed on the eastern edge of the tablelands and the great escarpment of the Great Dividing Range of New South Wales, Australia. © Marion Anstis*

The tribe Lophiohylini is also restricted to the Neotropics. This tribe includes 10 genera, many of which include species characterized by heavily modified skull architecture, including fusion of several bones and unusual ornamentations, earning them the name of "casque-headed frogs". An interesting characteristic of this tribe is that many of its species depend on bromeliads and/or tree holes for refuge and even for reproduction, with one genus (*Phyllodytes*) and some of the species of other genera (*Osteocephalus*, *Osteopilus*) laying eggs in the water trapped by the leaf axils of bromeliads, where the tadpoles then spend their entire larval life. The members of the genus *Nyctimantis* and some species of *Trachycephalus* are suspected, or known, to lay their eggs in water trapped in tree holes.

The tribe Hylini includes 16 genera and is mostly concentrated in Central America and North America, with species of the genus *Hyla* also present in temperate Eurasia, including extreme northern Africa and the Japanese Archipelago. This diverse tribe includes common species such as the Green Treefrog *Hyla cinerea* (LC), the cricket frogs (genus *Acris*), the unusual and diverse *Plectrohyla*, from the mountains of Mexico, Guatemala, and Honduras, and the rarely seen fringe-limbed species of *Ecnomiohyla*.

According to the results of the Global Amphibian Assessment, only a single hylid is classed as Extinct, namely *Phrynomedusa fimbriata*, which has not been recorded since it was first collected in 1898 in south-eastern Brazil. In addition, the Global Amphibian Assessment identified another 123 hylids as "Critically Endangered" or "Endangered"; interestingly, of these, 81 are from the tribe Hylini (roughly 50% of the known species in the tribe!), while only 43 belong to the remaining groups (4 phyllomedusines, 12 pelodryadines, 2 Dendropsophini, 13 Cophomantini, and 7 Lophihylini).

Among those hylids classed in the Critically Endangered or Endangered categories, the overwhelming threat is habitat loss (113 species). However, whether the overwhelming majority of Hylini present on the list of Critically Endangered and Endangered hylids is partially the consequence of differences in the perceived threat posed by habitat destruction by different specialists, or a genuine reflection of real destruction of the most diverse areas in Central America and the Caribbean, deserves further study. One important problem facing the conservation of hylids in many countries is our ignorance about the geographic distribution of a large number of species, a problem that complicates any assessment of the status of their populations. A further problem stems from our plain ignorance about the taxonomy of several groups; there are likely many dozens of species of hylids that are unknown to scientists sitting on the shelves of biological collections, not to mention many species still awaiting discovery in poorly surveyed regions.

In conclusion, Hylidae is a large and diverse family of amphibians, but, like most other amphibian families, its members are facing population declines in the face of a litany of threats (Blaustein *et al.* 1994; Beebee and Griffiths 2005). Although actions to mitigate against threats such as habitat loss are undoubtedly necessary, the resolution of this environmental crises depends firstly on an attitude change of the humans in relations to their environment.

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Phyllomedusa nordestina, *a representative of the subfamily Phyllomedusinae, is known from north-eastern Brazil. The species was only recently described in 2006, and has yet to be assessed according to IUCN Red List criteria. © Célio F.B. Haddad*

Bokermannohyla luctuosa *(Least Concern), a representative of the subfamily Hylinae, is a common species from south-eastern Brazil. © Célio F.B. Haddad*

ESSAY 1.6. THE AMPHIBIAN TREE OF LIFE

Recent advances in the field of computational biology and high-throughput DNA sequencing have opened up possibilities for exploring the relatedness between large numbers of species in a much more rigorous way than was previously possible (Wheeler 1996; Wheeler *et al.* 1996-2003). As a result of these advances, Frost *et al.* (2006), presented the first ever comprehensive amphibian tree, and this was subsequently modified by Grant *et al.* (2006) (see Figure 1). The analysis by Frost *et al.* (2006) addressed the relationships of 522 species of amphibians, from all nominal families as well as a informative selection of genera. Details of this very large tree are undoubtedly going to change as data on more species become available, but the broad picture is now probably reasonably well delimited.

The tree shows that caecilians are not only the most distinctive group of amphibians; they are also the sister group of all other living amphibians (i.e., Batrachia, the salamanders and the frogs). In other words, the 172 species of caecilians form one ancient major branch in the tree, and the remaining 5,746 species of salamanders and frogs form the other major branch. Among the salamanders and frogs, the next major division is, not surprisingly, between these two groups; they are sister groups of each other.

Within the salamanders, two families (Cryptobranchidae and Hynobiidae) arguably form the sister group of all the other salamanders. According to Frost *et al.* (2006), these two families (collectively comprising 49 species) are centred on East Asia, with one species of Cryptobranchidae occurring in North America and a single species of Hynobiidae just reaching Europe. The remaining clade of salamanders (comprising seven families and 486 species) is, with the exception of the Salamandridae, overwhelmingly North American. The position of Sirenidae, placed as the sister taxon of Proteidae by Frost *et al.* (2006), is controversial as this family was traditionally considered to form the sister taxon of all other salamanders. We can only assume that this result will be either further confirmed or rejected as more data come to bear on the question.

The taxonomic changes within frogs are more drastic, although the bulk of the Frost *et al.* (2006) results have been suggested previously and many can be considered conventional, the taxonomy having just lagged behind the general understanding of frog evolution. The vast majority of the species continue to belong to the Neobatrachia (see Figure). However, several groups branch off from the stem of the tree before we reach the Neobatrachia. The first group to branch off comprises a single family, the Leiopelmatidae (the New Zealand frogs and the tailed frogs of western North America), comprising just six species. This is the sister group of all the other frogs (5,205 species). Traditionally, this family would be considered "primitive", but there is no particular reason to consider these frogs as being more or less "primitive" than any others. However, they do comprise the most phylogenetically isolated group of frogs in the world.

The next major branch among the bulk of the frogs puts two families, the Pipidae (30 highly aquatic species in tropical Africa and South America) and Rhinophrynidae (one species from Mesoamerica) as the sister group to all remaining species. The Alytidae (midwife toads and painted frogs – 12 species in Europe and the Mediterranean region) and the Bombinatoridae (fire-bellied toads – ten species from western and eastern Eurasia and Southeast Asia) are the next major branch to diverge from the tree, followed by the spadefoots (Megophryidae from East and Southeast Asia, Pelobatidae and Pelodytidae from western Eurasia, and Scaphiopodiae from North and Central America), which form a distinct clade of 142 species. As suggested by Frost *et al.* (2006) and other authors (e.g., Savage 1973; Roelants and Bossuyt 2005) spadefoots are the sister group of the Neobatrachia, which comprises the remaining 5,010 species.

The first split within the Neobatrachia is between the Heleophrynidae (the six species of South African ghost frog) and the remaining species, the Phthanobatrachia. The Phthanobatrachia consist of two familiar major groupings, the Hyloides (3,157 species – 60% of all frog species) and the Ranoides (1,975 species – 38% of the frogs).

The Hyloides is the dominant group of frogs in the Americas and Australia. Of the 18 families, 13 are endemic to the Americas, and two (Limnodynastidae and Myobatrachidae) are centred on Australia. Of the remaining families, the Hylidae is overwhelmingly concentrated in the Americas and Australia (but with a few species in Eurasia), the Bufonidae is globally widespread except in Australasia, and the Sooglossidae is restricted to the Seychelles Islands and the Western Ghats of southern India.

The Ranoides is the dominant group in Africa and Eurasia, to which 13 of the 16 families are endemic. Of the remaining families, the Microhylidae is widespread through both the New World and Old World tropics, the Ranidae is globally widespread except in the southern parts of South America, Africa and Australia, and the Ceratobatrachidae ranges from East Asia to the islands of the South Pacific.

An understanding of the relationships between these families is important for conservation. In deciding conservation priorities, consideration needs to be given to the evolutionary distinctness of species, as well as to the severity of threat to species. For example, using such considerations we would devote much more conservation attention to the caecilians than they currently receive. And within the frogs, we should focus much more on the New Zealand frogs and tailed frogs as the most evolutionarily distinct group of species.

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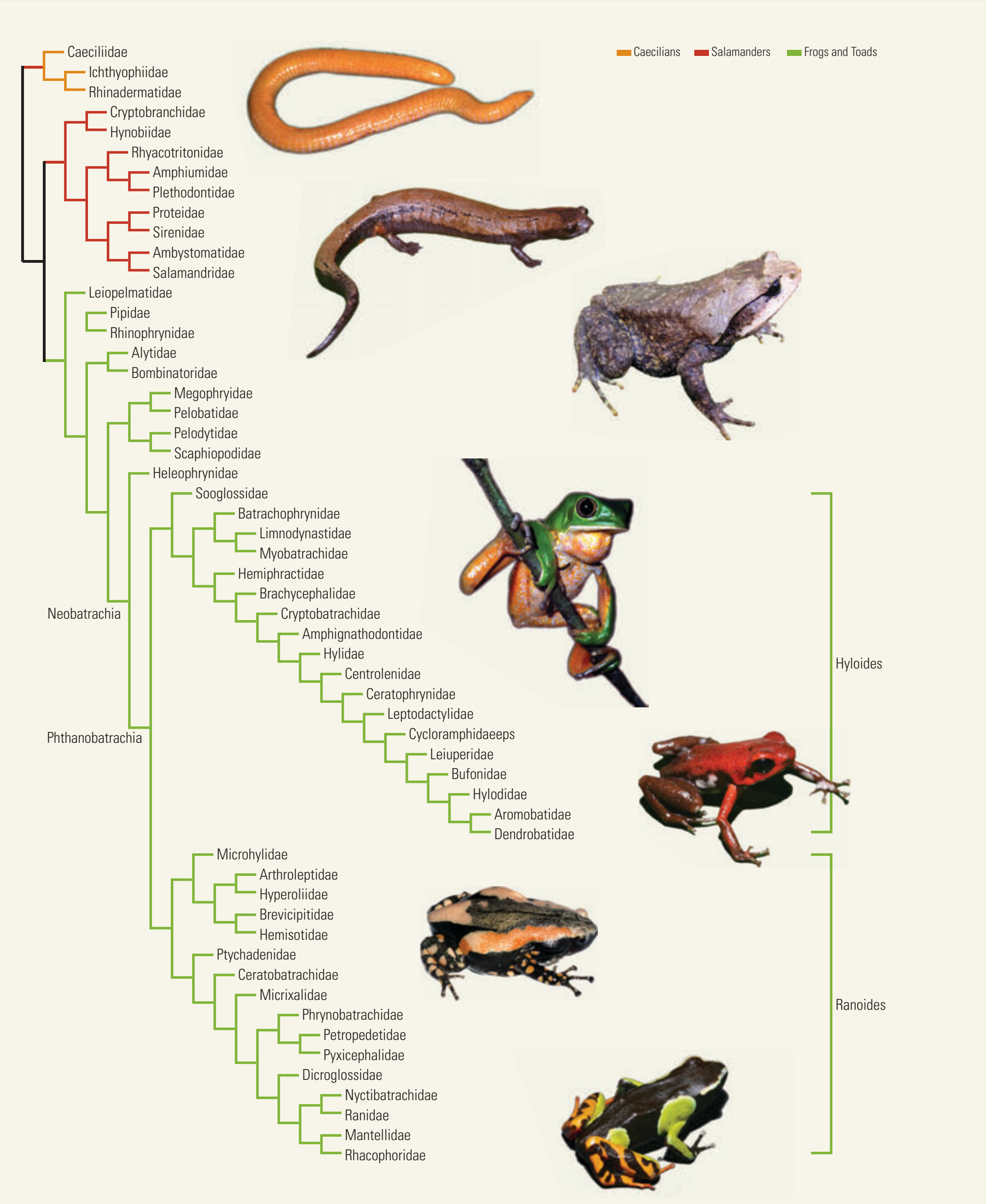

Figure 1. *The amphibian tree of life, showing the relationships between amphibian Orders and Families, according to Frost* et al. *(2006), as modified by Grant* et al. *(2006).*

CHAPTER 2. WHY SAVE AMPHIBIANS?

Neil Cox, Richard J. Berridge, Don Church, Peter Paul van Dijk, Mirza Kusrini, Michal Lau, Thomasina Oldfield, Louise Rollins-Smith and Feng Xie

While scientists discuss the urgency of preventing further amphibian declines, it is clear that many people are uncertain about why we should care about the loss of these species. When the ongoing extinction crisis is discussed, the question often asked is "why save amphibians?" This chapter provides a brief discussion of some of the reasons for saving amphibians.

AMPHIBIANS AS FOOD

To many people, it may be surprising to hear that amphibians are a valued food source throughout much of the world. The use of amphibians for food can range widely from the consumption of animals for subsistence means, to their inclusion as essential ingredients in gourmet dishes. The results of the GAA indicate that ~220 of the world's amphibian species are used for food.

The muscular back legs of the larger species of frogs, particularly members of the families Ranidae and Leptodactylidae, are eaten in many cultures; in some regions, other body parts of both frogs and salamanders are also consumed. Liner (2005) has helpfully documented 193 recipes for frogs and toads, and 26 for salamanders (mostly recipes from North America), and freely admits that this total does not include many of the expected high number of recipes from Asia and Europe. In some instances, species that may seem particularly unappetising are eaten; for example, the Campa Indians of central Peru are reported to roast (to remove noxious skin alkaloids) and eat the poison frog *Epipedobates petersi* (Rodríguez and Myers 1993).

Subsistence harvesting of amphibians for food is often quite small-scale or opportunistic, and may have little overall impact on amphibian populations (with the exception of some restricted-range species). The results of the GAA suggest that at least 212 amphibians are used for subsistence food; however, the diversity of species consumed is probably under recorded, and further studies will almost certainly reveal additional species not previously identified as being used.

Commercial harvesting of wild amphibians for food operates at scales ranging from the local collection and transportation of animals to regional or provincial markets, to the extensive international trade in frog legs. Unfortunately, commercial collection of wild amphibians has often been unsustainable, and in many cases appears to have resulted in significant reductions in amphibian populations. Declines of formerly common species have been reported from the United States (Jennings and Hayes 1985), Europe (Szilárd and Csengele 2001; Ljubisavljevic *et al.* 2003; Török 2003), South Asia (Fugler 1983; Abdulali 1985; Niekisch 1986), China (Ye *et al.* 1993), Viet Nam (Nguyen Quang Truong 2000), and several Andean countries (Lehr 2000, 2006).

From a global conservation perspective, amphibians with localized distributions, or those that are in high demand, such as the Critically Endangered Chinese Giant Salamander *Andrias davidianus*, have undergone even more alarming declines. Many restricted-range species that are collected for food are now threatened with extinction (such as the frog *Batrachophrynus brachydactylus* EN, confined to the region of Lake Junin in Peru, and the Mountain Chicken Frog *Leptodactylus fallax* of the islands of Montserrat and Dominica [Rollins-Smith *et al.* 2005a]), and while some species such as the Chinese Giant Salamander are protected by both national and international legislation (nationally protected in China since 1988; listed on CITES Appendix I in 1997), unsustainable harvesting continues to threaten dwindling populations (and see Essay 4.7).

The international trade in frog legs still largely depends on the collection of wild animals, with the majority of animals in trade (all species) coming from wild sources (possibly up to 85% in 2002; see FIRI 2005). While frog legs are sold globally, the largest market by far is Western Europe, particularly France, Belgium, the Netherlands [almost exclusively wholesale for re-export], Luxembourg, and Switzerland (Niekisch 1986; Kusrini and Alford 2006). The principal source of frog legs exported to these countries were initially India and Bangladesh; however, concerns about the ecological damage resulting from the heavy harvest of amphibians, in particular of the species *Hoplobatrachus tigerinus* (LC) and *Euphlyctis hexadactylus* (LC), led to export bans in the mid-1980s, and the listing of both species on CITES Appendix II in 1985, to establish controls on international trade aimed at keeping it within sustainable levels. Exports of frog legs from Indonesia (mostly from Java) have continued to increase since the first exports in 1969, and this country is now considered to be the world's primary exporter. In 2002, around 3,800t of frog legs, largely of the Mangrove Frog *Fejervarya cancrivora* (LC), were exported from Indonesia, with 83% of these exports going to Europe (Kusrini and Alford 2006). The impact of this heavy collection on Indonesia's frog populations is unclear, especially as the large domestic market still needs to be fully investigated (see Essay 2.1). The results of the GAA given here indicate that the Fanged River Frog *Limnonectes macrodon* of Indonesia now meets the criteria for the category of Vulnerable, in part as a result of the frog legs trade.

In order to meet both international and domestic market demands for frogs, commercial frog aquaculture has developed in some parts of the world. While frogs have generally been considered difficult to farm, as they often require moving food and are relatively slow to reach marketable size, suitable pelleted food has recently been developed for feeding to both adults and larvae. Fishery statistics available from the FAO indicate that farms in China alone annually produce substantial numbers of frogs; in 2004 these farms are reported to have provided 73,837t of frogs (all species) (FAO-FIDI, c2004). In some instances, it is possible to find example statistics for the cultivation of a single species of amphibian. Approximately, 1,382t of American Bullfrogs *Rana catesbeiana* were reportedly produced by farms in 2004 with most originating from Taiwan (Province of China) (FAO-FIDI, c2004; FIRI 2005). Lau *et al.* (1999) report that more than six million Chinese Edible Frogs *Hoplobatrachus rugulosus* were imported to Hong Kong from Thailand in 1999[1]. Unfortunately, frog aquaculture has in many instances been detrimental to wild stocks, with a key problem being the escape of large, often non-native amphibians (such as the American Bullfrog) and their diseases, into surrounding environments (see Lanza and Ferri 1997; Rueda-Almonacid 2000; Kiesecker *et al.* 2001; Mazzoni *et al.* 2003; Goris and Maeda 2004) (and see Essay 4.8).

In much of the world, amphibians, most especially frogs such as this mix of Fejervarya cancrivora *(Least Concern) and* Limnonectes macrodon *(Vulnerable), provide an important but often overlooked source of animal protein. © Anisa Fitri*

MEDICINAL USE OF AMPHIBIANS

While amphibians have long been recognized for their value in traditional medicines[2], they are increasingly also being acknowledged as an important potential source of chemical substances for use in modern medicine. According to the GAA, at least 73 amphibians are considered to have some kind of medicinal value.

In many parts of the world amphibians are still collected for use in traditional medicines by tribal and local peoples, often to meet primary health needs. Aside from this more localized use, there are some areas, notably East Asia, where commercial markets exist for the use of amphibians in traditional medicinal practices. More than 30 species of amphibian have been recorded in Traditional Chinese Medicine alone (Ye *et al.* 1993). Most of the animals used in the various traditional medicines tend to come from wild sources, and although much of the harvesting is of common or widespread species (and may often have little overall effect on the conservation status of populations), there is concern that a number of restricted-range species, such as the Critically Endangered Achoque *Ambystoma dumerilii*, a salamander from Lake Patzcuaro in Mexico, are now significantly threatened by over-harvesting.

The potential value of amphibians to modern medicine is coming under increasing scientific study, with the diverse skin secretions produced by amphibians being of particular interest. The skin of an amphibian must protect the animal against many environmental pressures, including both disease and predation. Chemical secretions identified so far fall into the four categories of biogenic amines, bufodienolides (bufogenins), alkaloids and steroids, and peptides and proteins (Clarke 1997; Pukala *et al.* 2006). Of these substances, perhaps the most familiar are the alkaloids produced by the Neotropical poison frogs (Dendrobatidae), which rank among the most powerful animal poisons known. Hundreds of alkaloids have now been identified in extracts from amphibian skins, with many of these considered to be potentially very useful chemicals (Daly 1995; Philippe and Angenot 2005). For example, the alkaloid epibatidine, isolated from the skin of the Ecuadorian species *Epipedobates tricolor* (EN), is a potent non-addictive analgesic considered to be around 100 to 200 times more effective than morphine (Badio *et al.* 1994). While a number of ongoing studies have demonstrated that many of the alkaloids in amphibian skin are not produced directly by the animals themselves, but are sequestered from the arthropods that make up much of their diet (Daly 1995; Smith and Jones 2004; Saporito *et al.* 2004), emerging evidence suggests that some species of Australian frogs in the genus *Pseudophryne* are capable of directly biosynthesizing skin alkaloids (pseudophrynamines) (Smith *et al.* 2002).

A number of important advances have recently been made in the study of the peptides synthesized and typically stored in granular glands of amphibians. Several hundred peptides have now been recorded from amphibians, and many of these are known to have antimicrobial properties that act as an important natural defence against skin pathogens (Rollins-Smith *et al.* 2005b). Antimicrobial peptides from amphibian skin have potentially very significant applications for both human health and conservation. Exciting work by VanCompernolle *et al.* (2005) has identified three amphibian antimicrobial peptides that inhibit Human Immunodeficiency Virus (HIV) infection of human immune system T cells. Importantly, these peptides have also been found to be effective at preventing transmission of HIV from dendritic cells to T cells (see Essay 2.2).

One important finding, particularly with regards to global conservation efforts, is that of Rollins-Smith *et al.* (2002, 2003) who determined that a number of amphibian skin peptides can inhibit the growth of the chytrid fungal pathogen *Batrachochytridium dendrobatidis*, which is implicated as a major cause of ongoing global amphibian declines. Indeed, it now appears that many amphibian species produce antimicrobial peptides that protect against infection with the chytrid pathogen (Rollins-Smith *et al.* 2005b). However, as many amphibians are suffering chytrid-associated population declines, it seems entirely plausible that in many instances these natural defences have now been compromised by other environmental factors (Rollins-Smith *et al.* 2005b).

THE INTERNATIONAL PET TRADE

Since the mid 20th century, a wide range of amphibian species has been represented in the international pet trade. The GAA recorded that at least 278 species of amphibian were in the pet trade alone, and it is likely that many additional species enter the trade on a regular basis. The main centres of export for the amphibian pet trade are the wet tropics, with species largely coming from the rainforests of Africa (including Madagascar), Central America, South America and Southeast Asia. Comprehensive data covering all amphibians traded are often hard to come by, especially as there is no global database or monitoring system for the trade in non-CITES species (Schlaepfer *et al.* 2005). Very generally, the main international markets for pet amphibians are considered to be within North America and

A number of brightly coloured amphibians are now regularly bred in captivity and kept as pets. Pictured here is the Dyeing Poison Frog Dendrobates tinctorius *(Least Concern), a native species of the lowland forests of the Guianas and adjacent Brazil. © Henk Wallays*

Europe, and developed countries such as Japan. Schlaepfer *et al.* (2005) provide a valuable study of imports of wild reptiles and amphibians into the United States from 1998-2002; during this period at least five million amphibians, reported as being from wild-caught sources, entered the US primarily for the purposes of the pet trade[3].

The export of mantella frogs (Mantellidae) from Madagascar has been particularly closely examined, and provides a helpful case study of the value of some amphibians in the international pet trade. Data gathered by Rabemananjara *et al.* (in press) reveal that over the 10-year period from 1994-2003 the top ten importers of mantella frogs were: the United States (71% of all mantellas exported from Madagascar), the Netherlands (5.5%), Germany (5.2%), Canada (4.6%), Belgium (4.5%), France (2.2%), Japan (1.9%), Switzerland (1.1%), Great Britain (1.3%), and Spain (1.0%). This trade comprised over 230,000 animals, and over a period of three years (2001-2003) was worth almost US$250,000 in foreign currency revenue for Madagascar. Although these figures relate just to mantellas, and are therefore subject to certain influences[4], the broad trends in these data, particularly in terms of which countries have the highest demand for pet amphibians, are likely to apply across many other genera.

The most common amphibians in the international trade are the frogs and toads, and among these several groups of species predominate. The brightly coloured poison frogs (Dendrobatidae) and the equally attractive mantellas from Madagascar (Table 1) have always been in high demand. Other popular anurans include similarly spectacular species, such as treefrogs (most often in the family Hylidae), fire-bellied toads (Bombinatoridae), horned frogs (*Ceratophrys*, in the Leptodactylidae) and several aquatic frogs (often species in the genera *Hymenochirus* or *Xenopus*). Several salamander species are also traded, with aesthetic appeal seeming to be the main criterion for inclusion. Popular taxa include the Asian fire-bellied newts of the genus *Cynops*, members of the North American family Plethodontidae, and other brightly coloured salamanders such as the European Fire Salamander *Salamandra salamandra* (LC), and several newts of the Asian genus *Tylototriton*. Salamanders of the family Ambystomatidae are also in demand as pets, often because of their large size, general ease of maintenance and, perhaps most particularly in the case of the Axolotl *Ambystoma mexicanum* (CR), their fascinating ecology and breeding biology. Caecilians tend to be comparatively rare in the international pet trade, with the easier to observe fully aquatic species (such as *Typhlonectes natans* LC), being more readily available than the predominantly subterranean forms.

While the vast bulk of the international pet trade in amphibians comprises wild-caught specimens, in several instances captive-bred individuals feature more prominently. For example, some captive-bred colour morphs of particular poison frogs (such as the pink and yellow morph of *Epipedobates tricolor*) now appear to be commoner in the trade than their wild progenitors. A comprehensive study of the trade in dendrobatid frogs by Gorzula (1996) revealed that an increasing proportion of the animals recorded in trade from 1987 to 1993 were reported as having been captive-bred; of nearly 16,000 poison frogs in international trade during this period, live captive-reared frogs represented 13.1% of the total traded[5]. It seems possible that the implementation of various regulatory controls, such as CITES (which has also had a marked effect on the availability of particular species), has provided a stimulus for the development of captive-breeding methods, which in turn have reduced the need for wild-caught individuals. Several amphibians that are particularly popular as pets are also captive-bred in commercial quantities, such as the *Ceratophrys* horned frogs, some treefrogs (such as Red-eyed Treefrog *Agalychnis callidryas* LC), and a number of poison frog species. And, indeed, the Axolotl *Ambystoma mexicanum* is more common in captivity now than it is in the wild.

There is potential scope for developing sustainable *in situ* harvesting, or farming, of some of the more desirable species, where their ecology is sufficiently well understood for sustainable harvest quotas and practices to be established (see also Chapter 11). This could have profound conservation benefits, as although most amphibian species kept as pets have been now bred in captivity on occasion, the great bulk of all animals in trade are still collected from wild populations. And even where the capture of wild specimens does not yet constitute a threat to a species, the development of *in situ* harvesting practices could provide the required incentive to motivate landowners to protect and even enhance the species' habitat. A local, sustainable, production programme for species of relatively high worth (e.g., mantella frogs or poison frogs) could also have the additional benefit of playing a role in poverty reduction strategies for some of the poorest parts of the world (and see Chapter 11).

ECOSYSTEM ROLE OF AMPHIBIANS

Although generally unseen, amphibians can often be very abundant in some ecosystems. In both temperate and tropical environments, amphibians may exceed all other terrestrial vertebrate classes (reptiles, mammals, and birds) in both the numbers of individuals and in the proportion of total available biomass (Stebbins and Cohen 1995). Examples of particularly high abundances of amphibians include findings by Gergits and Jaeger (1990) of densities of 7-10 individuals per square metre in Red-backed Salamander *Plethodon cinereus* populations within the Shenandoah National Park, eastern USA; and estimates by Stewart and Rand (1991) of as many as 20,570 adult Puerto Rico Coqui Frogs *Eleutherodactylus coqui* per single hectare of forest.

Table 1. *Export of Mantella frogs between 1994 and 2003 from Madagascar as reported in the CITES annual report data obtained from the UNEP-WCMC trade database (data collated on 2 May 2005). The species* M. baroni, M. cowani, M. haraldmeieri, M. madagascariensis *and* M. pulchra *have gone through stages of profound taxonomic rearrangements between 1988-1999, and these have been largely confounded also in the pet trade. The trade figures of these species therefore need to be viewed with some caution (reproduced from Rabemananjara* et al. *in press).*

Taxon	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	TOTAL	%
Mantella spp.	0	0	0	230	620	200	6,760	9,853	1,420	1,291	**20,374**	8.71
Mantella aurantiaca	100	11,965	16,693	17,406	3,194	8,850	11,445	10,335	4,780	2,681	**116,196**	49.68
Mantella baroni	0	0	0	0	0	0	0	0	10	650	**660**	0.28
Mantella bernhardi	0	0	0	0	0	30	490	1,005	650	60	**2,235**	0.96
Mantella betsileo	0	0	0	1,000	435	175	150	4,040	1,215	1,465	**8,480**	3.63
Mantella cowani	0	0	0	0	52	150	425	975	1,520	500	**3,622**	1.55
Mantella crocea	0	0	0	0	395	250	1,157	1,750	630	100	**4,282**	1.83
Mantella expectata	0	0	0	100	624	105	1,260	1,790	2,585	1,100	**7,564**	3.23
Mantella haraldmeieri	0	0	0	0	0	0	240	310	380	350	**1,280**	0.55
Mantella laevigata	0	0	0	100	435	415	2,537	2,795	1,170	1,581	**9,033**	3.86
Mantella madagascariensis	0	0	0	125	2,182	1,535	6,195	8,805	5,945	4,848	**29,635**	12.67
Mantella milotympanum	0	0	0	0	0	0	0	0	1,270	1,780	**3,050**	1.30
Mantella nigricans	0	0	0	100	200	0	155	490	80	0	**1,025**	0.44
Mantella pulchra	0	0	0	0	784	905	3,277	4,430	2,990	2,560	**14,946**	6.39
Mantella viridis	0	0	0	125	690	385	1,951	3,825	2,495	2,040	**11,511**	4.92
TOTAL	**100**	**11,965**	**16,693**	**19,186**	**9,611**	**13,000**	**36,042**	**50,403**	**27,140**	**21,006**	**233,893**	**100**

It is probable that amphibians can occur in such abundance because both adults and larvae are often the immediate primary vertebrate predators of invertebrates (especially insects), in both freshwater and moist terrestrial environments (Stebbins and Cohen 1995). Additionally many larvae are primary consumers of plant matter, such as algae, and detritus and can be frequently found at high densities in freshwater habitats. In agricultural landscapes, such as rice paddies, amphibians have been suggested as important agents in the control of invertebrate pests (Abdulali 1985; Oza 1994). There is some concern that the removal of amphibians from these systems could lead to increases in these pests, and subsequently to an increase in the need for the application of insecticides and other agrochemicals. It should be noted here that a number of amphibians, such as the Cane Toad *Bufo marinus* (LC), have been widely introduced as biological controls of insect pests. In the majority of cases, naturalized populations of non-native amphibians are considered to have had damaging ecological and/or socioeconomic consequences. Lever (2003) provides extensive details on the effects of known amphibian introductions worldwide.

Amphibians are one of the key links in many ecosystem food webs. As "cold-blooded" ectotherms, ingested energy from food is efficiently converted to high-quality new tissue, with this biomass then becoming readily available for transfer to higher trophic levels (Pough 1983; Stebbins and Cohen 1995; Whiles *et al.* 2006). In both freshwater and terrestrial ecosystems, amphibians as adults and larvae represent a major food resource for many predators, including large invertebrates, fishes, other amphibians, reptiles (snakes in particular), birds, and mammals. Through the process of metamorphosis, they also provide a link in the transfer of nutrients from aquatic systems to terrestrial ones (including forest, see Gibbons *et al.* 2006).

From the few studies that have been undertaken into the potential consequences of removing amphibians from an ecosystem, it appears that important changes can take place in both ecosystem processes and services. Among the structure and functions affected by the removal of amphibians are algal communities, invertebrate populations, predator dynamics, organic matter dynamics, patterns of primary production, leaf litter decomposition, and nutrient cycling (Whiles *et al.* 2006).

The future impact of ongoing amphibian declines on the world's ecosystems is still uncertain with much further study needed. However, given the important role of amphibians in many food webs it seems likely that significant measurable changes in both freshwater and terrestrial environments will eventually take place.

MONITORING ENVIRONMENTAL CHANGE

Amphibians have a number of physiological, ecological and life history characteristics that make them susceptible to environmental changes. They are often considered to be valuable bioindicators of environmental change in both aquatic and terrestrial environments, and declines in amphibian populations or species diversity have frequently been directly linked to habitat degradation (Harfenist *et al.* 1989; Vitt *et al.* 1990; Blaustein and Wake 1995; Stebbins and Cohen 1995; Dodd 1997; Southerland *et al.* 2004).

It seems that relatively few attempts have been made to explicitly estimate how good amphibians are as indicators compared with other taxonomic groups. Welsh and Droege (2001) argued that the low variation in counts of plethodontid salamanders among studies relative to Lepidoptera (butterflies and moths), passerine birds, small mammals, and other amphibians suggests that these salamanders provide a statistical advantage over other species for monitoring forest health[6]. In contradiction to Welsh and Droege (2001), Bailey *et al.* (2003, 2004a,b,c) explicitly estimated detection probability and temporary movement in plethodontid salamander populations using marked individuals and found that counts of animals varied both spatially and temporally, thereby potentially confounding any studies that use simple counts by themselves as a surrogate to population size. In other words, the findings of Bailey *et al.* (2004a,b,c) suggest that counts that are not corrected by incorporating detection and temporary movement probabilities across temporal and spatial components of a study area are likely to provide inaccurate and potentially biased indications of how populations and, thereby, the environment are faring. As further complication to the potential of plethodontids as indicator species, Bailey *et al.* (2004a) found that accounting for detection probability can only do a reasonable job of correcting counts if temporary movement from a population is a random process.

Although there remains some uncertainty concerning the overall value of amphibians as bioindicators, especially with regards to monitoring more difficult to observe species, the following text outlines some of the commonly recognized characteristics of amphibians that are believed to be of use in recording environmental change.

Physiologically, the skin and egg capsules of amphibians are often highly permeable to gases and liquids and may readily absorb pollutants such as toxic chemicals, endocrine mimics, and other substances from the surrounding environment (Stebbins and Cohen 1995; Dodd 1997). Contamination with many of these substances can often result in rapid declines in amphibian populations, and, perhaps more pervasively, can frequently lead to abnormal metamorphosis from the larval stage to the adult form (malformed animals may often be observed in contaminated populations).

Amphibian larvae feed on a wide variety of plant and animal matter, in all parts of the water column from the benthic detritus to the surface film. The larvae are often susceptible to ingesting persistent chemicals attached to particulate matter. The chemicals can readily accumulate in fat deposits, and sequestered contaminants may also significantly affect normal development or metamorphosis when the fat deposits are drawn upon. As adult amphibians largely feed on invertebrates, they are also vulnerable to bioaccumulation of persistent chemical pollutants, such as polychlorinated biphenyls (PCBs) or dichloro-diphenyl-trichloroethane (better known as DDT), in the food web (Hall *et al.* 1985; Stebbins and Cohen 1995; Dodd 1997; Fagotti *et al.* 2005; DeGarady and Halbrook 2006).

Amphibian populations can decline in response to changes in the acidity of aquatic habitats, through either a decrease or increase in pH levels. Sources of changes in pH include acidic precipitation, or point pollution, such as runoff from abandoned mines (Dodd 1997; Middlekoop *et al.* 1999). In general, eggs and developing larvae are the most sensitive life stages to low pH (< 4.5) (Dodd 1997).

Adult temperate and montane amphibians are often heliothermic, and may expose themselves to sunlight in order to increase their body temperatures. This characteristic may make animals more susceptible to increases in ultraviolet (UV) radiation, often associated with a thinning of the ozone layer (Stebbins and Cohen 1995). In addition, as amphibians are moisture dependent ectotherms, they are generally sensitive to any changes in temperature or precipitation levels. Unfavourable conditions may prevent reproduction, possibly for many years (Stebbins 1995).

Amphibians are one of the key links in ecosystem food webs, providing a significant food source for snakes and other predators. This juvenile Pink-sided Treefrog Agalychnis litodryas *(Vulnerable) has become prey for the snake* Leptodeira septentrionalis. *© H. Mauricio Ortega-Andrade*

Increases in sedimentation or turbidity of streams and other waterbodies may be revealed through changes in both the species richness, and population sizes, of amphibians present (Welsh and Ollivier 1998). Many species, possibly most especially in their larval stage, are sensitive to the loss of certain microhabitats or food sources resulting from increased levels of particulates. Other species may be affected by a reduced efficiency of their gills within turbid waters.

Unlike many vertebrates, such as birds, some amphibian species have a low inclination or ability to disperse and tend to be largely confined to small areas of moist habitat (although see Chapter 1) (Smith and Green 2005). These sites, and the amphibian populations present, are often naturally fragmented and there can be little or no movement between populations. Consequently, the loss of one of these populations, for instance through a temporary pollution event, does not necessarily mean that the site will be easily recolonized from any nearby populations. The loss of amphibian populations in some species can, therefore, be used to track ecological disturbance with some confidence that recolonization from adjacent populations will not mask any notable changes to the environment.

It has sometimes been suggested that while some invertebrates have the ecological characteristics that make amphibians helpful bioindicators, they generally differ in that many species are short-lived and can have significant population fluctuations within a short timeframe. However, amphibian populations may also exhibit unstable population dynamics (e.g. Pechmann *et al.* 1991). To use them as bioindicators it is necessary to either monitor their populations over long periods or establish a solid understanding of the relationships among population vital rates, the environmental factors that influence these rates, and how the environment is likely to change in the future so that stochastic population projections can be performed.

While nearly all caecilian and salamander species make little, if any, noticeable vocalizations, the often loud calls by frog species are well known to most people. Communication between individual frogs is a helpful means by which the general species composition of the area, and relative density of the individuals for each species, can be roughly determined. Auditory monitoring of frog vocalizations can help indicate any changes in either species composition or density of individuals (which in turn may reflect changes in environmental quality of the site) (Crouch and Paton 2002; Brandes *et al.* 2006).

LEARNING FROM AMPHIBIANS

For many people, one of their first experiences in handling amphibians is in dissecting a frog during school biology classes. Frogs are most frequently used in these classes, as they cost relatively little and are often readily available. The primary aim of such lessons, of course, is to observe the animal's major internal organs (such as the heart and the liver), and thereby allow students to gain a better understanding of basic vertebrate (including human) anatomy and physiology. As many biology classes require a course in dissection, there is understandably a high demand for subject animals. Although the volume of frogs specifically used in dissection classes is difficult to determine, an early study by Gibbs *et al.* (1971) reported that approximately 326.5t of wild-caught animals (Leopard Frogs *Rana pipiens* and Bullfrogs *Rana catesbeiana*) were annually supplied for educational and research purposes in the United States[7]. Pandian and Marian (1986) estimated that 18 million frogs were used in 1980 by the education sector in India; a significant rise on the 2.6 million animals estimated to have been used in 1956. It is difficult to determine the current volume of animal use in countries such as the United States, as supply companies are perhaps understandably concerned about the confidentiality of these data. However, information kindly provided by Carolina Biological Supply Company (USA) suggests an overall decline in the use of frogs (both live and preserved) within the United States for dissection in education (D.E. James pers. comm.). Most of the frogs now used in the classroom appear to originate from cultivated stock, although small numbers of wild animals are still available[8].

Today, modern technology means that there are now a number of interactive or 'virtual' programmes and software available for use in dissection and anatomy classes (Kinzie *et al.* 1996). Many of these programmes use virtual frogs as the dissection subject, and in some instances provide an alternative to the use of animals in classes.

Outside the classroom, amphibians have contributed to important medical research and discoveries. In fact, seven Nobel prizes have been awarded based on research done with amphibians. While using a dissected frog, the 18th century Italian anatomist Luigi Galvani found by chance that muscle and nerve cells produce electricity. During the discovery, Galvani's assistant accidentally touched an electrically charged scalpel to the sciatic nerve of the dissected frog, causing the limbs to violently twitch and convulse. This observation and subsequent experiments by Galvani helped to establish the basis for the study of the nervous system through the scientific disciplines of neurophysiology and neurology.

Amphibian oocytes (a cell which may produce an egg [ovum] by meiotic division) are commonly used in 'patch clamp' experiments for measuring the electrical properties of biological cells and tissues. The Nobel Prize-winning team of Bert Sakmann and Erwin Neher developed this technique, which is used to measure the movement of electrically charged molecules through individual channels in the membranes of cells (Neher and Sakmann 1976). To conduct an experiment, a very fine, polished glass pipette is placed in contact with the membrane of a cell, and then slight suction is used to make a very tight seal between the pipette and the 'patch' of cell membrane underneath the pipette's tip. The passage of electrically charged molecules through the cell's membrane channels, both into, and out of the cell, is then measured. *Xenopus* oocytes are commonly used for these experiments because of their relatively large size (at approximately 1mm across they are 10 times larger than most animal cells), which makes their handling and manipulation easier. Not only can patch clamping be used to examine the electrical properties of the channels that are normally found in the membranes of *Xenopus* oocytes, but treatment with genetic material from other organisms makes the oocytes 'express' other organisms' membrane channels too, making *Xenopus* oocytes an extremely valuable tool for neurological research. Molecules that are temporary copies of DNA (mRNA - messenger RNA) can be extracted from the cells or tissues of other organism, and then injected into the *Xenopus* oocyte, which will manufacture the foreign proteins, and incorporate that organism's foreign channels into its own membranes, as if they were actually its own[9].

Amphibian eggs have an especially important role in the field of embryology – the study of the formation, early growth, and development of living organisms. The large size of amphibian eggs and their translucent jelly-like coat provide a helpful window into embryonic development, with the African-clawed Frog *Xenopus laevis* (LC) most regularly used as the model organism for embryology studies (Gurdon and Hopwood 2000). During the 1930s, it was discovered that female *Xenopus* could be induced to ovulate when injected with the urine, and hormones, of a pregnant woman. Additional research demonstrated that other species of frogs, such as *Rana pipiens* and *Bufo viridis*, could also be used as pregnancy tests (Miller and Wilberger 1949; Rabau and Szeinberg 1959). For some time during the 1940s and 1950s the use of *Xenopus*, or the Hogben test as it was called, was the only pregnancy test readily available to hospitals. Once it was realized that large eggs suitable for microsurgery could be obtained year-round from domesticated *Xenopus*, embryologists no longer needed to rely on the seasonal collection of wild amphibian eggs for their experiments. The eggs of *Xenopus* are now the leading choice for many embryology studies, as they are ideal for microsurgery, and can be easily manipulated both morphologically and genetically (Stebbins and Cohen 1995).

It may be of some interest that the world's first successful cloning experiments relied on the use of amphibians. In 1952, the two scientists Robert Briggs and Thomas King managed to clone a Leopard Frog by carefully transferring early stage nuclei (from blastula cells) into enucleated eggs (Briggs and King 1952). Although some of Brigg's and Kings' initial attempts failed, they continued perfecting their methods and by the end of the project a number of eggs had successfully developed into normal tadpoles. However, during their

Laboratory studies using the African Clawed Frog Xenopus laevis *(Least Concern) have led to significant medical breakthroughs. © Louis du Preez*

It was once believed that the Common Fire Salamander Salamandra salamandra *(Least Concern) was invulnerable to fire, mostly because hibernating animals would quickly emerge from firewood once it had been lit. © Jelger Herder*

experiments, Briggs and King were unable to clone frogs using nuclei from older, differentiated, embryo cells. The breakthrough came in 1962, when the scientist John Gurdon finally demonstrated that successful cloning could be achieved from differentiated cells. Gurdon transferred intestinal cell nuclei from *Xenopus* tadpoles into enucleated eggs and managed to produce 10 normal tadpoles (Gurdon 1962). Although there was some initial scepticism among scientists concerning Gurdon's results, his later experiments confirmed that a major advance in our understanding of cloning had indeed taken place. The potential importance of the achievements of these cloning pioneers is difficult to overestimate. Their experiments with amphibians have formed the scientific basis for later landmark events, such as the cloning of Dolly the sheep, the first mammal to be successfully cloned from an adult cell (Wilmut *et al.* 1997).

Unfortunately, although we are continuing to gain an appreciation for the value of amphibians for medical advances and in research, it seems as though one important lesson may have been lost forever. The two species of gastric-brooding frogs (*Rheobatrachus silus* and *R. vitellinus*) from the rainforests of Queensland, Australia, had extraordinary reproductive habits in which the females brooded young within the stomach and disgorged the fully developed young through the mouth. Research by Tyler *et al.* (1983), when the species was already rare, provided evidence that the tadpoles secrete a substance (prostaglandin E_2) that inhibits the secretion of gastric acid by the female. It certainly seems possible that further studies of this remarkable reproductive mode could have resulted in medical advances in the treatment of people who suffer from gastric ulcers. Sadly, neither of the *Rheobatrachus* species has been seen since the mid-1980s, despite extensive field surveys, and both are now considered to be extinct (see Essay 6.1).

THE CULTURAL USE OF AMPHIBIANS

Amphibians have long been represented in the cultures of many human societies. As it is difficult to present a concise picture of the spiritual, material, intellectual and emotional uses of amphibians, the following examples are intended to provide only a very brief overview of their many contributions.

Within written records, amphibians are well represented in antiquity by the Ancient Egyptians, most especially in the form of the goddess Heqet who symbolized birth and rebirth, life and fertility. Heqet is depicted in hieroglyphs as a frog or as a woman with a frog's head, a reflection of the sudden abundance of calling frogs during and following Nile River floods. An important cultural reference to both frogs and Ancient Egypt is found within the Biblical book of Exodus and Sura 7 in the Quran, in which Moses leads the Israelites from Egypt. In Exodus, 10 plagues are inflicted upon Egypt by God to convince Pharaoh to allow the Israelites to leave. The second of these plagues was a horde of frogs that overran the land. Pharaoh gave permission for the Israelites to leave if Moses would agree to remove the frogs; however, once the frogs had died Pharaoh reneged on his word. God subsequently sent eight more calamities to Egypt before the Pharaoh agreed to let the Israelites leave.

Frogs are not the only amphibians that have been associated with religion, spiritualism or mysticism. Salamanders were long associated with the popular European myth that these animals were invulnerable to fire. Indeed, it was often believed that salamanders preferred the hottest or fiercest of fires. It seems as though this legend is almost certainly derived from the frequent hibernation of Fire Salamanders *Salamandra salamandra* in stacks of firewood. The Axolotl of Mexico provides another helpful example of a culturally important salamander (see Essay 2.3).

There are several local festivals around the world in which frogs are the leading feature, and a few examples are given here. During the Maguai (= frog) festival of the Zhuang people of Guangxi, China, a frog is captured, honoured and then buried in order to ensure good weather and an excellent harvest for the following year. Since 2003, the city of San Fernando on Luzon Island in the Philippines has held the Pyestang tugak frog festival; with the purpose of perpetuating the Kapampangan people's traditional methods of catching and cooking frogs. The City of Rayne in Louisiana, USA, declares that it is the "Frog Capitol of the World"! People attending this annual festival can see frog races and jumping competitions, as well as frogs dressed up in small uniforms.

In Japan, the frog is traditionally viewed as a symbol of good fortune endowed with magical powers. The word for frog in Japanese, 'kaeru', also means 'to return'; this may include a return from travel, the return of a fortune, or the return of youth. Small charms of frogs are often carried, and are considered to be especially lucky if the frog's mouth is open.

People may often be surprised by how many simple images of amphibians surround them in daily life. For example, this baker's shop in Denmark sells tasty frog-shaped cakes. © Thomas Brooks

Amphibians are regularly found in both classical literature and fairy tales. Shakespeare gives a familiar view of the toad in the comedy '*As You Like It*' ("Sweet are the uses of adversity, which, like the toad, ugly and venomous, Wears yet a precious jewel in his head."), and amphibians are an important ingredient of a witches brew ("eye of newt and toe of frog") in the tragedy '*Macbeth*'. Mark Twain wrote about the unfortunate gambler Jim Smiley and his trained frog, Daniel Webster, in the short story '*The Celebrated Jumping Frog of Calaveras County'*. The much-loved central characters of the children's stories, '*Jeremy Fisher'* by Beatrix Potter, '*The Frog Prince'* by the Brothers Grimm and '*The Wind in the Willows'* by Kenneth Grahame, are all amphibians. Aesop included frogs in two of his most popular fables '*The Frog and the Ox*' and '*The Frogs Who Desired a King*'.

Images of amphibians, especially frogs, are often used for advertising or entertainment in popular culture. International advertising campaigns for beer (Budweiser®) and telephone ring-tones (the '*Crazy Frog*') feature amphibians, as do advertisements and packaging for products as diverse as shoe-polish (Erdal®) and chocolate ('*Freddo Frog*'). Within entertainment, amphibians are commonly found in video games, such as the classic arcade game '*Frogger*', as puppets, such as the frog 'Kaj' in the popular Danish children's TV series "Kaj og Andrea", and as characters in various cartoons and manga comics including: *Michigan J. Frog*, an animated 'Looney Tunes' cartoon character; *Sergeant Keroro*, an anime character; *Flip the Frog*, an animated cartoon character who starred in a series of cartoons from 1930 to 1933; and *Baron Silas Greenback*, the recurring villain in the British animated television series, 'Danger Mouse'. Finally, of course, perhaps the most widely recognized amphibian in contemporary pop-culture is the puppet Kermit the Frog, famously associated with the well-known television programmes *Sesame Street* and *The Muppets*.

THE BEAUTY OF AMPHIBIANS

In concluding this chapter on the value of amphibians to society, it is important to discuss their aesthetic worth, and although this component of intrinsic value generally defies complete quantification in monetary terms, it is important to recognize, and provides perhaps the most important incentive for valuing amphibians (McCauley 2006a,b). In particular, because amphibians are abundant and generally harmless, they may be one of the first wild animals encountered by young children that can lead to an enduring appreciation of nature.

Carl von Linnaeus, the founding father of modern taxonomy, famously described amphibians as "ugly, disgusting creatures ... whose creator failed to try and make more of them" (Hofrichter 2000). However, there is, in fact, a diversity of colour, form, appearance and activity among amphibians to rival the aesthetic delights of anything else that the natural world cares to dazzle us with. Colours range from one end of the spectrum to the other, with every possible permutation in between, with reds, oranges, brilliant vermilions, blues, greens, violets, pinks, black, and even white. Some are paradigms in post-modernism, being delicately dipped in just one shade, while others combine crazy rainbow combinations with spots, stripes, hatches and stipples, madly finished off with tiger-striped legs. Yet others amaze with their uniform bright, almost fluorescent colouration, impossibly tastefully well offset by a crystal clear, shining bright black. No one who sees these species can fail to be amazed by their outlandish, excessive, seemingly pointless beauty.

Yet, these colours serve a very important purpose. Bright colours may serve to advertise fitness to a potential mate, and toxicity (to predators) in the dark confines of the rainforest. A tasteful mix of browns and greys is just the right combination to render a dainty treefrog identical, upon resting, to a very ordinary, quite unappetising bird dropping. Other species produce amazing visual displays by hiding their brightest surprises until the situation demands that they parade themselves in all their glory – the fire-bellied toads (*Bombina* spp.) are camouflaged on their upper surface, being a mixture of browns, blacks, and greens, but upon disturbance by a predator they arch their backs and reveal a stunning fiery belly, aflame with bright oranges, reds, and yellows, warning any foolish predator to back off, lest they ingest some of the poison the toads carry. The frog *Physalaemus nattereri* (LC) even reveals startling eye-patches on its hind legs when being pursued by a predator; the eye patches are actually inguinal venomous macroglands, but they contribute to the appearance of a large face with a pair of impressive large eyes.

The particular characteristics or forms are often reflected in their scientific names. The Latin name of the Golden Poison Frog *Phyllobates terribilis* (EN) is most apt when one considers that it is the most toxic species of frog in the world (Myers and Daly 1983). Another example is the Lake Titicaca Frog *Telmatobius culeus* (CR), whose names translates as 'aquatic scrotum' on account of this species' multiple folds of baggy skin, designed to enhance oxygen uptake in its cold water habitat.

There is little doubt that the sheer diversity of form and appearance provides an endless aesthetic treat for the interested observer. But perhaps the greatest appeal of amphibians is not visual, but acoustic as anyone who has ever been privy to a chirping chorus of frogs as they begin their courtship ritual in early spring will attest.

"*Frogs do for the night what birds do for the day... they give it a voice. And that voice is a varied and stirring thing that ought to be better known.*"

These words written by the zoologist, Archie Carr (Carr 1973) reflect the thinking of many of us who study amphibians. Sadly, such melodic rhapsodies are under threat; this book sets out to argue that we cannot stand by while the frogs croak their last.

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Amphibians have an amazing diversity of colours, body shapes and calls. The jewel-like Mantella frogs of Madagascar, such as Baron's Mantella Mantella baroni *(Least Concern), are among the world's most colourful animal species. © Frank Glaw & Miguel Vences*

Endnotes

1 Although it is unclear what percentage of these were cultivated, the species is commonly farmed in Thailand and most are suspected to have originated from farms (Pariyanonth and Daorerk 1995; P.P. van Dijk pers. comm.).

2 In China, the use of amphibians in traditional medicine was documented to at least 1500 years ago (Fei *et al*. 2006).

3 This represents the total number of only the three most frequently traded species identified as being primarily imported for the pet trade: *Hymenochirus curtipes* (2,376,647 animals); *Cynops orientalis* (1,635,362 animals); and *Bombina orientalis* (1,016,579 animals). In addition to this total, large numbers of poorly documented amphibians entered the US during the same period (presumably many of which were destined for the pet trade); there were seven families for which more than 100,000 individuals entered the US with no species-specific identification (Schlaepfer *et al*. 2005). Approximately 500,000 amphibians with a primary trade purpose as pets were reportedly exported from the United States during the same period of 1998-2002 (Schlaepfer *et al*. 2005).

4 This includes the 2001 decision by the European Commission to halt trade in all *Mantella* species (with the exception of the widespread *Mantella betsileo*), artificially inflating the percentage of the market being dominated by the United States.

5 In 1987 only 1.2% of the animals traded were reported to be captive-bred, by 1993, 39% of animals in trade were captive-bred.

6 This study therefore indicates that not all amphibian taxa are of equivalent quality in terms of providing an accurate and precise measure of ecosystem health, but that plethodontids may be overall superior indicators in North American forests.

7 The numbers reported by Gibbs *et al.* (1971) are considered by some to be overstated by several magnitudes; it is possible that frogs collected primarily for food were also included within these totals (D.E. James pers. comm.).

8 Carolina Biological Supply Company reports that there has been no news from collectors of declines in numbers of frogs harvested from the wild for dissection, including those populations within the main collecting areas of southwest Texas and Mexico (D.E. James pers. comm.).

9 The oocyte can also be induced to produce many more times the number of channels than the cells from the original organism would have done, and this, coupled with the fact that the oocyte is comparatively large and easy to use, makes *Xenopus* oocytes a very powerful system for conducting patch clamp experiments.

ESSAY 2.1. FROGS FOR HUMAN CONSUMPTION

Walking down the aisle of a traditional market or supermarket in many cities in Southeast Asia, you can find frogs sold for human consumption, either live or as fresh skinless legs. Although they are not consumed as universally as are other aquatic taxa such as fish and prawns, frogs have traditionally been used as food in many cultures. People in most regions of the world, including Europe, Asia, Africa, the Americas, and Australia, consume frogs. Usually, only the legs are eaten. Frogs' legs are often considered to be delicacies, and are sometimes highly appreciated as a unique dish, for example "*les cuisses de grenouilles*" of France.

The number of species exploited for frog legs varies among regions. For instance, in Europe the species most harvested are the green frog *Rana esculenta* (LC) complex and other species such as *Rana dalmatina* (LC) and *Rana ridibunda* (LC), whereas in Asia the species harvested are mostly associated with rice fields, such as *Fejervarya cancrivora* (LC) and *Fejervarya limnocharis* (LC). Asians also harvest some stream-associated species such as *Limnonectes macrodon* (VU) and *Limnonectes blythii* (NT). Most harvested species share several attributes: they are large, with heavy muscled legs (for example, *Limnonectes macrodon* exported from Indonesia have snout-vent lengths up to 15cm), are mostly in the family Ranidae, and most do not possess skin glands that produce secretions that are highly toxic to humans. The largest extant frog species, the African Bullfrog *Pyxicephalus adspersus* (LC), is consumed by many traditional cultures in southern Africa; in this case, most of the frog carcass is consumed (Okeyo 2004). On a local scale, which is probably too small to be of conservation significance, some smaller frogs are also harvested in many areas and sold for consumption by other animals, such as fish and pet snakes. In the USA, and probably in other countries, smaller frog species, juvenile ranids, and salamanders are also collected or raised and used or sold, usually locally, as fish bait (e.g., Meronek *et al.* 1997). The extent of this trade appears to be small, but it is of potential concern for its immediate impact on frog populations, the potential to disseminate pathogens such as the amphibian chytrid skin fungus, and for ethical reasons since most amphibians are used as live bait.

Most frogs consumed by humans are caught from the wild. Only one species of frog is widely farmed, the American Bullfrog *Rana catesbeiana* (LC), which has been introduced to many other countries, such as Indonesia, often specifically to boost the production of frog legs for export (Iskandar 1998). The introduction of bullfrogs may cause many problems (and see Essay 4.8). Several studies in the USA have suggested that feral populations of *Rana catesbeiana* outside the natural range of this species have caused declines of native frog populations by acting as competitors or predators (Hayes and Jennings 1986). This species also is likely to act as a vector and reservoir of amphibian diseases, including chytridiomycosis (Mazzoni *et al.* 2003).

Harvesting for consumption has led to declines in populations of some species, for example in the California Red-legged Frog (*Rana aurora draytonii*) in the USA (Jennings and Hayes 1985). The combination of population declines, ongoing demand, and expanding trade has led to the nomination of some edible species for protected status. When local species are protected in an area where frog consumption is traditional, the sources of frog legs shift to countries that do not restrict frog harvesting. Frozen frog legs have thus become an international commodity, in which developing countries in Asia or South America are the producers and developed countries, mostly in Europe, are the consumers. This has shifted the focus of consumption-related conservation concern from the consuming countries to exporting countries.

In 1985 two major producing countries, India and Bangladesh, placed their two edible species *(Euphyctis hexadactylus*, LC, and *Holobatrachus tigerinus*, LC) on CITES Appendix II because of declines in their populations (Abdulali 1985; Pandian and Marian 1986). As the number of frog legs exported from these countries declined, Indonesian exports rose markedly; currently Indonesia is one of the major exporters of frog legs in the world (Kusrini and Alford 2006). The maximum level of exports from Indonesia occurred in 1992, when approximately 5,600 metric tonnes, valued at US$23,596,841, were exported (Kusrini and Alford 2006). This underestimates the total harvest substantially as it ignores the large domestic market (Kusrini 2005). The total harvest of frogs in Indonesia may be as high as 400 million individuals per annum (Kusrini 2005).

Concern regarding the impact of frog harvesting is related not only to the viability of frog populations, but also to the fact that frogs provide ecosystem and even economic services, in particular pest control in agricultural systems (Abdulali 1985; Pandian and Marian 1986). It has been suggested that frog harvesting and pesticide use may interact synergistically: decreases in frog populations caused by harvesting may allow pest populations to increase, leading to increased use of pesticides, which may then have greater negative effects on frogs (Abdulali 1985; Pandian and Marian 1986).

The large number of frog legs exported from Indonesia has raised concern regarding the sustainability of populations of its edible frogs. During the early 1990s several Indonesian *Rana* species were proposed for listing on CITES Appendix II (Martens 1991). This proposal was rejected, perhaps in part for political reasons, but primarily because there was insufficient data on their population status and the extent of the trade to justify a CITES listing (Favre 1989; Schmuck 2000). More recently, research has shown that there is no evidence that harvesting has seriously depleted the populations of edible frogs, particularly the species that inhabit rice fields. Kusrini (2005) showed that harvesting in Indonesia is mostly accomplished using highly targeted manual techniques that do not disturb the habitat or affect populations of non-target species. Harvesting rates are constrained by the need to harvest during phases of the rice growing cycle when frogs can be efficiently captured without interfering with the crops. Kusrini suggested that populations of Indonesian rice field species have been able to withstand continuous harvest pressure because of these constraints on harvesting pressure, combined with their life history traits, which include rapid growth, early maturation, and relatively high reproductive output, and also with their ability to thrive in disturbed landscapes. This may not be true for species harvested in other habitats or environments. Stream-breeding frogs, for example, often appear to have lower reproductive capacities and slower population turnover, which may make them more vulnerable to the effects of harvesting. Temperate species that must concentrate their reproductive activity into restricted habitats during short growing seasons may have lower rates of replacement and be more vulnerable during their short, concentrated reproductive episodes. There is a need to improve the quality and quantity of information available on harvesting rates and trade in frogs and frog products, and our understanding of the biology of the species harvested, so that developing problems can be averted before they become serious.

Critiques of frog harvesting have mostly neglected the human dimension. Pandian and Marian (1986) briefly mentioned that the ban on Indian frog leg exports resulted in the collapse of this industry and the loss of jobs for many people. Since most frogs are caught from the wild, frog harvesting provides a substantial income for unskilled labour in developing countries. In the case of Indonesia, the trade has been well established for several decades and provides employment and a livelihood for many local people. Although Kusrini (2005) showed that the present Indonesian harvest appears to be sustainable, it may be approaching the critical threshold of unsustainability. In the case of Indonesia, it is of concern that the sizes and numbers of frogs harvested are not regulated, as they are in many other countries such as Romania (Török 2003). Additionally, exported frogs are often misidentified (Veith *et al.* 2000). In January 2007, the specific international Harmonized System Code for frogs' legs will be dropped from the Tariff of the World Customs Organization, making monitoring of the international trade more difficult. More thorough and evenly applied monitoring is needed within harvesting and exporting countries to ensure that populations are not being harvested at unsustainable levels, and the international trade needs to be more, rather than less, thoroughly monitored, so that the sources and destinations of traded frogs can be more reliably traced.

Hoplobatrachus rugulosus *(Least Concern) for sale in a market in Phnom Penh. © Jodi Rowley/Robert Puschendorf*

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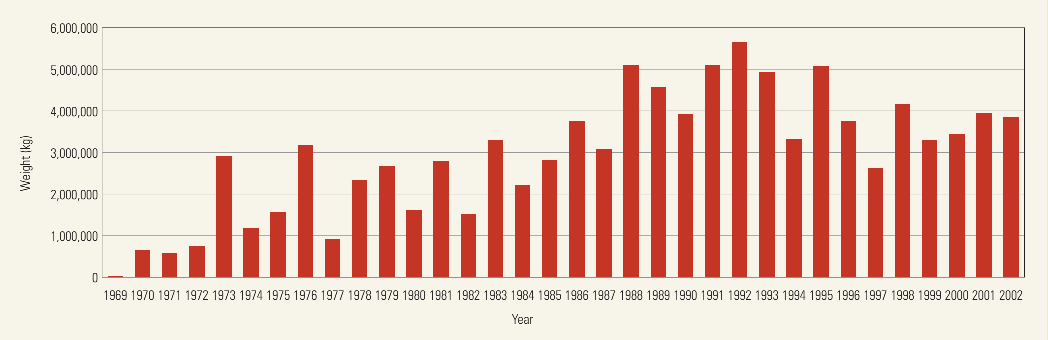

Figure 1. *Total export of Indonesian frogs legs from 1969 to 2000 (Source: Foreign Trade Statistical Bulletin, BPS).*

ESSAY 2.2. ANTIMICROBIAL SKIN PEPTIDES OF AMPHIBIANS

The skin of frogs and toads has been a component of folk medicine of many cultures since ancient times (Lazarus and Attila 1993). Each amphibian species seems to have its own arsenal of compounds that are stored in the skin to ward off predators and/or microorganisms. They include amines, alkaloids, and peptides (Pukala *et al.* 2006). These stored materials are essentially a "packet of poisons" to disarm predators along with a "first aid kit" containing antibiotics and pain relievers to help with the healing processes.

Granular glands in the skin (also called serous glands or poison glands) produce an array of bioactive substances, including peptides with antimicrobial properties. The peptides are synthesized as larger proteins that are cleaved to smaller active peptides and stored in high concentrations in membrane-enclosed granules within each gland. When the animal is alarmed or injured, the entire contents of the gland are pushed out onto the skin, and the peptides play their protective roles. Then the gland is reformed and new peptides are synthesized.

Most amphibian antimicrobial peptides (AMPs) are composed of 10 to 46 amino acids. AMPs tend to contain positively charged amino acids and hydrophobic amino acids and tend to form an -helix that folds in such a way that the positively charged regions and the hydrophobic regions are in discrete areas of the molecule (Yeaman and Yount 2003). This allows them to remain water soluble and capable of interacting with biological membranes. They kill microorganisms by disrupting the plasma membrane or by entering the cell and interfering with vital cellular processes such as DNA replication and protein synthesis.

Several hundred unique AMPs have been isolated from amphibian species, and the number is rapidly growing (Conlon *et al.* 2004; Pukala *et al.* 2006). They fall into a number of related families, but each species has its own repertoire of peptides with very little species overlap. Most of the AMPs were isolated and characterized by classical biochemical purification methods (high pressure liquid chromatography, testing for antimicrobial activity, Edman degradation sequencing of active peptides) (Conlon *et al.* 2004).

Most amphibian AMPs have been isolated for their antibacterial properties. They may be active against a broad spectrum of pathogens or active against a limited subset. One example of a broad spectrum peptide is caerin 1.1 from *Litoria caerulea* (LC). Caerin 1.1 has been shown to inhibit Gram positive and some Gram negative bacteria, inhibit growth of cancer cells, inhibit viral infection of target cells [human immunodeficiency virus (HIV) and herpes simplex virus], prevent growth of the malaria parasite, and kill nematodes (Apponyi *et al.* 2004; VanCompernolle *et al.* 2005). Another example of a recently discovered antibacterial peptide is brevinin-2TSa isolated from the Tsushima Brown Frog (*Rana tsushimensis*, LC) from Japan. This peptide effectively killed several important Gram negative pathogens (*Klebsiella pneumoniae, Enterobacter cloacae, Pseudomonas aeruginosa, Proteus mirabilis*) as well as problematic Gram positive bacteria (*Staphylococcus aureus and methicillin-resistant S. aureus, Staphylococcus epidermidis*, and *Enterococcus faecalis*). Yet, it was not harmful to red blood cells suggesting it would be a good candidate for drug development (Conlon *et al.* 2006).

Fewer of the amphibian AMPs have been tested for their antiviral activities. Because most of them are membrane active, it is very likely that many of them will be effective agents to inhibit infection of target cells by enveloped viruses such as HIV and influenza virus. Six amphibian AMPs inhibited infectivity by a frog ranavirus (frog virus 3) and a fish herpesvirus (channel catfish virus) (Chinchar *et al.* 2001, 2004) and 13 amphibian AMPs were tested for their ability to inhibit transmission of HIV. Three peptides from Australian frogs (caerin 1.1, caerin 1.9, and maculatin 1.1) were potent inhibitors of viral infectivity and could interfere with the transfer of virus from dendritic cells to lymphocytes (VanCompernolle *et al.* 2005). Brevinin-1 from Daruma Pond Frog *Rana porosa* inhibited infection by herpes simplex virus type 1 and type 2 (Yasin *et al.* 2000).

Another important set of pathogens are fungal pathogens. The chytrid fungus, *Batrachochytrium dendrobatidis* (*Bd*), is thought to be the cause of recent amphibian declines in the USA, Australia, and Central America (Lips *et al.* 2006; and see Essay 4.5). Many amphibian AMPs potently inhibit growth of *Bd* (Rollins-Smith and Conlon 2005), and those species whose peptides are most active against *Bd* in the laboratory tend to survive better in nature (Woodhams *et al.* 2006a,b). Many amphibian AMPs are also effective against the human fungal pathogen, *Candida albicans* (Conlon *et al.* 2004), which causes thrush.

A few amphibian AMPs have been tested for their ability to kill malarial parasites. Caerin 1.8 from *Litoria chloris* (LC; Apponyi *et al.* 2004) and dermaseptin S3 from *Phyllomedusa sauvagii* (LC) have been shown to have activity against malaria parasites, and S3 selectively kills parasites within host erythrocytes without harming the erythrocytes (Ghosh *et al.* 1997).

The mucous of frog skin is a rich environment for microorganisms, and control of potential pathogenic organisms is essential for life. It seems clear that the amphibian AMPs in the mucous play an essential role in protection of the species against skin pathogens. The peptide families are conserved, and the peptides can cooperate to be much more effective as mixtures.

What might this teach us that could benefit human health? Antimicrobial peptides have potential for development as therapeutic agents for use on the skin or at mucosal surfaces. Further, because most of the AMPs are small, they can be chemically synthesized. While costs of chemical synthesis are one barrier to the development of AMPs as effective drugs, safety and efficacy are also important concerns. It seems only reasonable that we should learn all that we can from the amphibians about how these unique peptides protect them and exploit this knowledge for the benefit of human health as well as the health of amphibians.

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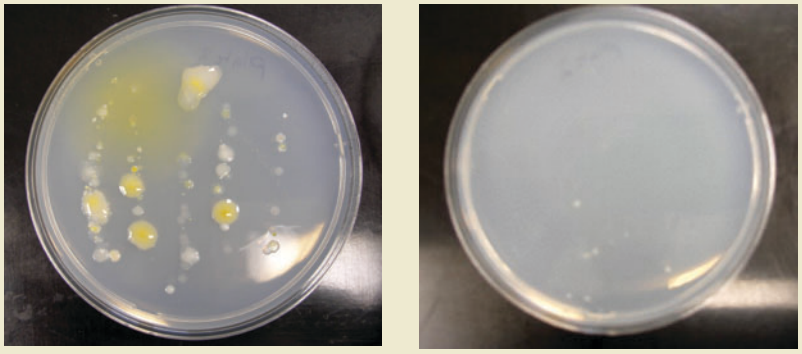

Antimicrobial peptides in leopard frog (Rana pipiens) *skin secretions dramatically reduce skin microbes. The left panel shows bacteria developing on growth medium from skin sampled before induction of skin secretions by injection of norepinephrine. The right panel shows growth from skin of the same frog sampled 15 minutes after skin peptide induction. © Douglas C. Woodhams, Vanderbilt University*

ESSAY 2.3. THE CULTURAL IMPORTANCE OF THE MEXICAN AXOLOTL *AMBYSTOMA MEXICANUM*

The term axolotl (*ajolote* in Spanish) originates from the ancient Aztec language, Nauatal (in which it is properly pronounced 'ashólotl'). Amongst its many translations it means: water slave, water-servant, water sprite, water monster or water dog (from *atl* for water and *xolotl* which has various meanings). These names are derived from Aztec mythology where the axolotl was considered to be the transfiguration of Xolotl, the twin brother of the famous feathered serpent deity named Quetzalcoatl. As with Quetzalcoatl, the exact significance and attributes of Xolotl have varied somewhat between Mesoamerican civilizations throughout history. Xolotl has been known as the God of the Evening Star (the underworld) who ruled over games, deformities, twins, and other irregularities in nature. He was also attributed with powers over the dead and the resurrected, having thought to be responsible for escorting newly deceased souls to the afterlife. Conversely, he was also believed to have brought mankind and fire from the underworld. One popular myth describes Xolotl attempting to escape death by disguising himself into various forms which were either monstrous or double in nature such as double-stalked corn or agave plants (Smith 1969). As each disguise was uncovered by the Gods, Xolotl made one final attempt to escape detection by transforming himself into the axolotl. It was in this state that he was finally captured and sacrificed to nourish the sun and the moon, thereby helping to ensure that the cycle of night and day would continue.

*An early depiction of Xochimilca farmers creating chinampas by piling up mud, vegetation and faeces inside corrals of the water-loving willow (*Salix bonplandiana*).*

An early Spanish image of the Axolotl in the Florentine Codex. Fray Bernardino de Sahagun described the Axolotl as a lizard-like animal with an eel-like tail and ears on the neck.

The Axolotl *Ambystoma mexicanum* is endemic to the canals of Lake Xochimilco, at the southern edge of the valley of Mexico. Archaeological excavations in the Xochimilco basin show that from at least 6000 BC Axolotls were part of a rich lacustrine habitat where it was considered the top predator (Shaffer 1989; Duhon 1997). Although the wetland was used for agricultural purposes before Aztec occupation, the development of *chinampas* (man-made, tree-lined corrals of agricultural land separated by canals) intensified during the construction of the Aztec capital Tenochtitlan.

For thousands of years the Axolotl has been used as a food source (Smith 1989). When the Spanish arrived, it was still an important part of the local economy, as the Franciscan missionary, Friar Bernardino de Sahagun, wrote in his seminal manuscript, the Florentine Codex (Sahagun 1938):

"There are some creatures in the water that are called axolotl that have feet and hands like small lizards, and they have the tail of an eel and the body as well; they have a very wide mouth and whiskers at the neck. It is very good to eat; it is the food of the lords."

Indeed, the Axolotl was considered such good eating that celebrated Spanish naturalist Francisco Hernandez (1959) thought it "provoked lechery". It has also been immortalized by the renowned artist Diego Rivera in his famous mural depicting the axolotl as a product in the ancient market of Tenochtitlan, and in Julio Cortazar's well-known essay "Axolotl" in his collection of short stories *The End of the Game.*

Today, the Axolotl continues to play a role in the local economy. Various medicines and tonics that feature the Axolotl as the main ingredient are sold in local markets and are believed to provide remedies for respiratory ailments, such as bronchitis. Similarly, a captive-bred population of a close relative, *Ambystoma dumerilli* (or Achoque), is harvested by nuns in Pascuaro, in north-western Michoacán, to make a medicinal syrup. This is also believed to cure lung illnesses and help children suffering from anaemia (McKay 2003). Many of the medical powers accredited to the Axolotl may stem from its ability to regenerate damaged or destroyed body parts, including limbs, parts of the cornea, brain, and heart cells. These abilities have made the Axolotl the focus of widespread medical research since the late 1800s.

Due to its diminished population and protected status in the wild, the Axolotl is not utilized to the extent that it was in the past. Nevertheless, they are still illegally harvested from the wild and are sold in markets for the local pet trade, biomedical research, and as a source of food and medicine (Griffiths *et al.* 2004). Due to a lack of trade data, it is difficult to measure the impact of this offtake, mainly because the market operates clandestinely and often involves a related species, *Ambystoma tigrinum*, which is easily confused with the Axolotl.

Because of its mythological connections and prominent position within the ancient lacustrine economy of the region, the Mexican Axolotl has become something of a cultural icon. Therefore, despite its precarious status in the wild, this remarkable species continues to represent not only a significant symbol of the past, but also a sobering example of the need for imaginative solutions required for the present. Indeed, with local people increasingly engaging with current attempts to promote the Axolotl as a flagship species for the conservation of Xochimilco's natural and cultural diversity (Griffiths *et al.* 2004), there is real hope that the species will continue to provide an important catalyst for sustainable development in the future.

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CHAPTER 3. THE GLOBAL AMPHIBIAN ASSESSMENT (GAA): HISTORY, OBJECTIVES AND METHODOLOGY

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Participants at the China and the Koreas GAA workshop in Chengdu, China, in March 2002.

Participants at the Southeast Asia GAA workshop in Bangkok, Thailand, in September-October 2002.

BACKGROUND

While there have always been some instances of localized amphibian declines, often in response to changes in the local environment, scientists had started to become increasingly concerned about the possibility of widespread and severe population declines when they met during 1989 at the First World Congress of Herpetology. A review of historical data suggested that significant amphibian declines had begun as early as the 1970s in the western United States, Puerto Rico and north-eastern Australia (Czechura and Ingram 1990; Kagarise Sherman and Morton 1993; Drost and Fellers 1996; Burrowes *et al.* 2004).

Subsequent reports from field sites revealed the true severity of the population declines. At one site in Costa Rica, 40% of the amphibian fauna had disappeared over a short period in the late 1980s (Pounds *et al.* 1997). In addition, sudden disappearances of montane species had also been simultaneously noted elsewhere in Costa Rica, and in Ecuador, and Venezuela (Pounds and Crump 1994; Pounds *et al.* 1997; Young *et al.* 2001; Ron *et al.* 2003). In some regions, the declines were taking place in seemingly pristine habitats (Czechura and Ingram 1990; Kagarise Sherman and Morton 1993; Pounds and Crump 1994; Drost and Fellers 1996; Pounds *et al.* 1997; Young *et al.* 2001; Ron *et al.* 2003; Burrowes *et al.* 2004).

Some scientists were initially skeptical about the reports; amphibian populations were already well known to sometimes fluctuate widely from year to year (Pechmann and Wilbur 1994). However, by using statistical tests and models, it was shown that the declines were far more widespread and severe than would be expected under natural conditions (Pounds *et al.* 1997). This evidence, in addition to many further reports of declines in the 1990s (Laurance *et al.* 1996; Lips 1998; Lynch and Grant 1998; Houlahan *et al.* 2000; Young *et al.* 2001), convinced most herpetologists that non-random and severe declines were taking place in the populations of many amphibian species.

Participants at the Mesoamerica GAA workshop in La Selva, Costa Rica, in November 2002.

THE INITIATION OF THE GAA AND ITS OBJECTIVES

The lack of a comprehensive global picture on the extent and severity of amphibian declines prompted IUCN, in partnership with Conservation International and NatureServe, to undertake the Global Amphibian Assessment (GAA), which commenced in 2001. The over-arching goal of the GAA was to stimulate concerted and well-targeted activities to halt the current wave of amphibian extinctions, through the development of an information baseline on amphibian status and conservation needs. The initial objectives of the GAA included:

- Identification of the most threatened amphibian species, using the IUCN Red List Categories and Criteria (see Appendix I) to determine which species were in need of urgent conservation action.
- Identification of the most important geographic regions and habitats that need to be conserved in order to prevent further amphibian extinctions.
- Identification of the most important threats to amphibians globally, specifically those resulting in rapid declines, and to propose both mitigating measures and prioritized conservation actions for these.
- Comparing the conservation needs for amphibians with those for mammals and birds, thus making it possible to determine the extent to which conservation initiatives can efficiently and simultaneously address the needs of all of these species' groups.
- Increasing and building the capacity of the IUCN Species Survival Commission expert network for amphibians, thereby allowing scientists to coordinate their conservation activities at the global level, and providing a base of expertise from which information collected during the GAA could be regularly updated.

To meet these ambitious objectives the GAA had to develop a sound methodology by which it could engage the scientific community and gather data on the distribution, abundance, population trends, habitat requirements, and threats for all of the ~6,000 described species of amphibians.

METHODOLOGY

The GAA process involved three core phases of data compilation: initial data collection; data review; and data correction and consistency check.

The task of collecting the initial data was divided into 33 geographic regions (Appendix II) that were defined to cover the global distribution of all amphibians. A network of regional coordinators – scientists with a broad knowledge of the region's amphibian species – were then identified and given the responsibility of collecting data on the amphibians within their region. During the initial data collection phase, regional coordinators were asked to produce distribution maps of each species' current geographic range, which were then digitized in a geographic information system (ArcView 3.x). These maps are most often in a standardized form of polygons that join known point localities.

In addition to range maps, coordinators provided general information on habitat requirements, population status, major threats and conservation measures for each species, and were also asked to make use of the IUCN Classification Schemes for coding up Countries of Occurrence, Habitat Preferences, Major Threats, Conservation Measures, and Utilization[1]. Finally, regional coordinators were asked to provide a provisional Red List assessment of the conservation status of each species by applying the IUCN Red List Categories and Criteria (Appendix I; and see later).

Once the initial data had been collected, they were subjected to a process of peer review. More than 500 amphibian specialists and experts from over 60 countries participated in this process. The means of undertaking reviews varied from region to region, but in most cases (usually the more species-rich regions) the process was handled through expert workshops. However, in other regions, peer-review of data was managed through individual review by leading herpetologists. The following GAA workshops have been held to date:

- Australia – Hobart, Tasmania, 6-8 February 2001.
- China and the Koreas – Chengdu, China, 18-21 March 2002.
- Sub-Saharan Africa – Watamu, Kenya, 16-18 April 2002.
- South Asia – Coimbatore, India, 1-5 July 2002.
- Southeast Asia – Bangkok, Thailand, 30 September – 4 October 2002.
- Mesoamerica (Mexico south through Panama) – La Selva, Costa Rica, 11-15 November 2002.
- The Papuan Region – Hawaii, United States, 24-27 February 2003.
- Tropical South America East of the Andes (merging the Amazonian Brazil, Atlantic Forest-Cerrado-Caatinga, Paraguay, and Guianas regions, and parts of the Colombia, Ecuador, Peru, Bolivia and Venezuela regions) – Belo Horizonte, Brazil, 31 March – 4 April 2003.
- Tropical Andes (merging the remaining parts of the Venezuela, Colombia, Ecuador, Peru, and Bolivia regions) – Tandayapa, Ecuador, 18-22 August 2003.
- Madagascar – Gland, Switzerland, 22-25 September 2003.
- Chile – Concepción, Chile, 3-4 October 2003.
- Argentina and Uruguay – Puerto Madryn, Argentina, 12-14 October 2003.
- Caecilians (the only taxonomic rather than geographically based workshop) – London, 23-25 February 2004.
- Caribbean – Santo Domingo, Dominican Republic, 19-21 March 2004.
- Mediterranean – Malaga, Spain, 13-17 December 2004.

Data review has been completed by correspondence with amphibian experts in the following regions: Northern Eurasia; Seychelles Islands; Japan; Australia (a continuation of the initial data collection workshop); New Zealand; West Asia; North America; Europe; and North Africa.

Following the review process, the GAA coordinating team undertook a final review of all the data to ensure that there had been a consistent approach in the collection and quality of the data between the different regions and taxonomic groups (members of the GAA coordinating team also attended all of the workshops to help promote consistent approaches during the review process). To the extent possible within the constraints of time and budget, when significant problems or uncertainties were encountered in the data, the coordinating team contacted the experts who contributed information about the species to ensure that any changes were correctly made, or information clarified, in order to ensure accurate and consistent conservation status assessments for each individual species. However, it is the GAA coordinating team, not the individual data providers, that takes responsibility for the content of each species account. The data providers are listed as "assessors" on each species account, but because of the limitations in time and funding, they have not all been given the opportunity to sign off on the content of each account to which their name is attached as an "assessor".

DATA LIMITATIONS AND CAVEATS

Taxonomy

As already noted under the introductory chapter, the taxonomic framework used for the Global Amphibian Assessment follows Frost (2004). Regional coordinators were initially asked to follow the systematic arrangement provided in Version 2.2 of *Amphibian Species of the World* (2000), and were only permitted to depart from this classification in a few well-justified circumstances. The GAA has continued to follow revisions to the ASW up to Version 3.0 (Frost 2004). The significant changes given in the most recent update of the ASW are discussed in the introductory chapter.

Distribution maps

The GAA process has endeavored to produce maps for all of the ~6,000 amphibian species; however, in a very few instances (~100) it has been impossible to produce a meaningful map, mostly for species that are currently known only from non-specific type localities. The maps are in the form of polygons that join known locations. A species' distribution map can consist of more than one polygon where there is an obvious discontinuity in suitable habitat. Data attached to each polygon include presence (e.g., extant, extirpated) and origin (native, introduced, reintroduced). In some cases, polygons were clipped to geographical features, such as rivers, or elevational contours.

IUCN Red List Categories and Criteria

The *IUCN Red List of Threatened Species*[2] (hereafter referred to as the Red List) is the accepted standard for species global threat status (Lamoreux *et al.* 2003; Rodrigues *et al.* 2006). The identification of threatened species is of great importance to biodiversity conservation, since it enables practitioners to target those species known to be at highest risk of extinction. The first Red List assessments were largely subjective and qualitative, and primarily focused on a few hand-picked species. However, in 1994, IUCN introduced a system of categorical rankings employing quantitative criteria and representing several advances, including: enabling consistent application by different people, being based around a probabilistic assessment of extinction risk, the incorporation of a time-scale, and the ability to handle uncertainty. The adoption in 2001 of the most recent version of the categories and criteria (IUCN 2001; Appendix I), has enabled considerable improvement of the rigor, justification, and transparency of Red List assessments.

Despite the development of objective criteria, consistency and subjectivity in the application of these remains an issue. The Red List criteria are designed to handle uncertainty, for example uncertainties in population size or trends and distribution (Akçakaya *et al.* 2000), but when there is inadequate information to make an assessment of extinction risk, the category Data Deficient must be used. In the course of undertaking a Red List assessment, there is a risk that errors will be introduced, specifically errors of omission (a species that is genuinely threatened is included in a non-threatened category, such as Data Deficient or Least Concern) and commission (a species that is not genuinely threatened is classed in a threatened category). The attitudes of assessors to such risk and uncertainty range along a spectrum from evidentiary (demanding substantial evidence of threatened status before allowing such a classification) to precautionary (allowing a species to be listed in a non-threatened category only if there is strong evidence that it is not threatened). For a well-known species with extensive quantitative data, the effects of the assessors' attitudes on listings are generally small. However, when the level of uncertainty is high, attitudes can easily cause the observed discrepancies. Assessors with strongly precautionary attitudes are concerned mainly about omission errors, whereas assessors with strongly evidentiary attitudes are concerned mainly about commission errors. Seeking to minimize the risk of one type of error inevitably increases the risk of the other type. IUCN is concerned about both types of error and, therefore, seeks to find a balance between the extremes. The purpose of the consistency check was to help ensure that the Red List category selected for each species reflected this balance.

Improved training in the use of the Red List criteria, particularly at a regional level, and assessor awareness of issues relating to criteria application can help ensure consistency and minimize discrepancies between the global IUCN Red List and national Red Lists.

Brazilian species

For 113 species endemic to Brazil, it was not possible to reach agreement on the Red List category between the GAA Coordinating Team and the experts on the species in Brazil (Appendix XIII). The Red List category for the individual species listed in this book are those that were agreed at the GAA Brazil workshop in April 2003. However, in the subsequent consistency check conducted by the GAA Coordinating Team, many of these were found to be inconsistent with the approach adopted elsewhere in the world. It is these consistent Red List categories that are used in the actual analyses presented in the introductory chapters of this book, and in Appendix V; the consistent categories are presented as footnotes in the species accounts in the book, where relevant.

Underlying data

The data upon which the analyses in this book are based, and the content presented in the individual species accounts that comprise the bulk of this work, are essentially the same as the information contained within the *2007 IUCN Red List of Threatened Species*. Any species described or revalidated after 31 December 2005, is not included. In addition, any information that was published before that date but which was only made available to the GAA Coordinating Team after that date, is also not included here (and, as already noted, the overarching taxonomic classification follows Frost 2004). However, the information presented in the species accounts has been fully edited for content and style, and a number of corrections have been made usually to correct inconsistencies in data or obvious data errors. In a few exceptional instances, we have introduced footnotes, where we feel it is necessary to draw attention to important recent findings (for example, rediscovery of *Conraua derooi* in West Africa).

Participants at the Papuan region GAA workshop in Hawaii, United States, in February 2003.

Participants at the Tropical South America East of the Andes region GAA workshop in Belo Horizonte, Brazil, in March-April 2003.

Rapidly Declining Species

In view of the rapid changes that are taking places in the status of amphibian species in many parts of the world, the GAA Coordinating Team attempted to define a group of species as "rapidly declining", based on an estimate of the likely IUCN Red List status of each species in 1980. Drawing on the data in the 2004 and 2006 IUCN Red List assessments, in particular on information on population trends, habitat decline trends, threatening processes and conservation actions, one member of the GAA Team (Simon Stuart) determined the likely Red List category for each species in 1980. This was estimated conservatively, with the default position being that no change had occurred unless there was strong evidence. Small changes in status were not considered to be sufficient to allow Red List category change. Changes in category were generally related to dramatic changes in the status of the species. Examples include: the disappearance of most, or all, of the population due to disease or poorly understood processes; a catastrophic decline due to over-harvesting; or severe habitat loss (especially for species that are not tolerant of habitat disturbance). Back-calculating of Red List categories has previously been done for birds in order to detect genuine trends in status over time, though this has only been done from 1994 back to 1988 (BirdLife International 2004).

Amphibians that moved to a higher Red List threat category between 1980 and 2006 were defined as "rapidly declining" species. The assignment of individual species to the "rapidly declining" group clearly requires further review. However, for broad multi-species geographic analyses, the results give what seems to be a reliable overall picture of the patterns of amphibian declines.

Participants at the Tropical Andes region GAA workshop in Tandayapa, Ecuador, in August 2003.

Participants at the Chile GAA workshop in Concepción, Chile in October 2003.

Participants at the Caribbean GAA workshop in Santo Domingo, Dominican Republic, in March 2004.

Participants at the Southern Cone GAA workshop in Puerto Madryn, Argentina, in October 2003.

Endnotes

1. http://www.iucnredlist.org/info/authority_files and http://www.iucn.org/themes/ssc/sis/authority.htm
2. www.iucnredlist.org

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CHAPTER 4. THE STATE OF THE WORLD'S AMPHIBIANS

Janice Chanson, Michael Hoffmann, Neil Cox and Simon Stuart

During the course of the 20th Century the global human population increased from 1.65 billion to 6 billion people. In April 2005, the United Nations launched the results of the Millennium Ecosystem Assessment[1], a four-year effort involving 1,360 scientists from 95 countries that aimed to determine more precisely how a burgeoning human population is impacting the planet's biodiversity and ecosystem services, and, conversely, how those changes are affecting human well-being. According to the Millennium Ecosystem Assessment, the world's population doubled between 1960 and 2000, while the global economy gre six-fols over the same time-period. Perhaps not surprisingly then, over the past 50 years, humans have changed the planet's ecosystems more rapidly and more extensively than in any other comparable period of time in human history, largely to meet rapidly growing demands for food, fresh water, timber, fibre, and fuel. The most important direct drivers of change in ecosystems are habitat change, overexploitation, invasive alien species, pollution, and climate change (Millennium Ecosystem Assessment 2005).

Many of the dramatic findings of the Millennium Ecosystem Assessment are telling indictments of the anthropogenic influences that a rapidly technologically evolving human society has brought to bear on earth's natural resources. More land was converted to cropland in the 30 years after 1950 than in the 150 years between 1700 and 1850. Cultivated systems (areas where at least 30% of the landscape is in croplands, shifting cultivation, confined livestock production, or freshwater aquaculture) now cover one-quarter of Earth's terrestrial surface. In the last 20 years, some regions have experienced very high rates of forest loss, particularly in the tropics: in Central America, Amazonia, the Congo Basin, the forests of eastern Madagascar, and south-east Asia (mainly in lowland regions), and it is projected that a further 10-20% of grassland and forestland will be converted between 2000 and 2050 (primarily to agriculture). More than two-thirds of the area of two of the world's 14 major terrestrial biomes and more than half of the area of four other biomes had been converted by 1990, primarily to agriculture. The amount of water impounded behind dams quadrupled since 1960, and three to six times as much water is held in reservoirs as in natural rivers; most water use (70% worldwide) is for agriculture. Since 1750, the atmospheric concentration of carbon dioxide has increased by about 32% (from about 280 to 376 parts per million in 2003), primarily due to the combustion of fossil fuels and land use changes. Approximately 60% of that increase (60 parts per million) has taken place since 1959 (Millennium Ecosystem Assessment 2005).

From a human welfare perspective, such dramatic changes are of primary importance because of the direct linkages between ecosystems and the essential provisioning, regulating and cultural services that they provide to humanity. That such changes already are having a dramatic effect on human society is undeniable. We already know, for example, that the impacts of the massive Tsunami that struck Aceh province in Indonesia on December 26, 2004, could have been significantly less were it not for the loss of coastal mangroves and offshore coral reef systems (e.g., Marris 2005). Similarly, the aftermath of Hurricane Katrina, which devastated the Gulf Coast of the United States, and in particular the city of New Orleans, may rekindle interest in bolstering the wetlands south of New Orleans to provide more of a barrier to future hurricanes (Travis 2005).

Unfortunately, these same aforementioned drivers of change are leading to a significant, irreversible loss of Earth's biodiversity – the very foundation upon which these ecosystem services are built. Although some species respond positively to anthropogenic pressures, the great majority show only limited tolerance of the increasingly widespread and rapid changes impacting ecosystems worldwide. There is already ample evidence that current species extinction rates are 100-1,000 times higher than the normal rate of extinction (Pimm *et al.* 1995; Baillie *et al.* 2004). At least in the last 500 years alone, nearly 800 documented extinctions have occurred, clearly an underestimate since this figure is based only on those species actually known to have gone extinct within this time frame (Baillie *et al.* 2004). And, at least one recent study suggests that we could lose at least *three times* this number of species within just a few decades (Ricketts *et al.* 2005).

The Global Amphibian Assessment is the first-ever attempt to undertake a comprehensive assessment of the conservation status of the world's ~6,000 amphibian species. Only 124 threatened amphibians appeared on the 1996 IUCN Red List (Baillie and Groombridge 1996), and only a few more were added to this number in the 2000 IUCN Red List (Hilton-Taylor 2000). Other than amphibians, only two other vertebrate Classes have been globally and comprehensively assessed: mammals were assessed globally for the first time in 1996 (Baillie and Groombridge 1996), and, at the time of writing, are the focus of a massive revision through the IUCN-led Global Mammal Assessment; birds, on the other hand, a Class of ~10,000 species, have been assessed globally four times since 1988 (most recently in 2004), with a fifth major global assessment planned for completion in 2008.

A comprehensive assessment of this nature permits us a clear picture of the state and distribution of global biodiversity. However, of greatest interest, particularly among amphibians, is the opportunity it presents to investigate the causes of the marked and rapid declines and disappearances that have been observed in amphibian populations the world over, especially those populations that have vanished in seemingly pristine habitats where apparent environmental degradation or anthropogenic impacts are low.

GLOBAL CONSERVATION STATUS

The GAA undertook risk assessments for 5,915 amphibian species[2], categorizing one-third of all extant species (1,893 out of 5,881) as threatened with extinction[3] (Figure 1). This is noticeably higher compared with other groups that have been globally and comprehensively assessed, specifically mammals (23%) and birds (12%) (Baillie *et al.* 2004). Not only are amphibians more threatened than mammals or birds, but they also have a higher proportion of species on the verge of extinction. Some 21% of amphibians are classed in the categories Critically Endangered or Endangered, compared with 10.5% of mammals and 5.4% of birds. Worryingly, it seems increasingly certain that this high level of threat is a significant underestimate of the true threat status of the class, since there is currently insufficient information available to assess the conservation status of 23% of amphibians (these species are placed in the category Data Deficient). These poorly known species (a number of which have only recently been described), are often rare and have small distributions, and with the availability of more information, particularly on threats, may warrant listing in a threatened category. Although the assessment revealed that 44% of amphibian species are currently not considered to be globally threatened (these are species listed in the categories Near Threatened and Least Concern), the populations of most of these species are still decreasing, albeit not currently at a rate sufficient to meet the criteria for listing in a higher category of threat (see later).

A total of 34 species[4] are listed as officially Extinct[5]; 19 of these species are from Sri Lanka[6] (see Figure 2; and see Essay 4.1). One species, the Wyoming Toad, *Bufo baxteri*, is considered Extinct in the Wild, since the surviving wild population persists only due to annual releases of thousands of captive-reared toadlets (see Essay 11.7). Furthermore, within the category Critically Endangered, 130 of the 455 species are flagged as being Possibly Extinct (see Appendix IX). These typically are species that have not been seen for an extended period of time, but for which there is still some lagging hope that they may yet be hanging on in their native habitat (see Butchart *et al.* 2006).

CONSERVATION STATUS BY CRITERIA

In order for a species to qualify for one of the three threatened Red List categories (CR, EN, VU), it must satisfy one or more of the five Red List criteria: A: Population reduction; B: Geographic range size and decline; C: Small population size and decline; D: Very small or restricted population; and E. Quantitative analysis of the probability of extinction (see Appendix I). By summarizing across species the criteria that trigger the Red List categories,

Red List Category	Number of species
🟥 Extinct (EX)	34
🟥 Extinct in the Wild (EW)	1
🟥 Critically Endangered (CR)	455
🟧 Endangered (EN)	768
🟨 Vulnerable (VU)	670
🟩 Near Threatened (NT)	369
🟩 Least Concern (LC)	2,236
⬜ Data Deficient (DD)	1,382
Total Number of Species	**5,915**

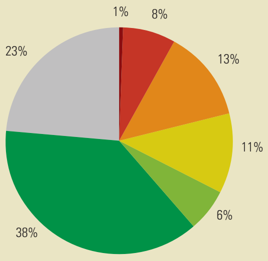


Figure 1. *Summary of Red List categories for all amphibian species. The percentage of species in each category is given in the pie chart above.*

One of four small families of amphibians at risk of extinction, the Leiopelmatidae of New Zealand is represented by only four species, including Leiopelma hochstetteri *(Vulnerable) from North Island, which is at possible risk from the chytrid fungus. © Paddy Ryan*

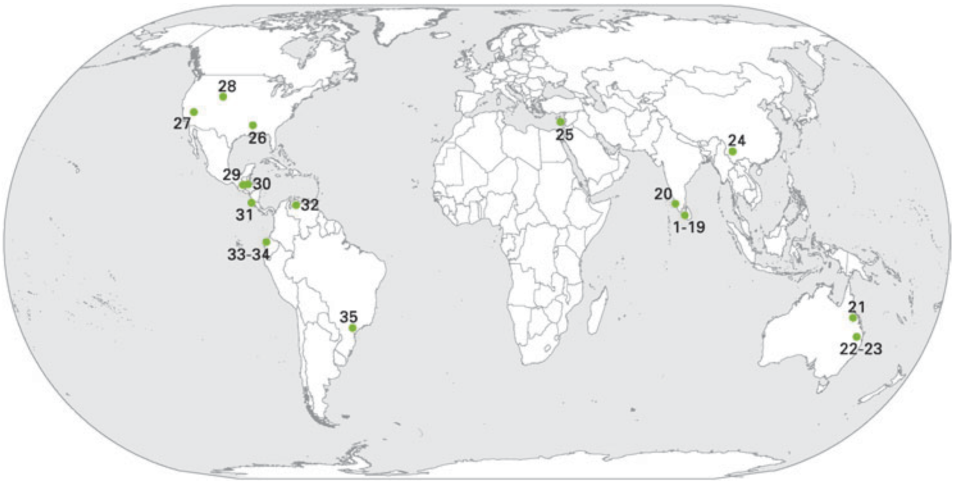


Figure 2. *The distribution of Extinct (n=34) and Extinct in the Wild (n=1;* Bufo baxteri*) amphibians (since 1500). Numbers correspond as follows: 1-19 –* Philautus malcolmsmithi, Adenomus kandianus, Nannophrys guentheri, Philautus adspersus, Philautus eximius, Philautus hypomelas, Philautus leucorhinus, Philautus nasutus, Philautus temporalis, Philautus variabilis, Philautus oxyrhynchus, Philautus halyi, Philautus dimbullae, Philautus nanus, Philautus rugatus, Philautus extirpo, Philautus stellatus, Philautus zal, Philautus zimmeri*; 20 –* Philautus travancorius*; 21 –* Rheobatrachus vitellinus*; 22-23 –* Rheobatrachus silus, Taudactylus diurnus*; 24 –* Cynops wolterstorffi*; 25 –* Discoglossus nigriventer*; 26 –* Plethodon ainsworthi*; 27 –* Rana fisheri*; 28 –* Bufo baxteri*; 29 –* Eleutherodactylus milesi*; 30 –* Eleutherodactylus chrysozetetes*; 31 –* Bufo periglenes*; 32 –* Atelopus vogli*; 33-34 –* Atelopus longirostris, Atelopus ignescens*; 35 –* Phrynomedusa fimbriata.

Red List Category	Number of species in category	A	% of category	B	% of species in category	C	% of category	D	% of category
Critically Endangered (CR)	455	189	42	316	69	8	2	5	1
Endangered (EN)	768	50	7	730	95	4	1	2	0.3
Vulnerable (VU)	670	36	5	463	69	1	0.1	177	26

Table 1. *A summary of the Red List criteria triggering each Red List category. No amphibians are listed under Criterion E, as quantitative analysis of extinction risk requires considerably more data over longer time periods than is usually available for threatened amphibians.*

Order/Family	Total	EX	EW	CR	EN	VU	NT	LC	DD	Number threatened	% Threatened or Extinct
Anura											
Allophrynidae	1	0	0	0	0	0	0	1	0	0	0
Arthroleptidae	51	0	0	3	9	2	3	18	16	14	27
Ascaphidae	2	0	0	0	0	0	0	2	0	0	0
Astylosternidae	29	0	0	2	11	8	2	5	1	21	72*
Bombinatoridae	10	0	0	0	1	4	0	5	0	5	50
Brachycephalidae	8	0	0	0	0	1	1	1	5	1	13
Bufonidae	476	5	1	85	71	52	26	171	65	214	45*
Caeciliidae	113	0	0	1	1	1	0	41	69	3	3*
Centrolenidae	138	0	0	6	16	29	10	28	49	51	37
Dendrobatidae	234	0	0	20	29	16	14	58	97	65	28
Discoglossidae	12	1	0	0	0	2	4	5	0	3	25
Heleophrynidae	6	0	0	2	0	0	0	4	0	2	33
Hemisotidae	9	0	0	0	0	1	0	4	4	1	11
Hylidae	804	1	0	71	64	47	27	431	163	183	23*
Hyperoliidae	253	0	0	1	19	29	17	133	54	49	19*
Leiopelmatidae	4	0	0	1	1	2	0	0	0	4	100
Leptodactylidae	1,238	2	0	145	247	172	61	351	260	566	46*
Limnodynastidae	50	0	0	1	7	2	1	37	2	10	20
Mantellidae	158	0	0	7	12	16	12	77	34	35	22*
Megophryidae	128	0	0	3	14	27	13	40	31	44	34
Microhylidae	430	0	0	6	27	39	18	177	163	72	17*
Myobatrachidae	71	1	0	6	2	4	3	49	6	13	18*
Nasikabatrachidae	1	0	0	0	1	0	0	0	0	1	100
Pelobatidae	4	0	0	0	1	0	1	2	0	1	25
Pelodytidae	3	0	0	0	0	0	0	3	0	0	0
Petropedetidae	102	0	0	3	13	8	10	39	29	24	24
Pipidae	30	0	0	1	2	0	1	21	5	3	10*
Ranidae	666	2	0	19	61	82	60	295	147	164	25*
Rhacophoridae	274	18	0	17	50	33	26	64	66	118	43*
Rheobatrachidae	2	2	0	0	0	0	0	0	0	2	100
Rhinodermatidae	2	0	0	1	0	1	0	0	0	2	100
Rhinophrynidae	1	0	0	0	0	0	0	1	0	0	0
Scaphiopodidae	7	0	0	0	0	0	1	6	0	0	0
Sooglossidae	4	0	0	0	0	4	0	0	0	4	100
TOTAL ANURA	**5,208**	**32**	**1**	**400**	**658**	**581**	**311**	**2,028**	**1,197**	**1,672**	**32**
Caudata											
Ambystomatidae	30	0	0	9	2	2	1	13	3	13	43
Amphiumidae	3	0	0	0	0	0	1	2	0	0	0
Cryptobranchidae	3	0	0	1	0	0	2	0	0	1	33
Dicamptodontidae	4	0	0	0	0	0	1	3	0	0	0
Hynobiidae	46	0	0	5	10	12	2	11	6	27	59*
Plethodontidae	365	1	0	36	82	58	37	91	60	177	48*
Proteidae	6	0	0	0	1	1	1	3	0	2	33
Rhyacotritonidae	4	0	0	0	0	1	2	1	0	1	25
Salamandridae	70	1	0	3	14	12	11	27	2	30	43
Sirenidae	4	0	0	0	0	0	0	4	0	0	0
TOTAL CAUDATA	**535**	**2**	**0**	**54**	**109**	**86**	**58**	**155**	**71**	**251**	**47***
Gymnophiona											
Ichthyophiidae	39	0	0	0	0	2	0	5	32	2	5*
Rhinatrematidae	9	0	0	0	0	0	0	4	5	0	0
Scolecomorphidae	6	0	0	0	0	0	0	3	3	0	0
Uraeotyphlidae	5	0	0	0	0	0	0	0	5	0	0
TOTAL GYMNOPHIONA	**172**	**0**	**0**	**1**	**1**	**3**	**0**	**53**	**114**	**5**	**3***

Table 2. *Red List Status by Order and Family*[8]. **The difference between these percentages and the percentages for amphibians as a whole is statistically significant*[9]

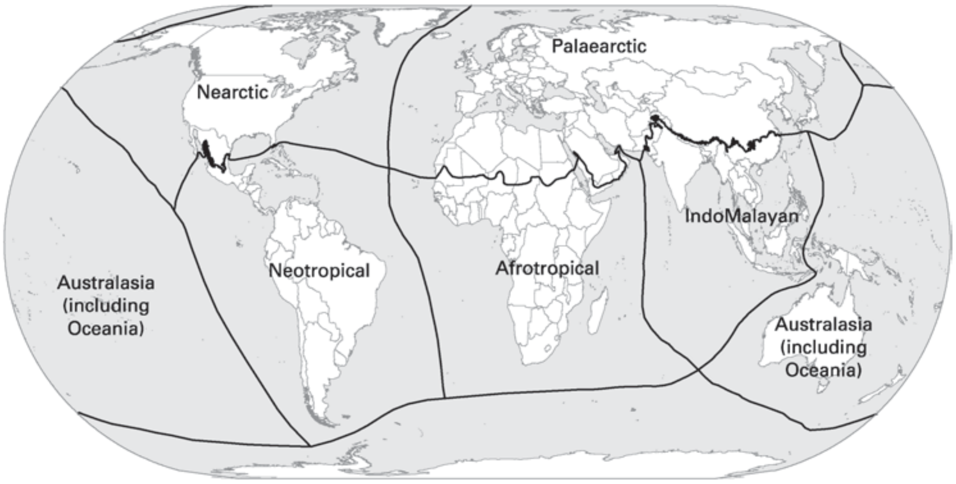


Figure 3. *Biogeographic Realms adapted from Olson* et al. *(2001).*

we can potentially obtain a better understanding of the factors driving species towards extinction (Table 1)[7].

Among Critically Endangered amphibians, 42% of the species meet the criteria for this category due to their having undergone a substantial population reduction (Criterion A), and 69% of species meet the geographic range criterion (Criterion B). The majority of amphibians that are recognized as threatened on the basis of population reduction most often fall within the category of Critically Endangered, with 69% of species meeting Criterion A being within this highest category of threat. Very few amphibian species meet either Criteria C or D (the exception being Vulnerable species meeting Criterion D2; see Appendix X) as the information necessary to appropriately apply these criteria is usually not available. For most species, it is considerably easier to observe a decline in the population, or to make an educated inference of the range size, than it is to estimate the actual number of individuals.

CONSERVATION STATUS ACROSS TAXA

There are significant differences among the three taxonomic Orders of amphibians in the total number of species and conservation status (Table 2). The Anura (frogs and toads), by virtue of absolute numbers of species, greatly influence the average threat level for all amphibians, with 32% either globally threatened or extinct. The less species-rich Caudata (salamanders and newts) are significantly more threatened than the global average, with 47% of species currently threatened or extinct. The smallest Order of amphibians, the Gymnophiona (caecilians), remain extremely poorly known, with two-thirds (66%) of caecilians currently assessed as Data Deficient. Only 3% of caecilians are known to be threatened.

Significant variations in both the total number of species and threat status are also evident between the 48 amphibian families (Table 2). Very diverse families of frogs and toads that are significantly more threatened than the global average include the Bufonidae, Leptodactylidae, and Rhacophoridae. Sadly, both species of the extraordinary Australian endemic family Rheobatrachidae (the gastric-brooding frogs) are now Extinct (see Essay 6.1). Four small families are at severe risk of disappearing altogether; the Leiopelmatidae of New Zealand, with all four species in the family threatened (see Essay 6.2); the Rhinodermatidae of Chile and Argentina with two threatened species, one of which (*Rhinoderma rufum*) has not been recorded since the late 1970s; the Sooglossidae, all endemics of the Seychelles, and the monotypic family Nasikabatrachidae. Diverse families that are less threatened than the global average include Ranidae, Microhylidae, and Hyperoliidae. Among the three most species-rich salamander families, Hynobiidae and Plethodontidae exhibit much higher levels of threat than Salamandridae.

CONSERVATION STATUS ACROSS BIOGEOGRAPHIC REALMS

Biogeographic realms are the eight continent-scale terrestrial and freshwater regions distinguished by characteristic biota that reflect shared evolutionary histories (Udvardy 1975). We adapted the biogeographic realm classification of Olson *et al.* (2001) (Figure 3) to allocate species to one of six biogeographic realms[10]. These realms are broadly similar to the six zoogeographic realms employed by Duellman (1999) in his regional comparison of amphibian distributions (see Fig 1:1 in Duellman 1999).

The Neotropical Realm, which stretches from central Mexico south throughout South America and includes all of the Caribbean Islands, is by far the leader in terms of overall species richness of amphibians, being home to almost half of the world's amphibians, of which 96% are endemic to the realm (Table 3). Two other realms have even higher levels of endemism, the Australasian (99%) and Afrotropical (98%) realms. The relatively low level of endemism in the Palaearctic is mainly due to the somewhat arbitrary border between the Palaearctic and Indomalayan realms in China, and similarly the level of endemism in the Nearctic is also reduced by the arbitrariness of the division of Mexico between the Nearctic and Neotropical realms.

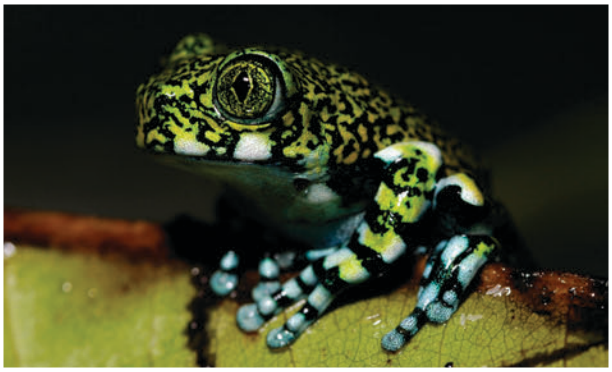
The Neotropical Realm also has the greatest proportion of threatened and extinct species, having experienced significant habitat loss, and is home to many narrow range endemics, especially in the Andes and Mexico. It is also the region that has been hardest hit by chytridiomycosis. Although there are many species that are threatened or extinct as a result of habitat loss, disease and introduced species in Australia and New Zealand, the contribution of the relatively unthreatened amphibians of the island of New Guinea results in the overall percentage of threatened species in the Australasian Realm being the lowest of all the regions, with only 13% and significantly less than the global average of 33%. The Afrotropics, Nearctic, and the Palaearctic are also regions with significantly less threatened species than the global average. In-depth syntheses of amphibian distributions in each of the six biogeographic realms are presented in Chapters 5-10.

SPECIES RICHNESS AND ENDEMISM

Nearly a decade has passed since the last major synthesis on the global distribution patterns of amphibians (Duellman 1999). Prior to Duellman's (1999) synthesis, the only major contributions in the last 50 years that have taken a global perspective on amphibian distributions are those of Savage (1973) and Duellman and Trueb (1986). There have, of course, been many treatises focusing on regional distribution patterns on continents, such as Central America (Savage 1982), China (Zhao and Adler 1993) and Europe (Gasc 1997), as well as island faunas, such as the Caribbean (Hedges 1996) and the Philippines (Inger 1954). However, Duellman's publication was the first to attempt a major synthesis of the global distribution patterns of amphibians, describing differences and similarities among continents, major islands and archipelagos, and discussing the implications of these patterns of distribution relative to conservation.

Realm	Total (endemics)	% endemics	EX	EW	CR	EN	VU	NT	LC	DD	Number threatened	% Threatened or EX
Afrotropical	969 (954)	98	0	0	33	107	100	53	467	209	240	25*
Australasian*	544 (538)	99	3	0	16	21	29	10	287	178	69	13*
Indomalayan	999 (800)	80	20	0	32	134	143	104	311	255	329	33
Nearctic	337 (230)	68	2	1	10	24	46	40	189	25	83	25*
Neotropical	2,916 (2,808)	96	7	0	358	456	324	140	956	675	1,145	39*
Palaearctic	468 (260)	56	2	0	13	40	58	48	245	62	113	24*

Table 3. *Red List status in each biogeographic region. *includes Oceania*



Leptopelis vermiculatus *(Vulnerable) is a range-restricted species endemic to several mountain blocks in the Eastern Arc chain of Tanzania, including the East and West Usambaras, Nguu, Udzungwa, Poroto and Mount Rungwe. Around two-thirds of amphibians have distribution ranges less than 50,000km^2. © Maik Dobiey*

One of the major advances of the GAA process is the collection of high resolution spatial data that allow us to undertake analyses that expand considerably upon the work and conclusions of these aforementioned earlier assessments, making comparisons possible across both broad geographic regions and political units. Importantly, we can make these comparisons across threatened species. Such an analysis of extent of occurrence data has not previously been possible for amphibians beyond that of a single continent (e.g., Brooks *et al.* 2001). It is also possible to compare these maps to human demographic data to gain a better understanding of the challenges faced by amphibians in an increasingly human dominated world (See Essay 4.2).

GEOGRAPHIC PATTERNS OF SPECIES RICHNESS AND ENDEMISM

The most obvious pattern to emerge from an analysis of the overlay of all species distributions is visual evidence that the tropics hold much higher species richness than do temperate regions (Figure 4). This is further supported by a summary of the number of species in each five-degree latitudinal band, which shows that species richness is much higher in the tropics than is to be expected based on area alone, and peaks around the equator (Baillie *et al.* 2004; Mace *et al.* 2005).

Areas of high global species richness among amphibians include Central America, the Andes and the Amazon Basin, the Atlantic forest of Brazil, the Upper Guinea forests of West Africa, the Afromontane regions of Africa (including the Albertine Rift, the highlands of Cameroon, and the Eastern Arc Mountains), eastern Madagascar, the Western Ghats, and montane Southeast Asia. The only non-tropical area with high species richness is the south-eastern United States, which is the global centre for salamander diversity. Species richness is lowest in arid regions, and there are no amphibians at all in the high latitudes of the northern hemisphere, central Asia, North Africa, south-central Australia, Antarctica, and most of New Zealand. Of course, this map must be interpreted with some caution when considering the problem of uneven survey efforts around the world; regions such as Indonesia, New Guinea and the Congo Basin are especially likely to be under represented on this map due to lack of adequate surveys, although the overall pattern of species richness decreasing away from the poles holds true. Considering existing maps of species richness among mammals and birds, there is an obvious degree of congruence in patterns of overall species richness among these groups (Baillie *et al.* 2004; Mace *et al.* 2005).

The global distribution of threatened amphibians (Figure 5) differs significantly from the map of overall species diversity. Major concentrations of threatened species are associated with insular systems (montane environments, islands), where there has been severe habitat loss and exposure to the fungal disease chytridiomycosis, including the sierras and trans-volcanic belt of Mexico, Central America, the tropical Andes, Brazil's Atlantic Forest, the Greater Antilles, the Upper Guinea forests of West Africa, the forest of western Cameroon and eastern Nigeria, the Albertine Rift, the Eastern Arc Mountains of Tanzania and other Afromontane outliers, the south-east coast of South Africa, Madagascar's wet forests, the Western Ghats and Sri Lanka, montane Southeast Asia, and eastern Australia. South and East China also emerge quite strongly, although the pattern is driven to a large degree by the formerly widespread, but now Critically Endangered, Chinese Giant Salamander.

In contrast then to published richness maps of threatened mammals (Baillie *et al.* 2004; Grenyer *et al.* 2006) or birds (Baillie *et al.* 2004; BirdLife International 2004; Orme *et al.* 2005; Grenyer *et al.* 2006), most of the world is devoid of threatened amphibians. It has already been established that there is a widespread correlation between a species' range size and extinction risk (Purvis *et al.* 2000), and geographic range is inherent in the Red List criteria (see Appendix I). Since amphibians are largely sedentary species, their ranges tend to be much smaller than more mobile species, such as birds (Baillie *et al.* 2004). Threatened amphibians are more likely to have small range sizes (Table 4) and tend to occur more densely in smaller areas than either mammals or birds.

Not only do most amphibians have small ranges, but these narrowly distributed species tend to co-occur in 'centres of endemism' (Anderson 1994). These centres of endemism tend to lie across isolated or topographically varied regions, and show extreme concentration in the tropics (Figure 6). This is the geographical manifestation of 'Rapoport's rule' (Rapoport 1982), which states that the mean latitude of a species' range correlates with the species' range size, although the generality of this 'rule' has been questioned (Gaston 1999). Previous analyses have already demonstrated the remarkable degree of overlap between centres of endemism across birds, mammals and amphibians (Baillie *et al.* 2004).

SPECIES RICHNESS AND ENDEMISM WITHIN COUNTRIES

An important contribution of any analysis of geographic patterns of amphibian distributions is reporting on the distribution of species by political units, specifically countries. Particularly

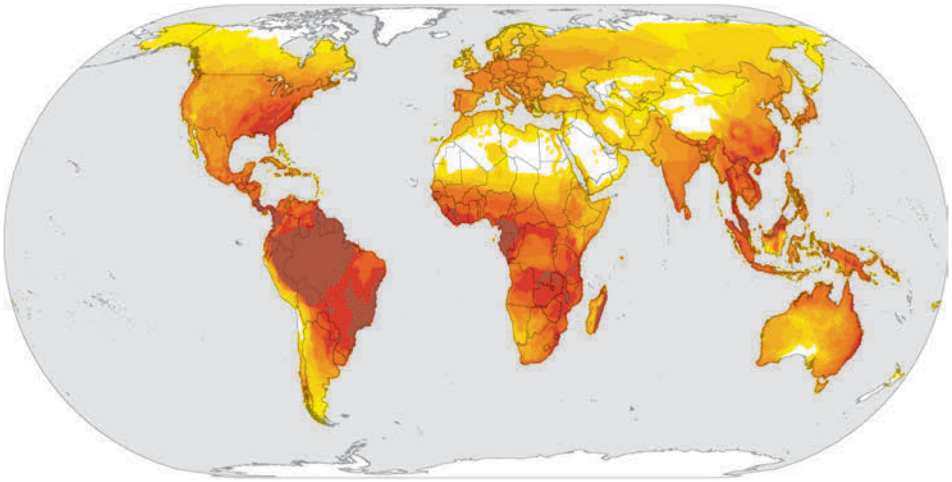


Figure 4. *Global species richness for amphibians, with dark red colours corresponding to higher richness. Colour scale based on 10 quantile classes. Maximum richness equals 144 species.*

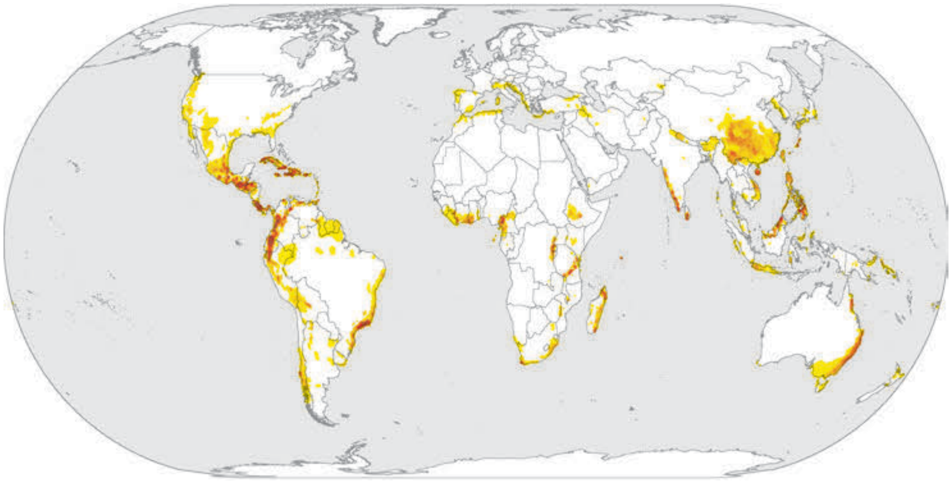


Figure 5. *Richness map of threatened amphibian species, with dark red colours corresponding to higher richness. Colour scale based on 10 quantile classes. Maximum richness equals 44 species.*

Order	**All species minus DD, EX and EW**		**All threatened species**	
	Median area (km^2)	**Number of species**	**Median area (km^2)**	**Number of species**
Anura	19,118	3,978	1,090	1,639
Caudata	4,378	462	417	249
Gymnophiona	33,224	58	44	5
All species	**16,794**	**4,498**	**976**	**1,893**

Table 4. *Median range size of species in each amphibian Order. Only extant non-Data Deficient species with a range map are included in the analysis*[11].

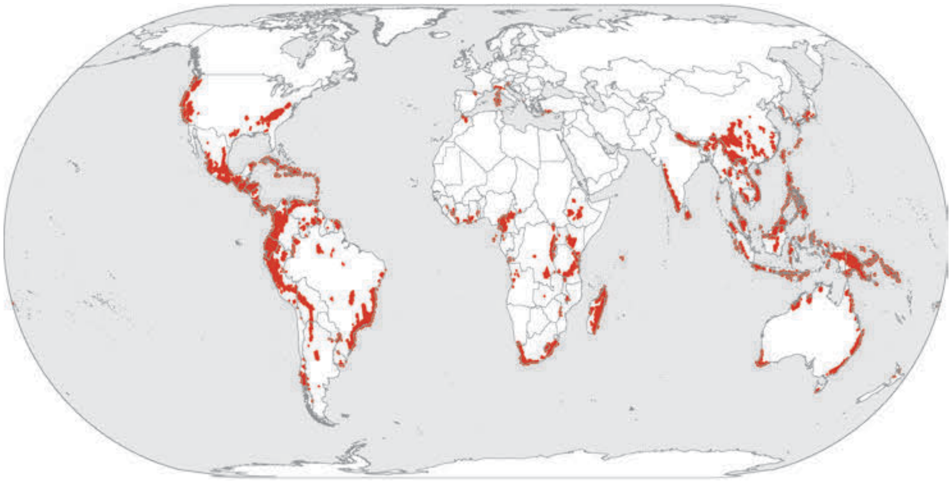


Figure 6. *Centres of endemism inhabited, respectively, by more than two overlapping species with global distributions of less than 50,000km^2* [12].

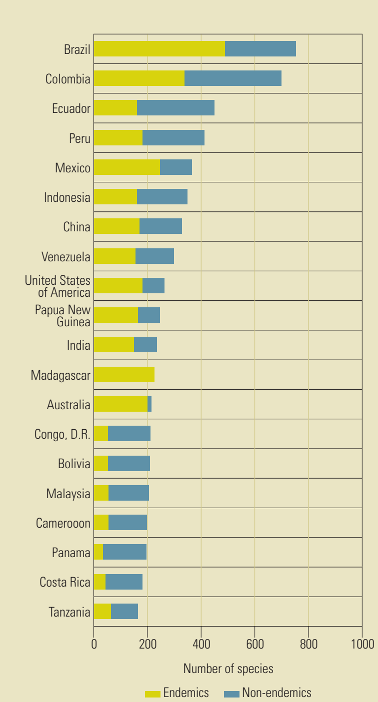


Figure 7

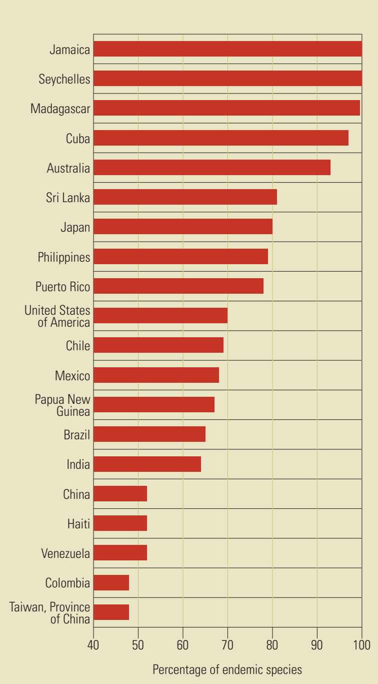


Figure 9

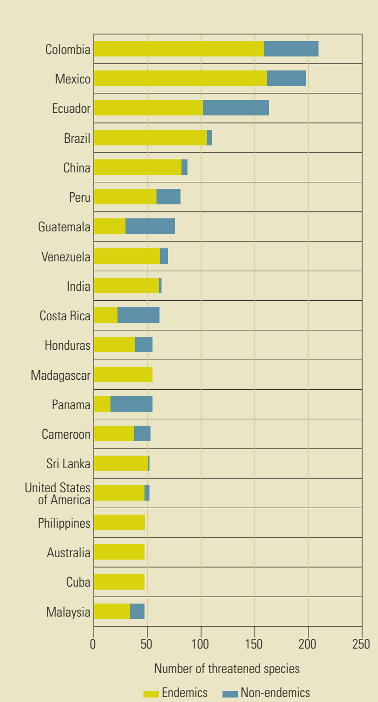


Figure 10

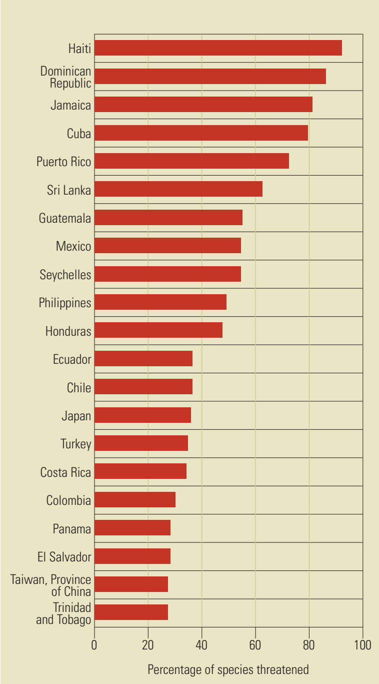


Figure 12

Figure 7. *The 20 most diverse countries for amphibians.*

Figure 9. *The 20 countries with the highest percentage of country endemics. Countries with less than 10 native species are excluded (NB. The totals for China include species in Hong Kong and Macau).*

Figure 10. *The 20 countries with the highest number of threatened amphibians.*

Figure 12. *The 20 countries with the highest percentage of threatened amphibians. Only countries with 10 or more native amphibians are included.*

informative are the numbers of species endemic to each country, and especially the numbers of endemic threatened species, because they can guide a "doctrine of ultimate responsibility" for each nation to ensure the persistence of global biodiversity (Mittermeier *et al.* 1998). Although the number of threatened species per country provides a coarse measure of threats to biodiversity, albeit heavily conflated by area (Balmford and Long 1995), dividing the number of threatened species by total numbers of species per country does give a useful measure of relative threat to a nation's biodiversity. Further, the presentation of threatened species occurrences by country is also useful in providing a cross-check to national Red Lists, and *vice versa* (Hilton-Taylor *et al.* 2000; Rodriguez *et al.* 2000), given the important implications of these for national conservation policy. A detailed summary for all countries is provided in Appendix V.

When comparing amphibian richness amongst countries, Brazil, with 751 species currently recognized, is first, followed closely by Colombia with 697 (Figure 7). These results need to be considered with some caution, particularly bearing in mind the relative level of survey effort in some countries. For example, both Colombia and Brazil have received extensive survey efforts in recent decades, and although both countries can be expected to add significantly to their totals (see Essay 9.5 and Essay 9.4, respectively), the level of increase is likely to be less than in some of the other highly diverse countries such as Papua New Guinea or Indonesia. In South America, Peru in particular is relatively poorly sampled and is almost certain to experience substantial increases in its number of recorded species, and could even surpass Ecuador. Nonetheless, the species richness in Ecuador is remarkable for a country one-thirtieth the size of Brazil. Figure 8 provides an alternative illustration of the relative significance of each country in terms of amphibian diversity.

The number and percentage of endemics within a country (Table 5 and Figure 9, respectively), gives a slightly different perspective on the importance of countries in amphibian conservation. When looking at the number of country endemics, the first two countries, Brazil and Colombia, not surprisingly emerge yet again at the top of the list. Interestingly, Ecuador with the third largest number of amphibians is only 11th in the list of percentage of endemics, with only 36% of species endemic. To put some perspective on the contribution these countries make to global amphibian species richness, the endemic species of the top 10 countries account for 40% of the world's amphibian species, and the top 20 for 56%.

When considering the percentage of country endemics, it is perhaps not surprising to see that the first nine countries listed are island states. Many of these have very small numbers of species, with the exception of Madagascar with 226 species currently described, only one of which is not endemic to the country. Similarly, Australia with a total of 214 species has 200 country endemics. The two countries with the highest number of endemics, Brazil and Colombia, are only ranked 18th and 24th when looking at percentage of endemic species.

Among countries with the highest number of threatened amphibians (Figure 10), there are some apparent differences to the most species-rich countries listed in Figure 7, suggesting that either amphibians in some countries are more susceptible to threats, or that threats vary between countries, or that there are other factors influencing the distribution of threatened species. Figure 11 illustrates the relative importance of each country to threatened amphibians. Colombia, the country with the second largest amphibian fauna, has the most threatened species. The major threat to amphibians in Colombia is habitat loss, although there have also been many as yet unexplained declines occurring (presumably due to chytridiomycosis). The dramatic topography of the Andes means that many of the amphibians have very restricted ranges thus making them more vulnerable to threatening processes.

Ranking of countries with the highest percentage of threatened species (Figure 12 is quite different to the list of countries with the highest number of threatened species (Figure 10). The first five countries[13] with the highest percentage are all in the Caribbean, and over 70% of all the amphibians in these countries are threatened. Compared with other regions, the Caribbean region stands out with by far the highest percentage of threatened species. Most notable in this regard is Haiti, with 46 of the 50 species native to this country threatened with extinction, almost entirely due to rampant habitat loss.

In Mexico, a country ranked fifth for species richness, but second in terms of number of threatened species, more than 50% of amphibians are threatened. Severe habitat loss is the overwhelming threat to Mexican amphibians, but chytridiomycosis is also present.

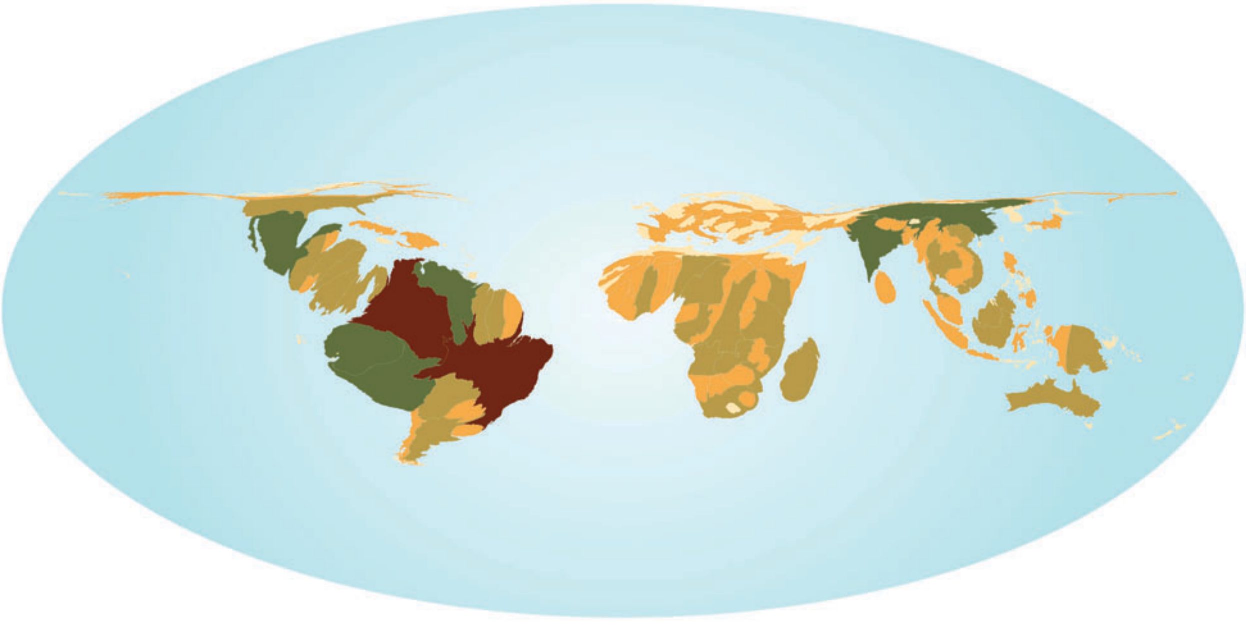


Figure 8. *The world according to amphibians. The size of each country represents the relative proportion of the world's amphibians found there. Map produced by Vineet Katariya.*

Ranking	Country	Native	Native Endemic	% endemics	Number threatened	Number threatened endemics	% Species Threatened
1	Brazil	751	489	65	110	106	15
2	Colombia	697	337	48	209	159	30
3	Mexico	363	246	68	198	162	55
4	Madagascar	226	225	99.6	55	55	24
5	Australia	214	200	93	47	47	22
6	United States of America	261	182	70	52	48	20
7	Peru	411	181	44	81	59	20
8	China	325	170	52	87	82	27
9	Papua New Guinea	244	164	67	10	8	4
10	Indonesia	347	161	46	33	23	10
11	Ecuador	447	159	36	163	102	36
12	Venezuela	298	155	52	69	62	23
13	India	236	151	64	63	61	27
14	Philippines	98	77	79	48	48	49
15	Sri Lanka	83	67	81	52	51	63
16	Tanzania	162	65	40	41	40	25
17	Cuba	59	57	97	47	47	80
18	Malaysia	203	56	28	47	34	23
19	Cameroon	196	55	28	53	38	27
=20	Bolivia	209	53	25	21	18	10
=20	Congo, Democratic Republic of the	211	53	25	13	4	6

Table 5. *The 20 countries with the highest number of country endemics.*

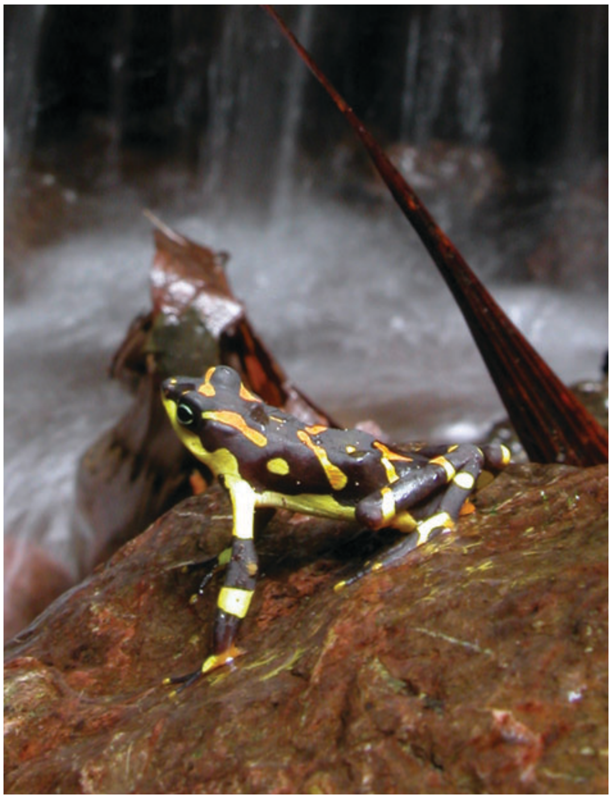
HABITAT AND ECOLOGY

Habitat Preferences

Recording the habitat preferences of species from a standardized classification scheme (see documentation on CD) is part of the required documentation in the Red List assessment process. Almost 80% of amphibians are forest species (Table 6 and Figure 13) and 90% of these species (4,251 species), in turn, occur in tropical forests. Of all forest species, 36% are either threatened or extinct, and for those occurring in tropical forests the percentage of threatened or extinct species is slightly higher at 37%. However, montane forest species (very generally defined here as forest at altitudes above 1,000m asl) are much more likely to be threatened than those occurring in lowland forest. This is probably because montane species are more likely to have restricted ranges and hence are more susceptible to threatening processes, and also because chytridiomycosis appears to be having a much greater impact on species occurring at elevations above 1,000m asl.

Only a small percentage of amphibians occur in relatively dry habitats such as arid and semi-arid habitats and savannah, 2% and 8%, respectively, and the percentages of species in these habitats that are threatened are very low (9% and 3%, respectively). The lack of species in these habitats is not surprising as amphibians are known to prefer moist habitats. These drier habitats are also usually less varied topographically and are relatively less impacted by anthropogenic disturbance, so it is to be expected that there will also be fewer threatened species.

Although amphibians are classically considered as leading 'dual lives', occurring in both land and water environments (hence the etymological origins of the word), in fact only two-thirds of species (3,775) undergo a free-swimming larval development stage in which they are dependent on a freshwater habitat. Those species that are not dependent on freshwater habitats are predominantly direct-developing species, which develop directly from eggs without a larval stage (see Chapter 1). It is the larval stage of larval-developing species that most likely occurs within freshwater habitats. In Table 6, occurrence in freshwater is divided into three subgroups: still, flowing, or swamp/marsh. Flowing freshwater habitats for amphibians usually include streams, creeks or brooks; still freshwater habitats are often temporary rainpools or other small pools of freshwater (favoured breeding sites for many explosive-breeding species). This distinction between freshwater habitats appears to have a significant influence on the likelihood that a species is threatened. Of species that are associated with flowing water, 36% are currently threatened or extinct, whereas only 15% of species associated with still water are currently threatened or extinct. This may be related to



While almost 80% of amphibians are forest species, only two-thirds undergo a free-swimming larval development stage in which they are dependent on some freshwater habitat (like Atelopus varius *pictured here). Species that are not dependent on freshwater habitats are predominantly direct-developing species, which develop directly from eggs without a free-living larval stage. © Twan Leenders*

Figure 11. *The world according to threatened amphibians. The size of each country represents the relative proportion of the world's threatened amphibians found there. Map produced by Vineet Katariya.*

Table 6. *The habitat preferences for all amphibian species. "All tropical forest" encompasses both lowland and montane tropical forest.*

Habitat type	All species	% of all species	Threatened or Extinct species	% of all species in habitat that are threatened or Extinct
Forest	4,710	80	1,678	36
All tropical forest	4,251	72	1,566	37
Lowland tropical forest	2,849	48	807	28
Montane tropical forest	2,507	42	1,142	46
Savannah	484	8	13	3
Grassland	987	17	217	22
Shrubland	860	15	148	17
Secondary terrestrial habitats	1,496	25	258	17
Flowing freshwater	2,506	42	897	36
Marsh/swamp	722	12	113	16
Still open freshwater	1,793	30	275	15
Arid and semi-arid habitats	94	2	8	9

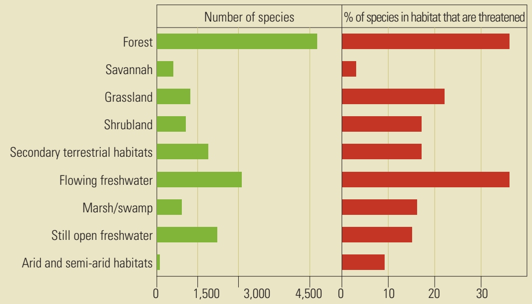


Figure 13. *The number of species occurring in a particular habitat, and the percentage of species occurring within each habitat that are threatened.*

the likelihood of exposure to disease increasing in flowing water, as the water may be acting as a vector for disease.

Reproductive Modes

As noted earlier (see Chapter 1), for the purposes of analysis in this book, amphibian reproductive modes have been combined into three general groups: *larval developing* – species that lay eggs, from which free-living larvae hatch; *direct developing* – species that lay eggs in which the larvae develop and metamorphose prior to hatching; and *live-bearing* – species in which the larvae develop inside the mother, with no eggs being laid (including viviparous and ovoviviparous species). By far the most common reproductive mode is larval development, with 4,004 species known or believed to use this mode. Direct development is also quite common, being present or strongly suspected in 1,742 species, whereas there are only 58 known or suspected live-bearing species. There are 111 species for which the reproductive mode remains completely unknown and cannot readily be inferred from close relatives.

The global distribution of larval-developing, direct-developing, and live-bearing amphibians is shown in Figure 14. The richness map of larval developers is very similar to the richness map for all amphibian species (Figure 4), which is not surprising considering that over two-thirds of amphibians are larval developers. The few regions that differ significantly are the Caribbean; a region extending from southern Mexico south to Ecuador and Venezuela; New Guinea; and the mountains of the eastern United States, which have very few larval-developing species compared with overall species richness. Compared with larval developers, direct developers occur in relatively few areas. The main concentrations are in the Caribbean, the Andes of South America extending through Central America to southern Mexico, the Atlantic Forest of Brazil, New Guinea, Sri Lanka (see Essay 4.3), the mountainous regions of the eastern United States, and the west coast of the United States. Lesser concentrations are also found in east and central Africa, Madagascar, the Western Ghats and the Philippines. The number and overall range of direct-developing species in the Old World tropics is still greatly under-estimated, especially because large numbers of species in the genera *Philautus* (Indomalayan) and *Arthroleptis* (Afrotropical) probably remain to be described. Live-bearing species are only found in a few places: the Amazon, Central America, Europe, West Africa, the Eastern Arc Mountains and West Asia.

A map of the global distribution of all three reproductive modes (Figure 15) shows that the majority of the global range of amphibians is home only to larval-developing species. This is perhaps why most people think of amphibians as being freshwater, larval-developing species only, and are often surprised to hear of the existence of other remarkable reproduc-

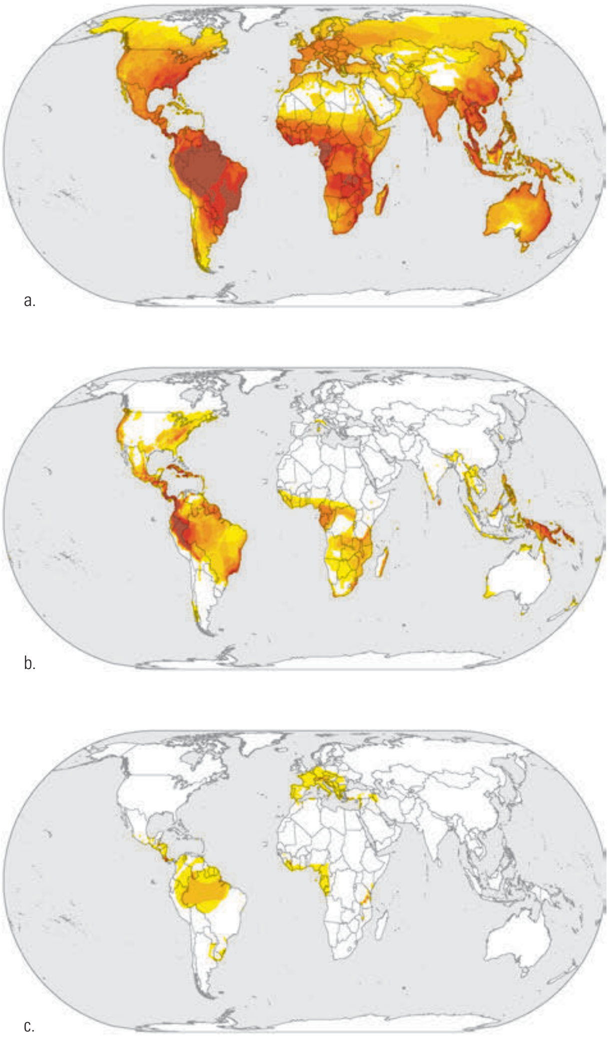


Figure 14. *Richness map of a) larval-developing amphibians; b) direct-developing amphibians; and c) live-bearing amphibians. Darker red colours correspond to regions of higher richness. Colour scale based on 10, 10 and 5 quantile classes, respectively. Maximum richness equals 127, 55 and 9 species, respectively.*

Family	Larval-developing	Direct-developing	Live-bearing	Unknown
Anura				
Allophrynidae	1	0	0	0
Arthroleptidae	16	35	0	0
Ascaphidae	2	0	0	0
Astylosternidae	29	0	0	0
Bombinatoridae	8	0	0	2
Brachycephalidae	0	8	0	0
Bufonidae	426	24	13	13
Centrolenidae	138	0	0	0
Dendrobatidae	232	2	0	0
Discoglossidae	12	0	0	0
Heleophrynidae	6	0	0	0
Hemisotidae	9	0	0	0
Hylidae	800	0	0	4
Hyperoliidae	250	1	0	2
Leiopelmatidae	0	4	0	0
Leptodactylidae	394	836	1	7
Limnodynastidae	50	0	0	0
Mantellidae	125	20	0	13
Megophryidae	128	0	0	0
Microhylidae	192	233	0	5
Myobatrachidae	63	8	0	0
Nasikabatrachidae	1	0	0	0
Pelobatidae	4	0	0	0
Pelodytidae	3	0	0	0
Petropedetidae	90	10	0	2
Pipidae	25	3	0	2
Ranidae	585	80	0	1
Rhacophoridae	138	130	0	6
Rheobatrachidae	0	2	0	0
Rhinodermatidae	1	1	0	0
Rhinophrynidae	1	0	0	0
Scaphiopodidae	7	0	0	0
Sooglossidae	1	3	0	0
TOTAL ANURA	**3,737**	**1,400**	**14**	**57**
Caudata				
Ambystomatidae	30	0	0	0
Amphiumidae	3	0	0	0
Cryptobranchidae	3	0	0	0
Dicamptodontidae	4	0	0	0
Hynobiidae	45	0	0	1
Plethodontidae	50	315	0	0
Proteidae	6	0	0	0
Rhyacotritonidae	4	0	0	0
Salamandridae	57	0	13	0
Sirenidae	4	0	0	0
TOTAL CAUDATA	**206**	**315**	**13**	**1**
Gymnophiona				
Caeciliidae	8	27	28	50
Ichthyophiidae	39	0	0	0
Rhinatrematidae	9	0	0	0
Scolecomorphidae	0	0	3	3
Uraeotyphlidae	5	0	0	0
TOTAL GYMNOPHIONA	**61**	**27**	**31**	**53**
TOTAL ALL AMPHIBIANS	**4,004**	**1,742**	**58**	**111**

Table 7. *Variation in reproductive mode between taxonomic Orders and Families.*

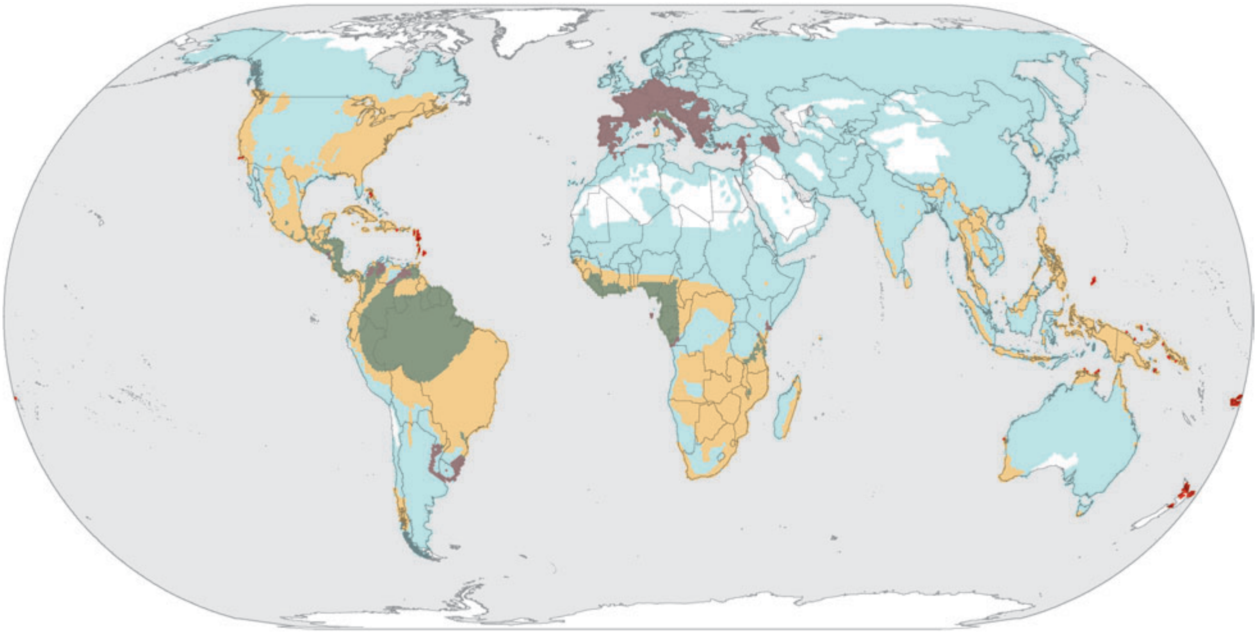


Figure 15. *Combined distribution of amphibian reproductive modes.*

Breeding Strategy
🟦 Larval developers only
🟥 Direct developers only
🟧 Larval and direct developers
🟪 Larval and live-bearing
🟩 Larval, direct and live-bearing

tive modes. Live-bearing species always occur sympatrically with larval-developing species, and sometimes with direct-developing species. The regions where all three reproductive modes co-exist are the Amazon Basin, Colombia to southern Mexico, West and Central Africa, East Africa and north-central Italy and south-eastern France. Direct developers are the only amphibians in New Zealand, Fiji, the Lesser Antilles, the Bahamas, Palau, the Solomon Islands and various small islands off New Guinea, but otherwise are always found in areas inhabited by larval developers.

The prevalence of the various reproductive modes varies between the different taxonomic Orders (Table 7). All three Orders have species representative of each reproductive mode. The most common strategy for frogs and toads is larval development (over 70% of species), and the most common strategy for salamanders and newts is direct development (59%). While the most common strategy for caecilians is larval development (35% of species), the majority (54%) of live-bearing species are caecilians. There is still very little known about most caecilian species, and the reproductive mode for nearly one-third (30%) of caecilians remains unknown.

Larval development is a very common reproductive mode amongst amphibian families, and all but four families have some larval-developing species. The three anuran families, Brachycephalidae, Rheobatrachidae and Leiopelmatidae, contain direct-developing species only, and the caecilian family Scolecomorphidae has three live-bearing species in one genus, and the reproductive mode for the three species in the other genus are unknown. Compared with larval development, direct development and live-bearing are reproductive modes restricted to far fewer families. Only 19 families have species that are direct developers, and the overwhelming majority of these are within the anuran family Leptodactylidae, and in particular the largest amphibian genus *Eleutherodactylus*. Amongst other anuran families, slightly more than half of the microhylid species, and almost half of the rhacophorid species are direct developers. There is only one salamander family containing direct-developing species, Plethodontidae, and only one caecilian family, Caecilidae.

Within the Caudata there are 13 live-bearing species all in the genera *Salamandra* and *Lyciasalamandra*. There appear to be few live-bearing frog and toad species (14 species in total), relative to the diversity of this Order. Most of these species, such as the Critically Endangered Kihansi Spray Toad *Nectophrynoides asperginis* and Golden Coqui *Eleutherodactylus jasperi* are ovoviviparous, with the equally highly threatened *Nimbaphrynoides liberiensis* and *Nimbaphrynoides occidentalis* being the only truly viviparous anurans.

The reproductive mode of a particular species is related to whether or not it is likely to be threatened with extinction (Table 8). Amongst direct developers, 45% of species are currently threatened with extinction or are already extinct, which is considerably higher than the global average of 33%. Twenty-one of the 34 extinct amphibians were direct developers. Larval developers are relatively less threatened than the global average.

The median range size of amphibians employing each of the three different reproductive modes is summarized in Table 9. When considering all extant, non-Data Deficient species, the median for larval-developing species is much greater than that of direct-developing species. The much smaller range size of direct developers makes these species more susceptible to habitat loss and other threats compared to larval developers. This might partly explain why direct-developing amphibians are proportionately more threatened than larval-developing amphibians.

Major Threats

As part of the Global Amphibian Assessment, the major threats to all amphibians were collated. Analyses of these data permit a quantitative perspective on the major causal mechanisms not only driving amphibians to extinction, but also allowing us some insight into the threats that are driving amphibians *most rapidly* to extinction.

Given the major finding of the Millennium Ecosystem Assessment that humans have changed ecosystems more rapidly and extensively in the last 50 years than in any comparable period of time in human history, it is not surprising that habitat loss remains the number one threat to amphibians globally, with two-thirds (63%) of species affected, of which almost nine out of every 10 species (87%) are threatened with extinction (Table 10; Figure 16). These figures for threatened amphibians are comparable with those for threatened birds, where habitat loss and degradation affects 86% of species (BirdLife International 2004). These results take on more meaning when one considers that nearly three-quarters of amphibians are inhabitants of tropical forest environments – the same habitats that are subject to the highest rates of forest loss. The most common form of habitat loss is clearance for crops, followed very closely by extractive processes, such as logging (be it for subsistence purposes or due to selective and/or clear-cutting[15]), and urbanization and industrial development (Table 10).

But just how high are rates of forest loss? In Indonesia, the vast majority of forest loss has occurred over the last 30 years or so, mainly the result of commercial logging, followed by massive agricultural projects (particularly rubber, oil palm, industrial timber for pulp production, and so forth) and smallholder agriculture. One recent estimate alone indicates that Kalimantan's protected lowland forests declined by 56% between 1985 and 2001 primarily due to logging (Curran *et al.* 2004). Another study combining high-quality remote sensing applications and extensive field surveys across an area of 1.17 million ha in south-west Sumatra determined that the single largest contiguous area of forest standing across their study area had been nearly halved in the space of three decades (692,850 ha to 344,409 ha between 1972 and 2002), at an average rate per original forest cover of 1.69% per year (Gaveau *et al.* 2007). In Madagascar, rates of forest loss have been estimated at slightly less than 1% per annum (Harper *et al.* 2007).

One of the key consequences of habitat loss is habitat fragmentation. Decreasing patch size and increasing isolation of patches results in an increased risk of demographic, stochastic and genetic events, thereby increasing extinction risk by reducing demographic and genetic input from immigrants (not to mention reducing the chance of recolonization after local extinction) (Cushman 2006). Connectivity is therefore important in the regional viability of amphibian populations, being predominantly affected by means of juvenile dispersal. However, in fragmented landscapes, the survival of dispersers is often lower than required for population viability, and even species with limited dispersal abilities are likely to be imperilled by habitat loss and fragmentation over longer time periods (see Cushman

Reproductive mode	All species	EX	EW	CR	EN	VU	NT	LC	DD	Number threatened or EX	% Threatened or EX
Larval-developing	4,004	11	1	266	412	410	262	1,775	867	1,100	27
Direct-developing	1,742	23	0	176	337	249	106	418	433	785	45
Live-bearing	58	0	0	7	9	4	1	18	19	20	34
Unknown	111	0	0	6	10	7	0	25	63	23	21

Table 8. *The Red List status of species with varying reproductive modes.*

Reproductive mode	All species (minus DD, EX and EW)		All threatened species	
	Median area (km^2)	Number of species	Median area (km^2)	Number of species
Larval development	41,999	3,125	1,671	1,088
Direct development	2,272	1,286	454	762
Live-bearing	1,755	39	287	20
Not known	12,264	48	713	23
Total	**16,794**	**4,498**	**976**	**1,893**

Table 9. *Median range size for the different reproductive modes employed by amphibians. Only extant non-Data Deficient species with a range map are included in the analysis*[14].

2006 for review). Among those amphibians currently listed as threatened, 45% are affected by severe fragmentation of their habitat, particularly in regions such as the Western Ghats and Sri Lanka, the Philippines, the coastal forests of Eastern Africa, and the Atlantic Forest of Brazil (C. Boyd *et al.* unpubl.).

The second most significant threat to amphibians is pollution, affecting around one-fifth (19%) of species, and 29% of threatened species. These percentages are much higher than those recorded for mammals or birds (4% and 12%, respectively; Baillie *et al.* 2004), probably due to the fact that a high proportion of amphibians are aquatic. Among the over-riding causes of increasing pollution is the increasing use of agrochemicals (fertilizers, herbicides, fungicides, pesticides), especially in developing countries; other types of pollution include the discharge of industrial wastes into waterways, acid precipitation, and atmospheric pollution that results in thinning of the ozone layer and increased ultra-violet (UV) radiation. Most studies investigating the effects of pollutants and contaminants on amphibians have focused on physiology (e.g., disruption of the endocrine system; Hayes *et al.* 2002), behaviour (e.g., changes in activity patterns; Bridges 1997), and morphology (specifically, morphological anomalies, such as ectromelia, apody or syndactyly; Oullet *et al.* 1997[16]). Although a foreboding body of evidence suggests that pollutants and contaminants can compromise amphibian communities (see Essay 4.4), the relative contribution of contaminants to declines remains unclear. However, at least one recent study has demonstrated a correlation between population declines and chemicals carried by winds from agriculture in California (Davidson *et al.* 2002)[17].

Although disease appears to be a relatively less significant threat for amphibians, for those species affected it can cause sudden and dramatic population declines and disappearances (see Essay 4.5). That disease is operating in synergy with global climate change is now also strongly supported, with evidence suggesting that recent trends toward warmer nights and increased daytime cloud cover have created optimum conditions for the chytrid fungus, *Batrachochytrium dendrobatidis*, at mid-elevation sites (1,000-2,400m asl), which is where the preponderance of amphibian extinctions and disappearances have occurred (Pounds *et al.* 2006; and see Essay 4.6). In comparison, although habitat loss and degradation affect a much greater number of species, the rate at which species decline is usually much slower, and there are a number of strategies, such as the establishment of protected areas, available to counter this threat.

MAJOR THREATS ACROSS TAXA

The significance of a threatening process is influenced by a species' ability to adapt to this process. Some species are more able to adapt to certain threats than others; for example, species that are able to persist, or even thrive, in degraded habitats are much less affected by habitat loss than species that breed only in bromeliads. Comparing major threats to threatened species across taxonomic groups (Table 11) can potentially provide some insight into how susceptible particular groups of species are to certain threatening processes. Caution is needed in interpreting these results, given the uneven global distribution of both threats and biodiversity. Hence, it is not always possible to separate whether a particular taxonomic group is more or less susceptible to a threatening process, or whether exposure to threats is influencing these figures.

Across all the Orders, habitat loss is still overwhelmingly the most significant threat. For frogs and toads, and salamanders and newts, habitat loss affects around three times more species than the next most significant threat, pollution. Disease is the third most significant threat to frogs and toads, but only seventh in level of significance for salamanders and newts. Disease is almost three times more prevalent amongst threatened frogs and toads than salamanders and newts. To date, there have been no recorded incidences of disease amongst caecilians.

Looking at other major threats, utilization affects proportionally three times more threatened salamanders and newts, than frogs and toads, suggesting that salamanders and newts appear to be relatively more susceptible to utilization (particularly for human consumption and for the international pet trade). Salamanders and newts on average have a much longer generation length than the frogs and toads; in the Critically Endangered Chinese Giant Salamander, a species that has been subject to extensive exploitation (see Essay 4.7), it takes two months for the eggs to hatch after fertilization. Hence the effect of removing an individual from a wild population is likely to have a more significant impact.

When comparing the different types of habitat loss affecting threatened amphibians, frogs and toads are most significantly impacted by habitat loss for agricultural crops, followed closely by vegetation removal (mostly logging) and infrastructure development (mainly for human settlement) (Table 11). The relative significance of different types of habitat loss is slightly different for salamanders and newts, with vegetation removal affecting the most species, followed closely by infrastructure development and agricultural crops.

By comparing major threats to threatened species across taxonomic families it is possible to get a finer scale understanding of the variation in the significance of different threats to species (Table 12). Such an analysis can also assist species conservation by highlighting groups of species which are more or less likely to be impacted by particular threats. For example, 36% of threatened bufonids are affected by disease, compared with only 19% of all threatened species. It can be predicted that bufonids in any newly infected region would therefore have a high probability of being impacted by the disease.

Not surprisingly, across almost all families habitat loss affects the greatest proportion of species. The only exceptions are the families Caeciliidae, Leiopelmatidae and Sooglossidae. Two of the three threatened species in the family Caeciliidae, and all of the species in the Sooglossidae, are endemic to the Seychelles Islands and are listed on the basis of their restricted range with a major threat being invasive species. Similarly, the four species within the Leiopelmatidae are all endemic to New Zealand and are also threatened by invasive species. When looking at the families most affected by invasive species, it is island endemics (for example, the Mantellidae of Madagascar and the leptodactylids of the Caribbean) that are most affected. While many threatened amphibians are impacted by invasive alien species, some amphibians themselves can also be invasive, and in so doing become a threat in their own right (see Essay 4.8).

Pollution, the second most significant threat to all amphibians, also affects a significant number of species in almost all families, with no families in particular appearing to be more susceptible to this threat than others.

The incidence of disease, the third most significant threat to all threatened species, does seem to vary across families. Disease is only recorded in 15 of the 36 families containing threatened species, and in particular there are 10 families containing a higher proportion of species affected than the global average of 19%. These families are Leiopelmatidae (100%), Rhinodermatidae (100%), Discoglossidae (50%), Myobatrachidae (58%), Hylidae (51%), Bufonidae (36%), Dendrobatidae (28%), Leptodactylidae (21%), Centrolenidae (20%), and Limnodynastidae (20%). Of the 362 threatened species affected by disease, 286 (79%) of them are found in just three of these families: Leptodactylidae (118 species), Hylidae (93 species), and Bufonidae (75 species).

Species of the genus Lyciasalamandra, *such as* L. helverseni *(Vulnerable) from the islands of Karpathos and Kasos in Greece, are among the only live-bearing salamanders, giving birth to fully developed young. © Jan van der Voort*

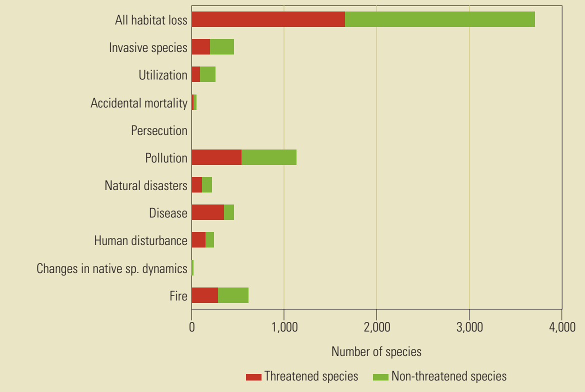


Figure 16. *The major threats to amphibians globally.*

Major Threat	All species	% of all species	Threatened species	% of Threatened species
All habitat loss	3,700	63	1,655	87
Agriculture – Crops	2,588	44	1,227	65
Agriculture – Tree Plantations	508	9	230	12
Agriculture – Livestock	1,376	23	620	33
Timber and other vegetation removal	2,529	43	1,169	62
Urbanization and industrial development	2,106	36	945	50
Invasive species	456	8	207	11
Utilization	250	4	105	6
Accidental mortality	47	1	22	1
Persecution	3	0.05	1	0.05
Pollution	1,122	19	544	29
Natural disasters	220	4	128	7
Disease	451	8	362	19
Human disturbance	243	4	151	8
Changes in native species dynamics (excluding disease)	16	0.3	4	0.2
Fire	615	10	290	15

Table 10. *The major threats to amphibians globally. Only present threats to species are tallied. "All species" excludes Extinct species.*

Major Threat	Anura	% of Anurans	Caudata	% of Caudata	Gymnophiona	% of Gymnophiona
All habitat loss	1,440	88	212	85	3	60
Agriculture – Crops	1,092	67	132	53	3	60
Agriculture – Tree Plantations	209	13	21	8	0	0
Agriculture – Livestock	560	34	60	24	0	0
Timber and other vegetation removal	1,013	62	155	62	1	20
Urbanization and industrial development	799	49	146	59	0	0
Invasive species	186	11	19	8	2	40
Utilization	72	4	33	13	0	0
Accidental mortality	18	1	4	2	0	0
Persecution	0	0	1	0.4	0	0
Pollution	479	29	62	25	3	60
Natural disasters	97	6	30	12	1	20
Disease	343	21	19	8	0	0
Human disturbance	129	8	22	9	0	0
Changes in native species dynamics (excluding disease)	3	0.2	1	0.4	0	0
Fire	220	13	68	27	2	40

Table 11. *The major threats to threatened amphibians globally in each amphibian Order. Only present threats to species are tallied.*

Family	Number of threatened species in family	All habitat loss	Invasive species	Utilization	Accidental mortality	Persecution	Pollution	Natural disasters	Disease	Human disturbance	Changes in native sp. dynamics (ex. disease)	Fire
Anura												
Arthroleptidae	14	13	0	0	0	0	1	0	0	0	0	1
Astylosternidae	21	21	0	1	0	0	4	0	0	0	0	1
Bombinatoridae	5	5	0	0	5	0	3	1	0	1	0	0
Brachycephalidae	1	1	0	0	0	0	0	0	0	0	0	0
Bufonidae	208	167	21	3	0	0	79	13	75	14	1	31
Centrolenidae	51	48	8	0	0	0	29	4	10	4	0	4
Dendrobatidae	65	57	12	9	0	0	27	3	18	1	0	4
Discoglossidae	2	2	1	0	0	0	0	1	1	0	0	0
Heleophrynidae	2	2	2	0	0	0	1	0	0	1	0	2
Hemisotidae	1	1	1	0	0	0	0	0	0	0	0	0
Hylidae	182	169	21	4	1	0	66	18	93	16	0	30
Hyperoliidae	49	47	3	0	0	0	2	1	0	0	1	5
Leiopelmatidae	4	2	4	0	0	0	2	3	4	0	0	2
Leptodactylidae	564	490	28	13	2	0	128	19	119	67	0	75
Limnodynastidae	10	9	8	0	1	0	8	0	2	2	0	2
Mantellidae	35	35	22	10	0	0	4	1	0	0	1	14
Megophryidae	44	36	0	5	2	0	14	0	0	2	0	3
Microhylidae	72	63	16	2	0	0	9	2	0	6	0	19
Myobatrachidae	12	11	10	0	0	0	6	5	7	2	0	6
Nasikabatrachidae	1	1	0	0	0	0	0	0	0	0	0	0
Pelobatidae	1	1	1	0	0	0	1	0	0	0	0	0
Petropedetidae	24	23	4	0	0	0	6	0	3	0	0	2
Pipidae	3	2	1	0	0	0	1	0	0	0	0	0
Ranidae	162	143	19	24	6	0	51	13	9	9	0	7
Rhacophoridae	100	89	1	1	1	0	35	13	0	4	0	8
Rhinodermatidae	2	2	0	0	0	0	2	0	2	0	0	1
Sooglossidae	4	0	3	0	0	0	0	0	0	0	0	3
TOTAL ANURA	**1,672**	**1,440**	**186**	**72**	**18**	**0**	**479**	**97**	**343**	**129**	**3**	**220**
Caudata												
Ambystomatidae	13	13	13	5	2	1	12	1	2	5	0	1
Cryptobranchidae	1	1	0	1	0	0	1	0	0	0	0	0
Hynobiidae	27	25	2	15	0	0	11	2	1	4	0	0
Plethodontidae	176	150	2	1	0	0	23	22	16	9	1	66
Proteidae	2	2	0	0	0	0	2	0	0	1	0	0
Rhyacotritonidae	1	1	0	0	0	0	0	0	0	0	0	0
Salamandridae	29	20	2	11	2	0	13	5	0	3	0	1
TOTAL CAUDATA	**251**	**212**	**19**	**33**	**4**	**1**	**62**	**30**	**19**	**22**	**1**	**68**
Gymnophiona												
Caeciliidae	3	1	2	0	0	0	1	1	0	0	0	2
Ichthyophiidae	2	2	0	0	0	0	2	0	0	0	0	0
TOTAL GYMNOPHIONA	**5**	**3**	**2**	**0**	**0**	**0**	**3**	**1**	**0**	**0**	**0**	**2**

Table 12. *The major threats to threatened amphibians globally in each amphibian Family.*

Utilization, a major threat for 6% of all threatened species, is also only recorded as a threat in 15 of the 36 families containing threatened species. There are seven families in particular that contain a greater proportion of species affected by utilization compared with the average: Hynobiidae (56%), Salamandridae (38%), Ambystomatidae (38%), Mantellidae (29%), Ranidae (15%), Dendrobatidae (14%) and Megophryidae (11%). Species in the Dendrobatidae, Mantellidae and Salamandridae are particularly popular in the pet trade, and those in the Ranidae and Megophryidae are quite popular, particularly in Asia for providing food.

MAJOR THREATS ACROSS BIOGEOGRAPHIC REALMS

Comparing threats across biogeographic realms, habitat loss is still by far the most significant threat, affecting at least over three-quarters of all threatened species in every region (Table 13). However, there is substantial variation in the relative importance of the various causes of habitat loss across the regions. For example, in the Afrotropics, 80% of threatened species are affected by expanding croplands, as are the majority of threatened species in the Neotropics and Indomalayan realms. In Australasia, on the other hand, only 6% of threatened species are impacted by this threat, and only 29% and 37%, respectively, are affected in the Palaearctic and Nearctic. These differences between the regions probably reflect the timing of large-scale agricultural expansion, the three regions with the minority of threatened species affected being those that have already converted most of their suitable land to agriculture. A similar trend, albeit to a lesser extent, is evident when one looks at habitat loss that has taken place as a result of timber and other vegetation removal. Again, the three regions most impacted are those that still have a more significant proportion of their original forest cover.

The significance of invasive species and disease as a major threat varies substantially between regions. Invasive species is the second most significant threat in the Australasian Realm, affecting 67% of threatened species, which is three times more than any other region, and much higher than the global average of 11%. The Afrotropics and Nearctic also have a higher proportion of species than the global average affected by this threat (22% and 21%, respectively). In the other three realms, the importance of invasive species as a threat is comparatively small. Australasia is also the region with the highest proportion of threatened species affected by disease (36%), followed by the Neotropics with 28%, and the Nearctic with 18%. In comparison, the Afrotropics, Indomalayan and Palaearctic realms have far fewer species affected, only 2%, 0.3% and 2%, respectively.

Utilization is a relatively minor threat in all regions (affecting 8% or less of threatened species), except for the Palaearctic Realm where 37% of threatened species are affected. This figure is mainly driven by the significant number of Chinese species that are utilized. The relative importance of the different threatening processes within each region is discussed further in Chapters 5-10.

Threat type	Afrotropical	Australasian	Indomalayan	Nearctic	Neotropical	Palaearctic
All habitat loss	92	76	88	79	89	81
Agriculture – Crops	80	6	61	29	71	37
Agriculture – Tree plantations	8	8	18	15	13	4
Agriculture – Livestock	33	36	5	14	42	14
Timber and other vegetation removal	75	26	64	49	64	43
Urbanization and industrial development	74	44	46	39	47	53
Invasive species	22	67	3	21	7	8
Utilization	6	2	8	8	3	37
Accidental mortality	0.4	3	3	8	0.3	4
Persecution	0	0	0	1	0	0
Pollution	13	47	32	34	29	37
Natural disasters	1	18	8	11	6	10
Disease	2	36	0.3	18	28	2
Human disturbance	0.4	24	6	15	9	10
Changes in native species dynamics (excluding disease)	1	0	0	1	0.1	0
Fire	21	24	6	16	17	4

Table 13. *The percentage of threatened species affected by each major threatening process across regions. Only present threats to species are tallied.*

Threat type	Larval	% of larval	Direct	% of direct	Live-bearing	% of live-bearing
All habitat loss	963	89	657	86	12	60
Agriculture – Crops	651	60	549	72	7	35
Agriculture – Tree plantations	133	17	96	13	0	0
Agriculture – Livestock	351	32	256	34	1	5
Timber and other vegetation removal	631	58	510	67	9	45
Urbanization and industrial development	586	54	336	44	9	45
Invasive species	168	15	32	4	1	5
Utilization	103	9	1	0.1	1	5
Accidental mortality	21	2	1	0.1	0	0
Persecution	1	0.1	0	0	0	0
Pollution	396	36	142	19	1	5
Natural disasters	68	6	60	8	0	0
Disease	250	23	110	14	2	10
Human disturbance	72	7	77	10	1	5
Changes in native species dynamics (excluding disease)	3	0.3	1	0.1	0	0
Fire	140	13	146	19	1	5

Table 14. *Major threats to threatened species employing different reproductive modes. Only present threats to species are tallied.*

MAJOR THREATS ACROSS REPRODUCTIVE MODES

Not surprisingly, habitat loss is the most significant threat across all three reproductive modes (Table 14). When comparing the various types of habitat loss there is no difference between larval and direct developers in the ranking of importance, although for direct developers

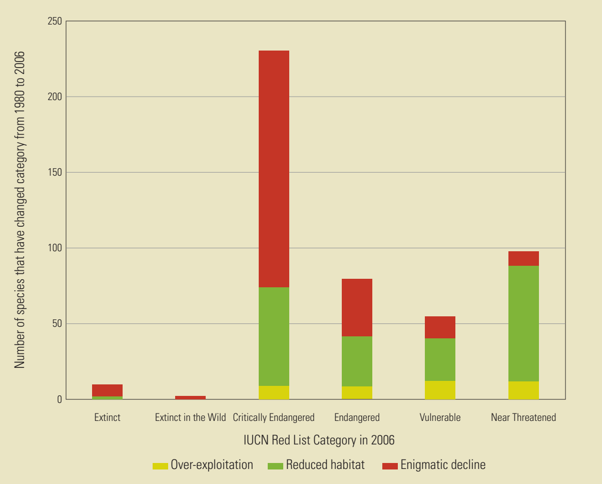
Table 15. *A summary of the population trends for all extant amphibians, as well as across the different realms, given as a percentage of all species in the realm.*

Population Trend	Number of extant amphibians globally	% of all extant species globally	Afrotropical	Australasian	Indomalayan	Nearctic	Neotropical	Palaearctic
Decreasing	2,500	42	44	10	52	31	45	53
Stable	1,567	27	23	53	16	48	25	27
Increasing	29	0.5	1	0.4	0.2	1	1	1
Unknown	1,788	30	32	37	31	20	29	19

Table 16. *The number of rapidly declining amphibians in each IUCN Red List category categorized by the type of threat they are experiencing.*

Threat	Number of species rapidly declining	EX	EW	CR	EN	VU	NT	Number threatened or Extinct	% of rapidly declining that are threatened or Extinct
Over-exploitation (A)	38	0	0	8	8	11	11	27	71
Reduced habitat (B)	206	1	0	66	33	29	77	129	63
Enigmatic decline (C)	226	8	1	156	38	14	9	217	96
All rapidly declining species	470	9	1	230	79	54	97	373	79

Figure 17. *The number of "rapidly declining" amphibians in the IUCN Red List Categories, broken into the major threat causing the decline.*



the percentage of species affected by expanding cropland, livestock and timber and other vegetation removal is slightly higher. For live-bearing species, it is difficult to identify any trends as there are only 20 threatened species employing this reproductive mode.

Invasive species are a much greater threat to larval developers, affecting 15% of threatened species. This is most likely because the vast majority of amphibians in Australia, the country most impacted by invasive species, are larval developers (87%). Utilization is primarily a threat affecting only larval-developing species, with 103 of the 105 species affected employing this reproductive mode. Like invasive species, this trend in utilization is most likely because the country that utilizes the most species, China, is also dominated by larval developers (there are only nine direct-developing species in China).

Pollution is a more significant threat to larval-developing rather than direct-developing species. Most larval developers rely on freshwater for breeding making them more susceptible to water pollution than direct developers that are more likely to be restricted to terrestrial habitats. Disease is also more prevalent amongst larval developers (23% compared with 14% for direct developers) and this may also be explained by larval developers being more often linked to freshwater habitats, since it is suspected that chytrid is most likely transmitted from one site to another through waterways.

Population Status and Trends

By measuring trends in the status of biodiversity, we can gain a better understanding of the impact that humans are having, and determine how successful we are at addressing biodiversity loss. This has become all the more important given the target set by the nations of the world for significantly reducing the rate of loss of biological diversity by 2010[18]. Here, we use IUCN Red List data for amphibians to present several insights into the overall trends of amphibian species globally, including the use of an indicator, developed specifically to help monitor progress towards achieving this ambitious target.

ESTIMATES OF POPULATION TRENDS

Red List data offer several means of estimating population trends. The most simple involves categorizing the current population trend for all extant amphibians as either decreasing, stable, increasing or unknown. These trend data are not necessarily derived from population data, and are often based on expert opinion related to the impact of threats, including, for example, habitat loss, invasive species and the confirmation of disease within populations, as well as changes in range size.

At least 42% of amphibian species are believed to be declining, only 27% are considered to have generally stable populations, and fewer than 1% of species are believed to be increasing (Table 15). As many as 30% of species are so poorly known that it is difficult to give even a rough estimate of population trends. Unfortunately, it seems plausible that this 30% will include many additional species that are undergoing population declines. These general figures give some indication of the magnitude of the decline in amphibian populations globally. Although currently one-third of species are globally threatened, there are also significant numbers of non-threatened species that have declining populations (albeit that are not currently declining at a rate fast enough to qualify for listing under a threatened category). It is inevitable that many of these species could eventually become globally threatened if threats are not mitigated and their populations continue to decline.

Although the small number of species with increasing populations includes populations that are recovering from past declines, for the most part these species are often widespread invasive animals that can represent a significant threat to native amphibian populations through predation, competition, hybridization, or disease transmission.

The magnitude of the decline in amphibian populations varies across biogeographic realms (Table 15). The two regions with the highest proportion of species with decreasing populations are the Indomalayan and Palaearctic realms. The Indomalayan Realm also has the lowest proportion of species with a stable population. The Australasian Realm has significantly more optimistic statistics, with only 10% of species considered to have populations in decline, and 53% of species with stable populations, although this very likely is partly due to the stabilizing effect of New Guinea (where threats are still relatively minor). This region also has the highest percentage of species for which the population trend is unknown (37%); however, again, most of these lesser known species are from New Guinea where populations are less likely to be in decline.

Table 17. *The number of rapidly declining species in each taxonomic Order and Family. *these percentages differ significantly from the global average[21].*

Family	Over-exploitation (A)	Reduced habitat (B)	Enigmatic decline (C)	Total rapidly declining species	% of Family
Anura					
Arthroleptidae	0	3	0	3	6
Bufonidae	0	26	81	107	22*
Centrolenidae	0	0	4	4	3
Dendrobatidae	0	6	11	17	7
Discoglossidae	0	3	0	3	25
Hemisotidae	0	1	0	1	11
Hylidae	0	17	49	66	8
Hyperoliidae	0	6	0	6	2*
Leiopelmatidae	0	0	1	1	25
Leptodactylidae	9	48	53	110	9
Limnodynastidae	0	4	3	7	14
Mantellidae	1	0	0	1	1*
Megophryidae	0	4	0	4	3
Microhylidae	3	7	0	10	2*
Myobatrachidae	0	2	7	9	13
Pelobatidae	0	2	0	2	50
Petropedetidae	0	7	0	7	7
Ranidae	17	31	6	54	8
Rhacophoridae	0	9	0	9	3*
Rheobatrachidae	0	0	2	2	100*
Rhinodermatidae	0	0	1	1	50
Scaphiopodidae	0	1	0	1	14
TOTAL ANURA	**30**	**177**	**218**	**425**	**8**
Caudata					
Ambystomatidae	2	4	0	6	20
Cryptobranchidae	1	0	0	1	33
Hynobiidae	1	1	0	2	4
Plethodontidae	0	16	8	24	7
Proteidae	0	1	0	1	17
Salamandridae	4	7	0	11	16
TOTAL CAUDATA	**8**	**29**	**8**	**45**	**8**
TOTAL ALL AMPHIBIANS	**38**	**206**	**226**	**470**	**16**

Biogeographic Realm	Over-exploitation (A)	% of rapidly declining species	Reduced habitat (B)	% of rapidly declining species	Enigmatic decline (C)	% of rapidly declining species	TOTAL	% of species in the region
Afrotropical	3	10	26	87	1	3	**30**	3
Australasian	0	0	12	34	23	65	**35**	6
Indomalayan	20	34	37	64	1	2	**58**	6
Nearctic	1	4	14	58	9	38	**24**	7
Neotropics	12	4	99	32	194	64	**305**	10
Palaearctic	18	43	23	55	1	2	**42**	9

Table 18. *The number of rapidly declining amphibians in each biogeographic realm, categorized by the type of threat they are experiencing.*

"RAPIDLY DECLINING" SPECIES

For amphibians, 2004 was the first time that all species were assessed using the Red List Categories and Criteria. The first comprehensive assessment of all species in a group is a measure of the current projected extinction risk of the group, but does not give any indication of how this is changing with time. Therefore, to estimate an overall trend in projected extinction risk for amphibians, the information used to make the assessments in 2004 was also used to assign a backcast Red List Category for 1980. These backcast categories were determined by the GAA coordinating team and not by the assessors of the species in 2004. They are *not* official Red List assessments, as these cannot be accepted retrospectively, but are instead used here to identify species that appear to be in rapid decline. When determining these backcast categories, it was assumed that the category in 1980 was the same as in 2004 unless there was evidence to support a change in category. It is most likely that this methodology for retrospectively assigning categories has resulted in a conservative estimate of the change in status of amphibians, since undoubtedly there would have been some changes in status for some species for which there was insufficient evidence available to support a change in category.[19]

Rapidly declining species are defined here as species that have moved to a higher Red List category of threat between 1980 and 2006. They have been categorized into three groups according to the most dominant threat that is thought to be causing the decline: over-exploitation (A); reduced habitat (B); or enigmatic decline (C).

Particular threats appear to be pushing amphibians to extinction more quickly than others. Of the 470 species that are rapidly declining (see Appendix IV), 373 (79%) are considered threatened or already Extinct (Table 16 and Figure 17). The most likely threat to push species into a threatened category or to extinction is enigmatic decline (96% of enigmatic decline species are threatened or already extinct). In contrast, only 63% of rapidly declining species suffering from reduced habitat are currently threatened or already extinct. For rapidly declining species experiencing over-exploitation, 71% of these species are currently threatened and there are no documented extinctions.

Species in certain taxonomic groups are more likely to be experiencing a rapid decline than other groups (Table 17). For example, there are no caecilians known to be in rapid decline at present, but around 8% of all frogs and toads and 8% of salamanders and newts are. Two families of anurans, Bufonidae and Rheobatrachidae[20], have significantly more species in rapid decline compared with the average. There are currently 476 species described in the Bufonidae, 107 (22%) of which are in rapid decline.

Amphibians in different regions of the world are experiencing different threats, and these threats also vary in their severity (Table 18). For example, in the Australasian and Neotropical realms most rapidly declining species are experiencing enigmatic declines. For the other four realms, reduced habitat is the reason for decline amongst the majority of rapidly declining species. In the Indomalayan and Palaearctic realms, over-exploitation is also responsible for over one-third of the declines amongst rapidly declining species. The Neotropics overall has the most rapidly declining species, with 10% of amphibians in the region currently considered to be in rapid decline. The Nearctic has the least number of amphibians in rapid decline, only 24; however, as a percentage of species richness in the region, the Afrotropics have the least rapidly declining species with only 3%.

Baskets of frogskins from a market in Thailand. The GAA recorded more than 220 species of amphibians currently used for human consumption, although in some cases such use does not always represent a major threat to the species. © Peter Paul van Dijk

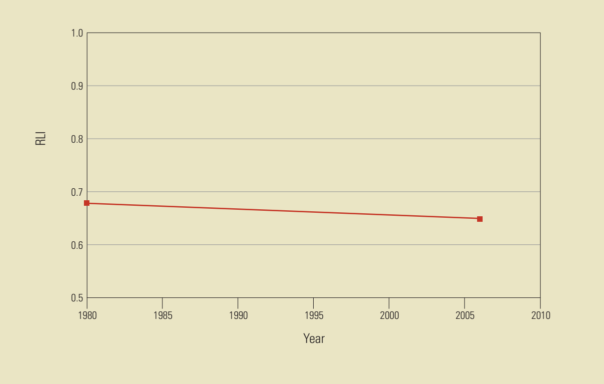


Figure 18. *Red List Index for amphibians. If all species are Least Concern the RLI is equal to 1, and if all species are Extinct the RLI is equal to 0.*

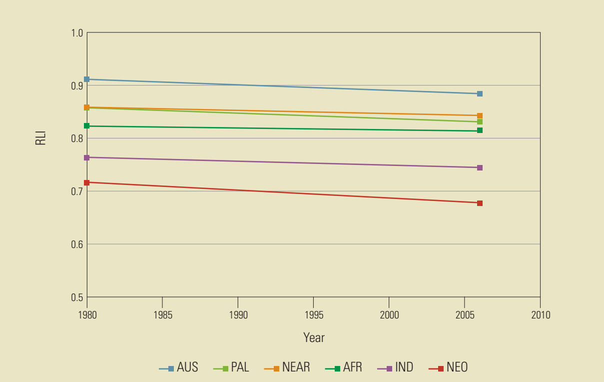


Figure 19. *Red List Index for amphibians in the different biogeographic realms. (Note: species that occur in more than one realm contribute to the RLI in all the realms in which they occur.) Key to realms: AUS = Australasian; PAL = Palaearctic; NEAR = Nearctic; AFR = Afrotropical; IND = Indomalayan; NEO = Neotropical.*

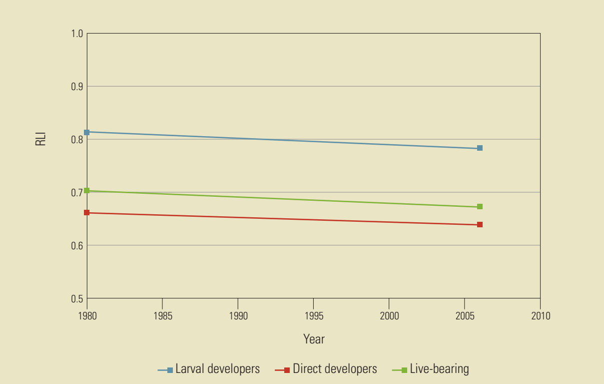


Figure 20. *Red List Index for amphibians across the different reproductive modes.*

RED LIST INDEX

The most robust means of looking at how the Red List status of large groups of species has changed over time is by means of the IUCN Red List index. The Red List Index (RLI) uses the Red List categories of species within a group, and how they change over time, to estimate an overall trend in projected extinction risk (Butchart *et al.* 2004, 2007). Every time a comprehensive assessment of all species in the group is completed, the Red List categories are then used to calculate a value for the RLI for this time period. For amphibians, the RLI was calculated in 2004 (Baillie *et al.* 2004), but since then the methodology for calculating the RLI has been revised, a small number of amphibians have been reassessed, and some assessments have been corrected. Here, we present a calculation of the RLI for amphibians using the revised formulation and use the most current categories for each species.

Between 1980 and 2006 there has been a decrease in the RLI, as illustrated by a downward trend in Figure 18, which indicates that the projected extinction risk for amphibians is increasing. In order to meet the Convention on Biological Diversity target of significantly reducing the loss of biodiversity by 2010 (Secretariat of the Convention on Biological Diversity 2003), the RLI must increase from the previous time period – i.e., the line in Figure 13 must show an upward trend. With only two data points for the amphibian RLI, at present it can only be shown that the projected extinction risk is increasing, but as the global assessment of amphibians continues on a regular basis, future data points will show whether or not the rate of increase is accelerating or decelerating.

The Red List Index can also be disaggregated, for example, by biogeographic realm (Figure 19) and by reproductive mode (Figure 20). All six realms show an increase in the projected extinction risk for amphibians from 1980 to 2006. However, the level of increase varies across realms, as does the average threatened status of amphibians. The current threat status of amphibians is best (that is on average there are less threatened species) in the Australasian Realm and worst in the Neotropical Realm. For all regions, the RLI shows a downward trend – i.e., the projected extinction risk has increased in 2006 compared with 1980, indicating that amphibian declines are a global problem. The rate of increase in projected extinction risk is lowest for the Afrotropics, and highest for the Neotropics.

The RLI was also calculated across the three different reproductive modes: larval developers, direct developers or live-bearing species. There are also quite a few species for which the reproductive mode is not known and these species were omitted from this RLI calculation. The results show that the average threatened status of larval developers in 1980 and 2006 is better than live bearers and direct developers. All three groups show a downward trend in the RLI, indicating an increase in projected extinction risk, but the increase for direct developers is less compared with larval developers and live bearers.

KEY FINDINGS

- The GAA assessed 5,915 amphibian species globally and categorized one-third of all extant species (1,893 out of 5,881) as threatened with extinction.
- There are 34 species currently listed as Extinct and one as Extinct in the Wild.

Endnotes

1 www.maweb.org
2 This is the number of amphibians officially recognized as valid by the GAA as of December 2006. At the time of going to press, 6,184 species were officially listed on *Amphibian Species of the World* (v 5.0), and 6,308 on AmphibiaWeb (Feb 25, 2008).
3 A threatened species is one that is included in the IUCN Red List Categories Vulnerable, Endangered or Critically Endangered.
4 At the time of going to press, there were reports of the rediscovery of one EX species, namely *Philautus travancoricus* from the Western Ghats in India (S.D. Biju pers. comm.).
5 A taxon is presumed Extinct, according to the IUCN Red List Categories and Criteria, when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycles and life form. Species that are believed to have gone extinct prior to 1500 AD are not considered.
6 At the time of going to press, Meegaskumbara *et al.* (2007) had just described two additional extinct species, *Philautus pardus* and *P. maia*, known only from collections made in Sri Lanka prior to 1876; both species await formal assessment.
7 When interpreting these results, it is necessary to bear in mind that a species can be listed in a category on the basis of one or more criteria, and that a species may trigger criteria for a lower category of threat than that for which it is listed (these criteria are not recorded). For example, a species may qualify for Endangered on the basis of criterion B and for Vulnerable on the basis of criterion C. When listed as Endangered only criterion B will be given.
8 As discussed elsewhere in this volume, the major reclassification by Frost *et al.* (2006) and Grant *et al.* (2006) has dramatic implications for amphibian classification at the family level. The results presented here can be expected to undergo substantial modification based on the conclusions of that study.
9 $P<0.01$ (binomial test)
10 No amphibian species occur in the Antarctic Realm, while only three species occur in the Oceanian Realm, so we include the Oceanian Realm in all discussion on the Australasian Realm. For further information on the boundaries between these regions, please refer to the regional summaries.

Plectrohyla dasypus *(Critically Endangered) from the Parque Nacional Cusuco in Honduras is one of many species that have undergone a rapid decline in status, in this case due to the effects of chytridiomycosis. © Silviu Petrovan*

- Within amphibian Orders, Caudata (Salamanders and Newts) contains the highest proportion of threatened species (47%), followed by Anura (Frogs and Toads) (32%) and Gymnophiona (Caecilians) (3%).
- Very diverse families of frogs and toads that are significantly more threatened than the global average include the Bufonidae (45%), Leptodactylidae (46%), and Rhacophoridae (43%). Diverse families that are less threatened than the global average include Ranidae (25%), Microhylidae, (17%) and Hyperoliidae (19%).
- The Neotropical realm has the highest number of species (2,916, of which 2,808 are endemic to the realm) and the greatest proportion of threatened species (39%).
- Major concentrations of threatened species include the sierras and trans-volcanic belt of Mexico, Central America, the tropical Andes, Brazil's Atlantic Forest, the Greater Antilles, the Upper Guinea forests of West Africa, the forest of western Cameroon and eastern Nigeria, the Albertine Rift, the Eastern Arc Mountains of Tanzania and other Afromontane outliers, the south-east coast of South Africa, Madagascar's wet forests, the Western Ghats and Sri Lanka, montane Southeast Asia, and eastern Australia.
- Brazil, with 751 species currently recognized, is the country with the most amphibian species, followed closely by Colombia with 697. These two countries also have the highest number of endemic species, 489 and 337, respectively.
- Four countries have more than 100 threatened species: first is Colombia with 209, second is Mexico with 198, third is Ecuador with 163, and fourth is Brazil with 110.
- Almost 80% (4,710 species) of amphibians occur in forest habitats, and 90% (4,251 species) of these species occur in tropical forest. Species occurring in montane tropical forests are more likely to be threatened (46% of species), than those occurring in lowland tropical forest (28% of species).
- When comparing reproductive modes of amphibians, 45% of direct-developing species, 28% of larval-developing species, and 34% of live-bearing species are currently threatened with extinction or are already extinct.
- Habitat loss, primarily due to expanding croplands, vegetation removal (mainly logging), and urbanization/industrial development, is the most pervasive threat to amphibians, affecting 63% of all species and 87% of threatened species. Other threats that are commonly recorded include pollution, invasive species, fire and disease. Disease is a major threat for 8% of all species and for 19% of threatened species.
- At least 42% of amphibian species are believed to have declining populations, only 27% are considered to have generally stable populations, and less than 1% of species are believed to be increasing. As many as 30% of species are so poorly known that it is difficult to give even a rough estimate of population trends.
- There are 470 "rapidly declining" species globally. Of these, 38 species are declining primarily due to over-exploitation, 206 are declining due to reduced habitat, and 226 are experiencing "enigmatic declines" (probably due to the effects of chytridiomycosis in combination with climate change).
- Calculation of the Red List Index for amphibians shows a worsening trend in extinction risk for amphibians from 1980 to 2006.

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[11] The range size for each species has been calculated using the area of the polygons representing each species' Extent of Occurrence.

[12] The methodology for mapping these amphibian "centres of endemism" follows that developed by BirdLife International in identifying their Endemic Bird Areas (Stattersfield *et al*. 1998). Around two-thirds of amphibians have range sizes less than 50,000km^2 compared with around one-quarter of birds.

[13] Table 10 only includes countries with more than 10 species. If all countries are included, the country with the highest percentage is New Zealand with all four of its species, which are also all endemic, threatened with extinction.

[14] The range size for each species has been calculated using the area of the polygons representing each species' Extent of Occurrence.

[15] Selective logging is generally defined as the process by which only the most desirable trees, often the largest and\or most commercially viable, are logged from an area of forest; in contrast, clear-cutting is generally defined to be a large-scale and commercial process, by which all trees from a given area are taken in a logging operation.

[16] Although amphibian deformities can result from exposure to contaminants, many cases of limb deformities in nature have been linked to other abiotic and biotic factors, such as UV radiation, parasitic infections, retinoids, predation, and the interaction of several of these factors (see Oullet 2000; Sessions 2003).

[17] In this study, pesticides that inhibit acetylcholinesterase were most strongly correlated with declines. Such cholinesterase inhibitors (or "anticholinesterase") suppress the action of the enzyme, and ultimately lead to death. Anticholinesterases are commonly used for killing insects in organophosphate and other pesticides.

[18] http://www.biodiv.org/2010-target/default.asp

[19] In 2006, a small number of species were reassessed, and the new information supporting these reassessments was also used to better estimate the categories in 1980, and where necessary some categories were changed. The Red List categories for all species in 2006 and the revised 1980 categories form the basis of the information in the section on rapidly declining species.

[20] The family Rheobatrachidae has only two species, both of which are now Extinct.

[21] $P<0.01$ (binomial test)

ESSAY 4.1. PICKLED FROGS HELP BIODIVERSITY ASSESSMENT

At a time when amphibian populations globally are in decline, the recent discoveries of large numbers of new frog species on Sri Lanka, an island from which the pathogenic chytrid fungus has not yet been reported, may seem heartening (Meegaskumbura *et al.* 2002). A total of 42 new species of anurans have been described since 1993, and many more species are in the process of being formally described. Description of these new species necessitated the examination of all available type material, as well as other preserved voucher material, for all Sri Lanka's amphibians. As a result of the country's five-century history of colonial occupation, these specimens, collected largely between 1850 and 1950, lie scattered amongst natural history museums in Europe, the United States and India. In particular, since Sri Lanka was a British colony from 1796 to 1948, most type specimens are housed in The Natural History Museum (formerly the British Museum of Natural History), in London. Sri Lanka's own national museum contains no amphibian types whatsoever. Although locality information beyond 'Ceylon' is usually lacking on the specimen labels, these specimens provide the only available baseline of Sri Lanka's amphibian fauna before the island's primary rainforests were reduced to their present-day extent of approximately 750km^2.

The recent review of historical material served to highlight several key aspects. First, a number of species described in the 19th century, and since relegated to synonymy, were shown to represent valid taxa. Second, several 'new species' lay silently undiscovered among the old collections (Manamendra-Arachchi and Pethiyagoda 2005; Meegaskumbura and Manamendra-Arachchi 2005). At the same time, the Wildlife Heritage Trust's 1993-2005 comprehensive survey of the island's amphibian fauna provides a reliable record of the species still persisting on the island and their relative abundance. A comparison of the results of the recent biodiversity survey, together with the historically preserved specimens, revealed that 19 named anuran species have apparently disappeared from the island (an additional two undescribed species also appear to be extinct). Given that these 19 species had not been reported since their original collections before 1940, and were not recorded during the recent surveys across the island's remaining forests, they were formally declared Extinct according to the IUCN Red List categories and criteria (GAA; Stuart *et al.* 2004). Apart from a single species each from the endemic genera *Adenomus* and *Nannophrys,* the Extinct species all belong to the Oriental shrub-frog genus *Philautus* (Ranidae: Rhacophorinae), which shows a remarkable radiation in Sri Lanka. A total of 62 of the approximately 140 species currently recognized in this genus are endemic to Sri Lanka.

To put these findings in a global context, according to the results of the Global Amphibian Assessment, 19 of 34 amphibian species confirmed as Extinct worldwide are from Sri Lanka. Even though a further 122 species are considered 'possibly extinct' globally, the Sri Lankan total is still remarkably high. Given that the island accounts for only around 2% of the world's anuran species (which is high given its relatively small size: 65,000km^2), it is surprising that more than half of the confirmed amphibian extinctions worldwide have occurred on Sri Lanka.

This extinction phenomenon in Sri Lanka (19 of the 103 native species described to date) appears to have been driven largely by the destruction of suitable habitat. Since 1815, approximately 95% of the island's 16,000km^2 of rainforest was lost to coffee and cinchona plantations, later to be replaced by tea and rubber (Kumar *et al.* 2004). While large expanses of dry forest and scrub persist elsewhere in the island, these habitats only support three of the 68 extant endemic amphibian species, with only a single species, *Philautus regius* (DD), restricted to dry forest. Of Sri Lanka's 84 surviving anuran species, 11 are Critically Endangered (seven of them *Philautus*) and 28 Endangered (20 *Philautus*). Many of these surviving amphibian species, especially the *Philautus,* have extremely restricted ranges. Even where there are large tracts of contiguous forest, the ranges of many of these species are restricted by altitude or vegetation, resulting in the total contemporary range of some species being as small as 5km^2. Some 17 species are known only from a single site each (per Ricketts *et al.* 2005), with some sites, such as Morningside and Knuckles Forest Reserve, being home to several endemic and threatened species.

Interestingly, though not unexpectedly, the results of the GAA also suggest that, among threatened direct-developing species worldwide, 65 out of the 115 (57%) species that are closely associated with freshwater are threatened by disease, compared with only 45 out of the 650 (7%) species not closely associated with freshwater. Given that the major global threat to direct developers appears to be habitat loss (Chapter 4), and most of the extant Sri Lankan direct developers are not associated closely with freshwater habitats, the role of waterborne diseases in Sri Lanka's extinction of direct developers may have been slight.

The large-scale extinction of many of the island's amphibians might have gone undetected if not for the historical collections in the world's natural history museums; unfortunately, old amphibian collections in Sri Lanka's National Museum have not survived the years to help facilitate this effort. Clearly, the extraordinary value historical collections represent by way of biodiversity baselines against which present-day surveys may be assessed, remains to be widely appreciated (Fig. 1). This is especially relevant at a time when the contemporary role and value of natural history collections is being questioned, and with many museums facing financial crises (Dalton 2003; Suarez and Tsutsui 2004; Winker 2004). Furthermore, historical collections can be useful in several other ways, as exemplified most recently by the detection of chytrid fungus in the skin of a museum specimen collected from near Monteverde, Costa Rica, and deposited in a museum well before declines were documented in the area (Puschendorf *et al.* 2006).

Interestingly, since most of the species that were recently described (Manamendra-Arachchi and Pethiyagoda 2005; Meegaskumbura and Manamendra-Arachchi 2005) were absent from early museum collections, it seems that past surveys of the island were not very thorough. The documentation of the extinction of so many species from such a limited collection suggests that these extinct species may be only a fraction of a much larger extinction event in Sri Lanka. The account of Sri Lanka's amphibian declines is also novel in that it combines a recent comprehensive survey of the island's amphibians with a re-examination of almost all preserved material worldwide. Many other tropical countries are similarly under-explored, and it is therefore likely that the global tally of recent amphibian extinctions will rise significantly when their historical collections are similarly evaluated and compared with current assessments of amphibian diversity.

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The collections of the world's natural history museums represent important biodiversity baselines. Here, preserved amphibian specimens collected in Sri Lanka ca. 1900 are stored on the shelves of The Natural History Museum in London © Barry Clarke/NHM

ESSAY 4.2. AMPHIBIANS AND HUMANS SHARING ONLY ONE PLANET

To effectively conserve amphibian populations in the wild it is not only necessary to understand the needs of the individual species, but also the context in which conservation efforts will need to take place. By comparing overlays of individual species range maps with recent and future human demographic variables (such as human population density, population growth, Gross National Income, and poverty), it is possible to elucidate the social and economic context in which conservation action must be implemented. Here, we investigate the relationships between amphibian species richness and two of these variables, human population density and levels of poverty – using Infant Mortality Rate data (CIESIN 2005) as a surrogate – not as a means of looking for causal relationships, but rather to identify regions where conservation may be more challenging.

Human population density

By comparing the current human population density in 2005 (LandScan 2005) with the global distribution of all amphibian species it is possible to identify the regions that are favoured by both humans and amphibians (Figure 1). Regions with a large number of amphibian species and a high population density are mostly found in Asia, in particular southern and eastern India, south-east China, southern Sri Lanka, and Indonesia (especially Java), as well as coastal parts of West Africa, the Ethiopian Highlands, and the Albertine Rift of Central Africa. There are also similar regions in the eastern United States, which is a hotspot for salamander diversity. In South America, the Atlantic Forest is the most prominent region.

Considering that humans and amphibians are dependent on freshwater for survival, the arid regions of the world are the places with the fewest amphibians (often none at all) and very low human population densities. For example, the deserts of North Africa, central Australia, central North America, and Central Asia. The majority of amphibians prefer moist tropical conditions, and many of the regions rich in amphibian species, but with low human population densities, are the world's tropical rainforests, for example the Amazon, the Congo, the tropical Andes, Southeast Asia and northern Queensland in Australia (the Queensland Wet Tropics). Regions with low diversity of amphibians, but high human population densities, are in general cooler regions such as northern India, northern China and much of Europe.

By comparing the diversity of threatened amphibians with human population density it is possible to highlight regions where species conservation is most likely to come into conflict with increasing demand by humans for natural resources (Figure 2). Many of these regions are the same as those highlighted in Figure 1, for example south-east China, Java (Indonesia), the Albertine Rift of Central Africa, coastal West Africa, and the Ethiopian Highlands. Notable additions are the larger islands of the Caribbean, southern Mexico, and the Philippines. In India, the highest density of threatened amphibians is focused on the Western Ghats. Parts of the eastern United States, Europe and India that are rich in amphibian species and have high human population densities are no longer highlighted as they have relatively few or no threatened species. In Europe and the United States this may be because species susceptible to habitat loss may have declined a long time ago, and perhaps also because many of the resources on which humans in these areas rely on come from other regions, for example the forests of Africa and Asia.

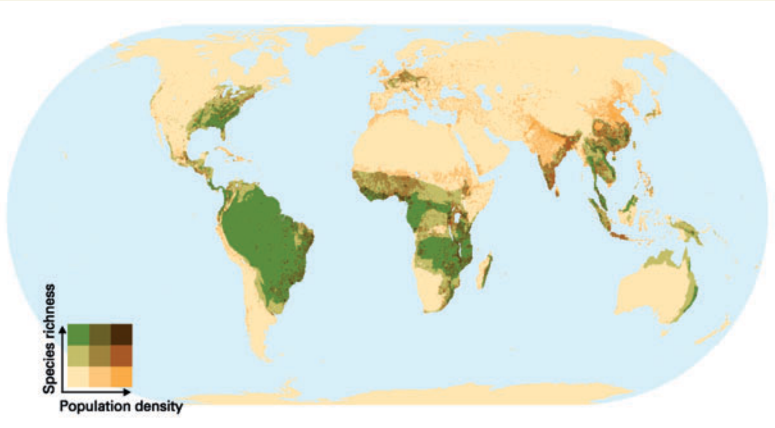

Figure 1. *Amphibian species richness compared with human population density. Each quarter-degree grid cell is coded according to the combined value of the two variables. Amphibian species richness is represented by the number of amphibian species per grid cell (Low: 0-15; Medium: 16-30; High: 30-144). Population density is classified by the number of people per km^2 (Low: 0-10; Medium: 11-100; High: >100).*

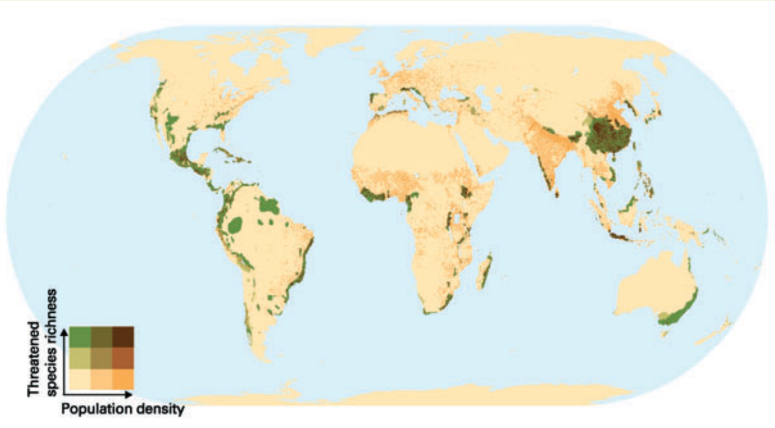

Figure 2. *Threatened amphibian species richness compared with human population density. Each quarter-degree grid cell is coded according to the combined value of the two variables. Threatened amphibian species richness is represented by the number of threatened amphibian species (Red List Categories Critically Endangered, Endangered and Vulnerable) per grid cell (Low: 0; Medium: 1-10; High: >10). Population density is classified by the number of people per km^2; Low: 0-10; Medium: 11-100; High: >100.*

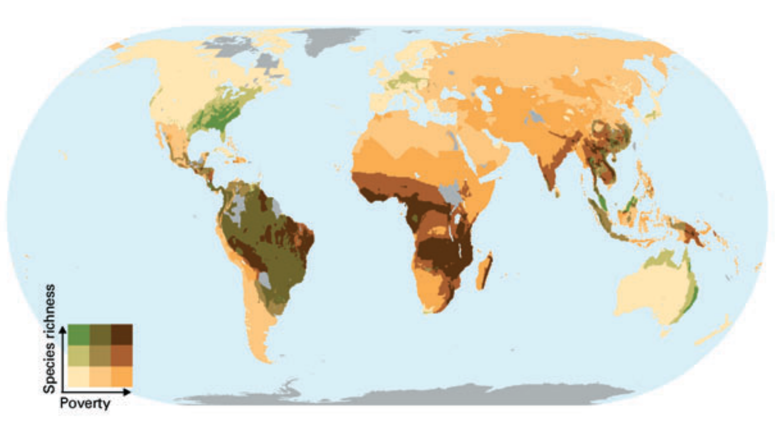

Figure 3. *Amphibian species richness compared with poverty. Each quarter-degree grid cell is coded according to the combined value of the two variables. Amphibian species richness is represented by the number of amphibian species per grid cell (Low: 0-15; Medium: 16-30; High: 30-144). Infant Mortality Rate data (CIESIN 2005) are used as an index of poverty. The rates are per thousand of live births and the data are at the sub-national level. The data were reclassed as: Low: 0-100; Medium: 100-250; High: >250.*

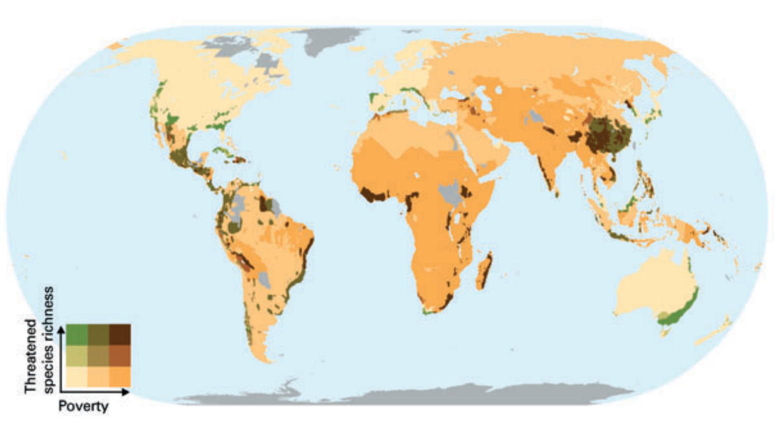

Figure 4. *Threatened amphibian species richness compared with poverty. Each quarter-degree grid cell is coded according to the combined value of the two variables. Threatened amphibian species richness is represented by the number of threatened amphibian species (Red List categories Critically Endangered, Endangered and Vulnerable) per grid cell (Low: 0; Medium: 1-10; High: >10). Infant Mortality Rate data (CIESIN 2005) are used as an index of poverty. The rates are per thousand of live births and the data are at the sub-national level. The data were reclassed as: Low: 0-100; Medium: 100-250; High: >250.*

Human poverty

An additional challenge to biodiversity conservation is the welfare of local human populations, in particular the degree of poverty. Many of the world's most densely populated regions are also some of the poorest, for example, China, India, mainland Southeast Asia and West Africa. When comparing the most impoverished regions with amphibian diversity we find these same regions emerging again, but also less densely populated regions are also highlighted, such as central and southern Africa, Madagascar, northern Brazil, Peru, and Bolivia (see Figure 3). The land surface area of the world's wealthiest nations is relatively small and these countries often have cooler climates not favoured by amphibians, hence the proportion of amphibian species found in these countries is relatively low. Exceptions are the eastern United States, coastal eastern Australia and central Europe. However, the relatively high numbers of species in these regions may be more a reflection of intense survey effort when compared with much poorer countries.

By comparing the diversity of threatened amphibians with the level of poverty it is possible to highlight those regions where biodiversity conservation will most likely succeed if it also improves the welfare of the local communities (Figure 4). In addition these regions will less likely be unable to shoulder any of the costs of conservation programmes. Many of these regions are the same as those highlighted when comparing threatened species with human population density, for example south-east China, the Albertine Rift of Central Africa, the Ethiopian Highlands, coastal West Africa, Puerto Rico, southern Mexico, the Western Ghats of India, and the Philippines. Regions with a high level of poverty that were not previously highlighted as also being densely populated include Peru, Bolivia, Guyana, the Solomon Islands, Vietnam, Madagascar, and the Cameroon highlands.

Conclusion

In an increasingly human-dominated world it is impossible for conservation to be successful without understanding the context in which it is to take place. By comparing the distribution of amphibians, and in particular threatened amphibians, with human demographic data, it is possible to gain a better understanding of some of the challenges facing conservation.

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ESSAY 4.3. THE USE OF PHYLOGENIES IN PREDICTING TRENDS FOR CONSERVATION: A CASE STUDY FROM SRI LANKA

The discovery of large numbers of new amphibian species in Sri Lanka and elsewhere (Pethiyagoda and Manamendra-Arachchi 1998; Köhler *et al.* 2005; and see Essay 1.1), even as population declines accelerate worldwide, presents profound challenges to conservation managers. Prioritizing conservation actions in the face of declines caused by a diversity of threats – including disease and habitat fragmentation and loss – is obviously difficult. Frequently, detailed natural history knowledge that would facilitate conservation, is missing for many, if not most, species. Nonetheless, it is often necessary to make decisions even in the absence of detailed information.

Phylogenetic analyses of species and genera can provide an important source of additional information, particularly when coupled with existing ecological data. In this respect, the anurans of Sri Lanka provide an interesting case study. Based on morphological characters, taxonomists had previously allocated the treefrogs (subfamily Rhacophorinae of the family Ranidae) of Sri Lanka among several genera, such as *Philautus* (including a subgenus *Kirtixalus*), *Polypedates, Rhacophorus* and *Theloderma*. However, recent phylogenetic analyses based on mitochondrial DNA have largely refuted these classifications and demonstrated that Sri Lankan treefrogs belong to only two clades: a large and diverse group of direct-developing species in the genus *Philautus*, and a much smaller clade of foam-nesting species in the genus *Polypedates* (Meegaskumbura *et al.* 2002) (Figure 1A).

While information on breeding strategy is available for 19 species of Sri Lankan rhacophorids, several lines of evidence suggest that the entire radiation of *Philautus* in Sri Lanka is characterized by direct development (i.e., their embryos undergo complete development within the egg, from which they emerge as fully developed froglets, enabling them to develop with the tadpoles bypassing the 'conventional' aquatic larval stage). The fact that each of the 19 species examined shows direct development suggests, at least, that the most recent common ancestor of those taxa was a direct developer (Figure 1A, 1B and 1C). The sister group of the Sri Lankan clade of *Philautus* is a diverse Indian clade (Meegaskumbura *et al.* 2002; Bossuyt *et al.* 2004) in which direct development has been observed for a number of species (Biju and Bossuyt 2005). This suggests that the most recent common ancestor of the Indian and Sri Lankan taxa was also a direct developer. Therefore, it is parsimonious to infer that all Sri Lankan *Philautus* are direct developing. In contrast, *Polypedates*, which has only five species in Sri Lanka, build foam nests on vegetation overhanging water, into which emerging tadpoles fall and continue to develop.

While all Sri Lankan *Philautus* are direct developers, they exhibit two distinct reproductive behaviours: soil-nesting and leaf-nesting (Bahir *et al.* 2005) (Figure 1B, 1C). While in amplexus, females of soil-nesting species excavate a pit in damp soil with their hands into which they deposit eggs, which are fertilized by the males. The females then cover up the nest with soil and leaf litter. Leaf-nesting females, on the other hand, attach their clutch to the underside of a leaf (also while still in amplexus), usually 1-2 m above the forest floor. Egg masses on leaves are highly vulnerable to desiccation when relative humidity falls below about 90%, and so the species depend on good-quality forests with dense shade and low wind speeds. The phylogeny suggests that leaf nesting, as a reproductive trait, is restricted to a single clade (Figure 1B and 1C).

Despite Sri Lanka having been connected by a land bridge to India for much of its history and as recently as 10,000 years ago, phylogenies of several groups of organisms indicate that there has been little recent biotic exchange between the two landmasses – particularly for taxa restricted to rainforest habitats (Bossuyt *et al.* 2004). This is true for Sri Lankan *Philautus,* which belong to an old lineage distinct from the Indian direct developers, except for a small group that appears to be derived from a species that migrated back to India over 9 million years ago. The Sri Lankan *Philautus,* therefore, encompass substantial phylogenetic diversity that necessitates their consideration as a unique entity from a conservation perspective.

In addition to conserving diversity *per se*, it is widely recognized that conservation must aim also to preserve the processes that generate diversity. A mt-DNA based phylogeny has shown how sister taxa are distributed across montane-forest refugia in Sri Lanka, suggestive of speciation by vicariance during the contraction of cool and wet habitats during dry periods of the Miocene and the Pliocene (Meegaskumbura and Manamendra-Arachchi 2005) (Figure 1D). This pattern of geographic isolation of sister taxa in patches of favourable habitat is seen also in several other major lineages of direct-developing frogs, including the Neotropical genus *Eleutherodactylus* (Savage 2002), and the Afrotropical *Arthroleptella* (Dawood and Channin 2000), and, interestingly, also in the direct-developing plethodontid salamanders of Central America (Garcia-Paris *et al.* 2000). These observations suggest that montane isolation may be an important mechanism of speciation in direct-developing amphibians. However, this does not mean that habitat fragmentation should be encouraged. In addition, phylogenies can also help to identify refugia that survive as habitats through successive major climatic oscillations (Hewitt and Nichols 2005). Such refugia can be identified because they will, for a given species, contain greater genetic diversity than areas of recent population expansion (Schneider *et al.* 1998) and they often contain a higher diversity of montane endemic species (Schneider and Williams 2005).

The rhacophorine phylogeny (see Figure 1A) also suggests that the more derived terrestrial direct development is associated with a larger number of species. The more basal *Buergeria*, containing only five species, shows conventional, and plesiomorphic, anuran reproduction, with eggs and larvae undergoing development entirely in water. On the other hand, ca. 200 species of *Philautus* are presently recognized, with dozens more species awaiting description (Biju 2001; Meegaskumbura *et al.* 2002). Direct development releases amphibians from dependence on water bodies for reproduction. This, in turn, appears to enable amphibians to colonize a wide array of moist terrestrial habitats, as evidenced by the diversity of such habitats (e.g., forest canopy, leaf litter, rock surfaces, and open grasslands) occupied by species of both *Philautus* and *Eleutherodactylus.* However, greater habitat specialization and/or smaller habitat patches would make them susceptible to stochastic population declines as well as putting them at risk due to climate change.

Phylogenetic information contributes to conservation in several important ways. First phylogenetic information is fundamental to identify biodiversity (i.e., to diagnose species or to identify evolutionarily significant units or endemic taxa). Second, phylogenies are necessary for identifying important adaptive diversity. For example, the Sri Lankan / Indian radiation of *Philautus* appears to have evolved direct development independently from Asian *Philautus* (Meegaskumbura *et al.* 2002). Separate instances of adaptive evolution are crucial for understanding adaptation and thus the Sri Lankan / Indian *Philautus* take on added importance for conservation. Third, knowledge of phylogenetic relationships allows us to extend our understanding of ecology and behavior in a few species to clades of closely related species for which we have limited data. For example, understanding phylogenetic relationships may allow us to use a relatively abundant species as a surrogate to develop captive-breeding protocols for a closely related, but Critically Endangered, species in urgent need of *ex situ* conservation. Phylogenies are important on several levels and now, with the widespread use of DNA sequencing and molecular phylogenetics, are likely to play an increasing role in conservation biology.

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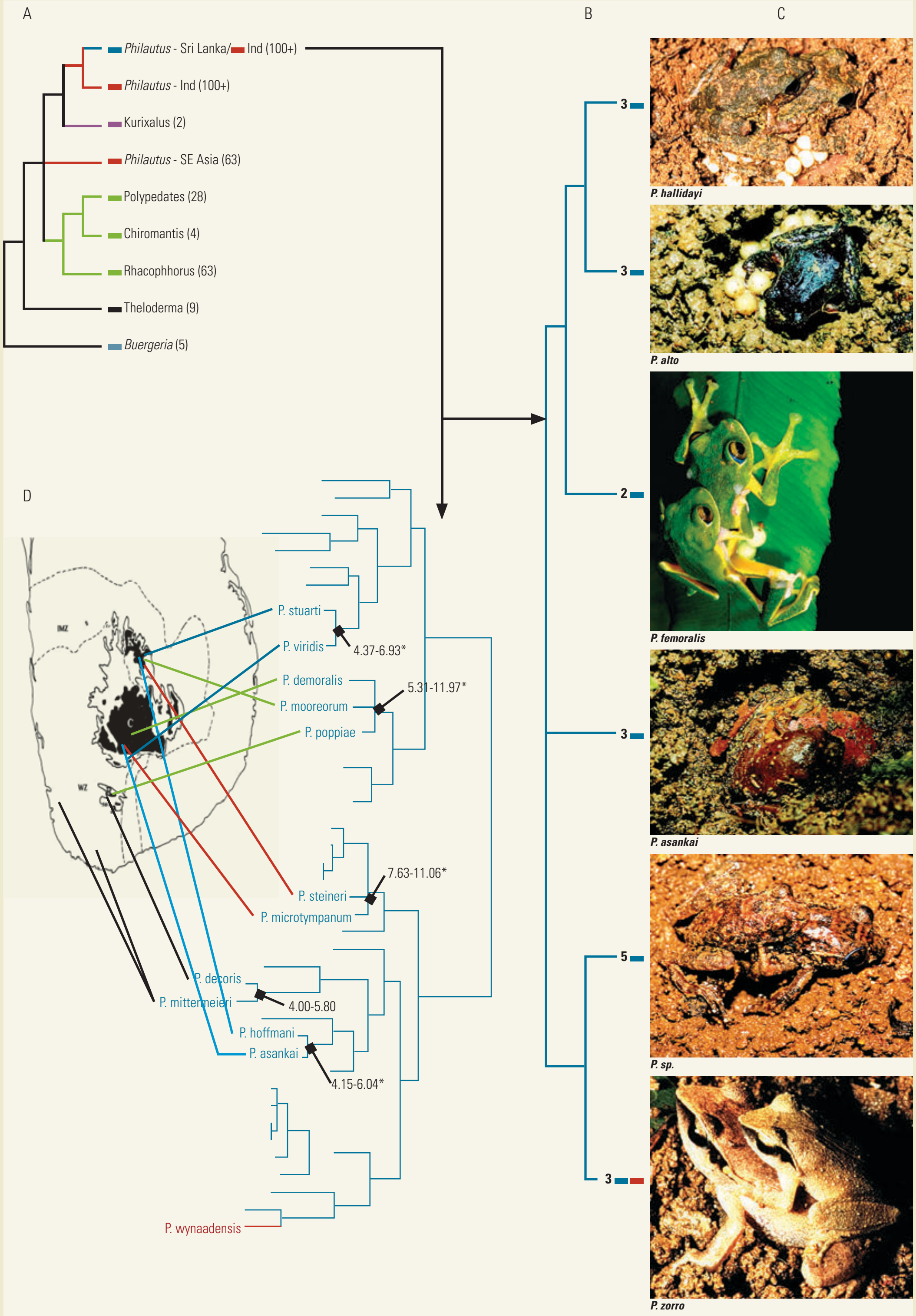

Figure 1. *The mt-DNA phylogeny of Sri Lankan* Philautus *(modified from Meegaskumbura* et al. *2002 and Meegaskumbura and Manamendra-Arachchi 2005). 1A: the genus level relationships of the Old World treefrogs shows that* Buergeria *is basal and shows aquatic breeding (light blue), while the more derived groups are tree-hole breeding (black), foam nesting (green), tree-hole nesting (purple) with brood care and direct developing (Red – South East Asian and Indian species, and Blue – Sri Lankan species). Number of species within each genus is depicted within brackets. 1B and 1C: the major clades within the Sri Lankan radiation, with the number of species for which breeding information is available inside the triangles. The leaf nesting clade is circled. 1D: some of the clades (highlighted by a *) restricted to cloud forest habitats and the sister taxa within these clades distributed on adjacent cloud-forest habitats (K - Knuckles Hills, C - Central Hills; R - Rakwana Hills). In contrast,* Philautus decoris – mittermeieri *clade is distributed across an altitudinal gradient. This information is useful for making conservation decisions.*

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ESSAY 4.4. THE EFFECTS OF PESTICIDES ON AMPHIBIANS

Since the general recognition of global amphibian declines in the early 1990s, biologists have sought to determine the underlying causes (Alford and Richards 1999; Stuart *et al.* 2004). During the past two decades, a number of hypotheses have been developed and it seems likely that many declines have a multitude of causes. One leading hypothesis is that some amphibian populations are declining due to exposure to chemical contaminants including the more than 10 billion kg of globally applied pesticides (U.S.E.P.A. 1997). Understanding all of the mechanisms by which contaminants may impact amphibian populations is certainly a difficult proposition because there are more than 80,000 registered chemicals in the United States alone, and the registration process does not require any tests on amphibians. Thus, the effect of pesticides on amphibian populations remains a very large and open question. Below, I very briefly review the evidence linking pesticides to amphibian declines and then discuss the various mechanisms by which pesticides affect amphibians and thereby potentially cause declining populations.

The evidence supporting a connection between pesticides and amphibian declines

Documenting a definitive link between pesticides and the decline of any organism in nature is a monumental task because it requires long-term monitoring data over large regions (because amphibian populations are normally quite variable over time) and, ideally, the ability to conduct controlled experiments at these same scales. Given the virtual impossibility of such a task, perhaps the best hope is to document pesticide-related patterns of declines in nature at large geographic scales and then identify the most likely mechanism(s) using smaller, more feasible experimental scales. This is the approach that has been employed by amphibian biologists during the past decade.

The most extensive regional data examining patterns of declines come from the western United States where a number of amphibian species are experiencing population declines across a large regional scale. By combining detailed records of annual pesticide use in the Central Valley of California with surveys of hundreds of amphibian populations in the Sierra Nevada Mountains, Davidson *et al.* (2001, 2002) found a positive correlation between population declines and the amount of agricultural land that is upwind. Subsequently, Davidson (2004) found a correlation between declining populations and the actual amount of pesticides that are applied upwind (Figure 1). Amphibians in these mountain sites contain pesticides in their tissues and reduced acetylcholine esterase activity (i.e., a signal of insecticide exposure; Datta *et al.* 1998, Sparling *et al.* 2001), further strengthening the hypothesis that pesticides may indeed be the underlying cause. If pesticides are a cause of amphibian declines, we need to consider the possible mechanisms by which this could occur.

Mechanism #1: Direct toxicity

The most obvious mechanism by which pesticides could cause amphibian declines is via direct toxicity. There are two key issues concerning this mechanism. First, because very high concentrations of pesticides are almost always lethal to amphibians, we must consider the actual concentrations that an amphibian would experience in nature. Second, to cause a population decline, the amount of death due to the pesticide would have to be over and above natural causes of death experienced by amphibians (which can be >90% for amphibian larvae; reviewed in Relyea 2007). For some pesticides including the herbicide Roundup® (Monsanto Corp., St. Louis, MO), researchers have observed 70-100% mortality of larval amphibians at concentrations that have been observed in nature (Relyea 2005; Relyea *et al.* 2005). However, for many of the pesticides that have been tested, including some of the most common insecticides (e.g., carbamates and organophosphates), the concentrations that cause amphibian death are above those concentrations that are most commonly found in nature (Boone and Semlitsch 2001; Relyea 2004) although seasonal spikes in pesticide use may make these rare, high concentration events quite important to amphibian populations. In either case, it is clear that we should also consider alternative mechanisms for how pesticides might cause amphibian declines.

Mechanism #2: Sublethal effects on amphibian behaviour, physiology, and endocrinology

One of the most striking discoveries in recent years is that pesticides can have some surprising and unintended effects on amphibians at very low, sublethal concentrations. Analogous to the side effects of human drugs, pesticides are now known to alter animal behavior in ways that can reduce feeding, impair locomotion, and weaken predator avoidance (Weis *et al.* 2001). Pesticides can also compromise the immune system, making amphibians more susceptible to parasites and pathogens (Christin *et al.* 2003). Moreover, there appears to be a correlation between the frequency of amphibian malformations (e.g., extra or missing limbs) and the proximity of agricultural land (Taylor *et al.* 2005). Perhaps the most striking discovery is that some pesticides (e.g., atrazine) at very low concentrations (i.e., within drinking water standards) can mimic sex hormones and cause adult male frogs to become feminized and grow eggs in their testes (Hayes *et al.* 2002; Hayes 2004). While these effects are certainly dramatic, it is currently unclear as to whether they can subsequently result in amphibian population declines.

Mechanism #3: Synergistic effects between pesticides and other stressors

One way in which low concentrations might impact amphibian populations is by interacting with other natural stressors and becoming more lethal than we appreciate. Traditional pesticide testing is done on a single species under laboratory conditions that typically lack any natural environmental stressors. In contrast, there are wide variety of stressors that occur in nature including elevated temperature, reduced pH, increased ultraviolet radiation, competition, and the threat of predation. To date, very few pesticides have been tested on amphibians in combination with different natural stressors, but the results thus far have been quite surprising; insecticides can become more lethal at higher temperatures (Boone and Bridges 1999) and more lethal when combined with the smell of predators in the water (Relyea 2003; Figure 2). The physiological mechanisms underlying these synergistic interactions are not yet known, but it is clear that natural stressors can make seemingly sublethal concentrations of pesticides become highly lethal to amphibians.

Mechanism #4: Indirect effects through a food web

Amphibians live in diverse ecological communities with a network of interactions, yet traditional pesticide testing is conducted on single species in the laboratory. As a result, we know relatively little about how low concentrations of pesticides that cannot directly kill amphibians might indirectly affect amphibians via changes in the food webs that contain amphibians. These effects can initially be positive if pesticides reduce or remove populations of amphibian predators whereas the changes can be negative when pesticides affect the food available to amphibians (Boone and Semlitsch 2001; Relyea 2005). Reduced food availability commonly reduces amphibian growth which can have long-term effects on the time to reproduction (i.e. generation time), future survival, and reproductive output (i.e., the number of eggs that can be laid; Relyea 2007). However, we do not yet know whether these indirect food web effects impact the population sizes of amphibians.

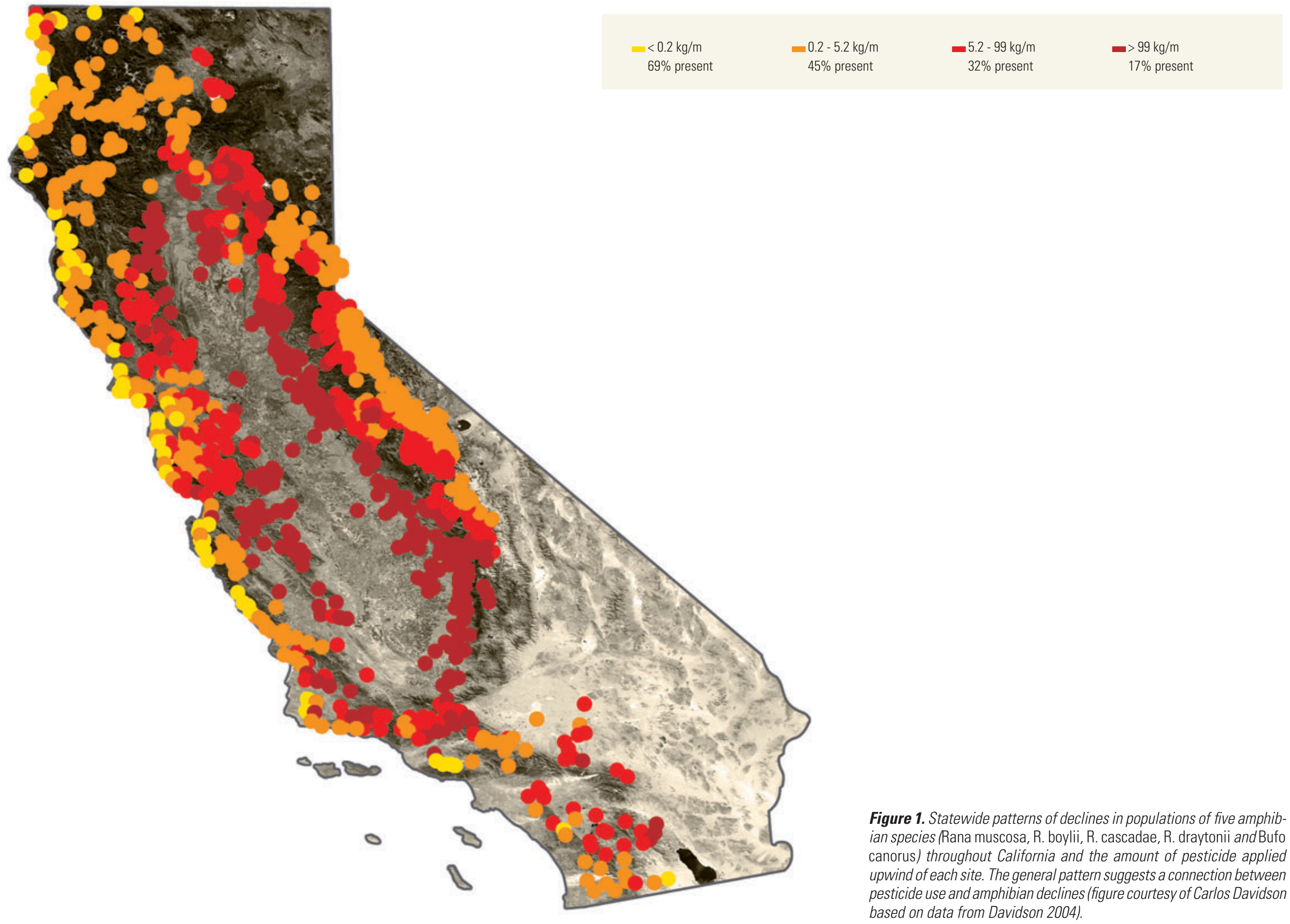

Figure 1. *Statewide patterns of declines in populations of five amphibian species (*Rana muscosa, R. boylii, R. cascadae, R. draytonii *and* Bufo canorus*) throughout California and the amount of pesticide applied upwind of each site. The general pattern suggests a connection between pesticide use and amphibian declines (figure courtesy of Carlos Davidson based on data from Davidson 2004).*

Conclusions

Confirming the role of pesticides in the global decline of amphibians is an extremely daunting task, but it is being rapidly addressed by researchers. Since realizing that amphibians were declining globally, we have been accumulating additional regional datasets on amphibian populations to assess their status and to test for correlative patterns with regional pesticide use. At the same time, experimentalists are rapidly delving into the wide range of possible mechanisms whereby pesticides might affect amphibians and discovering some mechanisms that were inconceivable only a decade ago. Unfortunately, most pesticide research is being conducted in North America and Europe on a small fraction of the 6,000-odd amphibian species that exist (and mostly on the larval stage), making our current power of inference rather limited (Schiesari *et al.* 2007). If pesticides are contributing to amphibian declines in nature, we will continue to require a multi-faceted approach from many sources of data to develop a solid case. A solid case is critical because it must withstand the doubtless challenges that will follow from the manufacturers and applicators of pesticides around the world. Importantly, while scientists can provide the data demonstrating the impacts of pesticides on amphibians, only societies can determine whether or not demonstrated pesticide impacts are acceptable.

Rick Relyea

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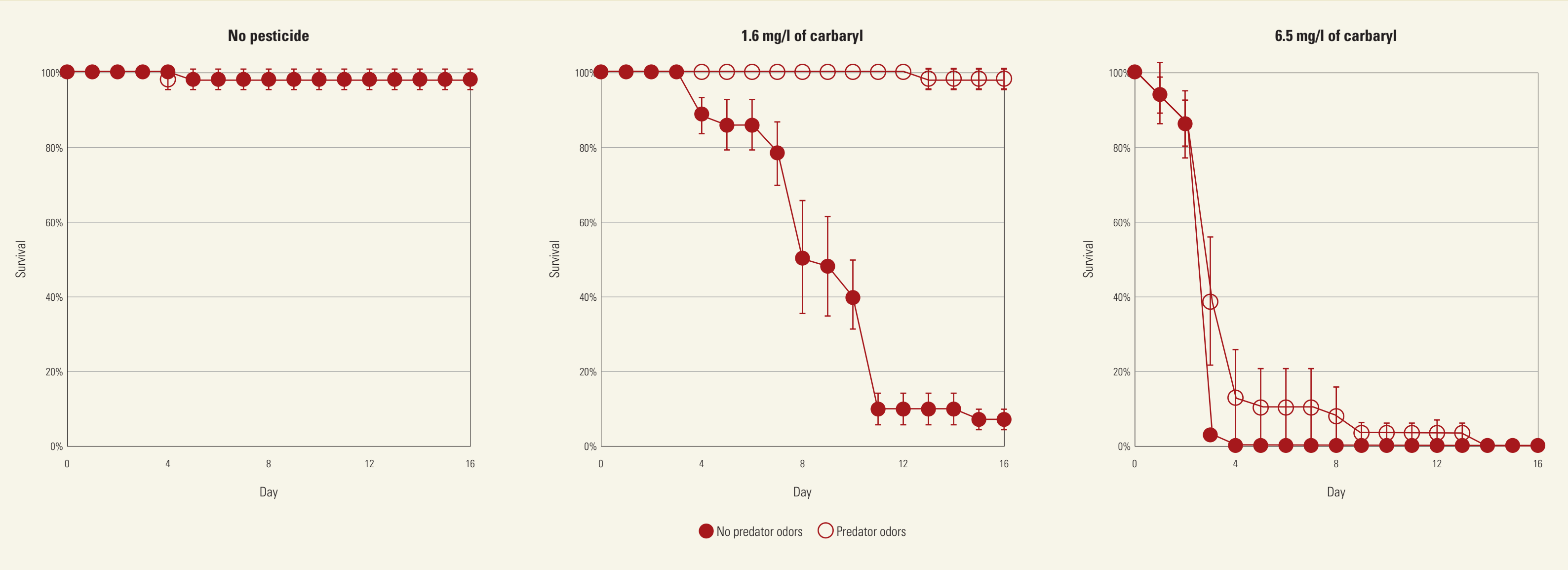
***Figure 2.** The synergistic impacts of an insecticide (carbaryl) on bullfrog tadpoles when combined with the presence or absence of predator odours in the water. When no insecticide is present, there is low mortality with or without the odour of predators. When the insecticide is present at high concentrations (6.5 mg/L) there is high mortality with or without the odour of predators. However, at intermediate concentrations (0.6 mg/L), there is low mortality in the absence of predator odours, but 46 times higher mortality in the presence of predator odours.*



ESSAY 4.5. CHYTRIDIOMYCOSIS: DRIVER OF AMPHIBIAN DECLINES AND EXTINCTIONS

Amphibian populations are declining at alarmingly rapid rates worldwide and species are disappearing from entire regions. A greater proportion of amphibians are at imminent risk of extinction than any other animal class, including birds. Some have already been lost forever. While habitat loss, overexploitation and the other "usual suspects" are partly to blame, the factor driving amphibians most rapidly to extinction is the emergence of the virulent fungal disease, chytridiomycosis. Chytridiomycosis is caused by a fungus in the order chytridiales (the chytrid fungi) called *Batrachochytrium dendrobatidis*. This fungus was unknown until 1998, when it was simultaneously discovered as the primary cause of catastrophic amphibian declines in the rain forests of Australia and Central America (Berger *et al.* 1998). While many chytrid fungi are parasites of invertebrates, *B. dendrobatidis* is the only chytrid fungus known to infect vertebrates. Although the fungus is known only to infect amphibians, it has low host specificity having thus far been recorded infecting at least 14 families and over 100 species of amphibian on five continents.

Although *B. dendrobatidis* was unknown until the late 1990s, retrospective studies have shown it to have been a major cause of amphibian declines at least as far back as the 1970s. Many amphibian declines considered to have been due to other reasons at the time, such as predation or competition by introduced species, or stress and disruption by human activities, are now known to have been due – at least in part - to chytridiomycosis (Green and Sherman 2001; Green *et al.* 2002; Muths *et al.* 2003; Carey *et al.* 2006).

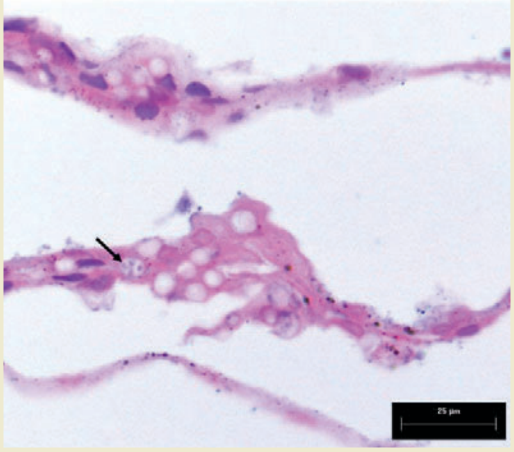
The primary hypothesis for the emergence of chytrid-caused declines is the exposure of naïve host populations to a newly introduced pathogen, although other hypotheses (such as a change in a pre-existing host-pathogen relationship) have not yet been discounted (Cunningham *et al.* 2003; Weldon *et al.* 2004). Some amphibian species, such as the North American Bullfrog (*Rana catesbeiana*) (Daszak *et al.* 2004) and the African Clawed Frog (*Xenopus laevis*) (Weldon *et al.* 2004), are generally unaffected by *B. dendrobatidis* infection and there has been speculation these species might act as transport hosts, introducing the infection to new areas and to new host species and populations (Mazzoni *et al.* 2003; Weldon *et al.* 2004; Garner *et al.* 2006). The global trade in amphibians, which began in the 1930s with the trade in *Xenopus laevis* for pregnancy testing, mushroomed in the 1970s and 1980s with the widespread harvesting of wild frogs in India, Indonesia and China for the international restaurant trade. The level of international trade continues to rise with the development of commercial frog farms in Asia and Latin America that export bullfrogs and other ranid species for the North American and European markets. There is evidence that this trade might be a major driver of the current chytridiomycosis pandemic (Mazzoni *et al.* 2003; Weldon *et al.* 2004; Garner *et al.* 2006; Kusrini and Alford 2006; Cronin *et al.* in press).

Infection with *B. dendrobatidis* is limited to the keratinized tissues of the animal: the most superficial, keratinized, cells of the skin in metamorphosed amphibians, and the mouthparts of anuran larvae (Daszak *et al.* 1999; Berger *et al.* 2005). The infection is intracellular (i.e. the fungus grows within the skin cell) and discharge tubes open onto the surface of the cell for the release of zoospores, the infective stage of the fungus. The presence of the fungus induces a number of host responses, including, in metamorphosed animals, hyperkeratosis, irregular foci of hyperplasia, disordered epidermal cell layers, spongiosis, erosion and ulceration of the skin. Areas of the skin more frequently in close contact with the water, such as the digits and the pelvic patch, are more severely affected (Berger *et al.* 1998). Inflammatory responses in the dermis are mild, if at all present, and involve mononuclear cells. Inflammation within the epidermis is rare. The lack of an immune response might be due to a lack of stimulation of the host immune system as the site of infection is both superficial and intracellular. Also, the degree of tissue damage is very low. There is no evidence of immuno-suppression either as an underlying factor to, or as a consequence of, *B. dendrobatidis* infection (Berger *et al.* 1999).

Signs of the disease include lethargy, loss of righting reflex and abnormal posture. Gross lesions are usually not apparent, but increased epidermal sloughing, epidermal ulceration and reddening (hyperaemia) of the digital and ventral skin have been reported (Daszak *et al.* 1999; Berger *et al.* 2000). Diagnosis is by visualization of the characteristic intracellular zoosporangia in the keratinized epidermis using either cytology of sloughed skin or histopathology of skin samples (e.g., toe-clip biopsies or post-mortem skin samples). Molecular techniques, such as the polymerase chain reaction (PCR) and quantitative PCR, have largely superseded cytology and histopathology for rapid diagnosis and for screening large numbers of animals.

Despite almost a decade of research on chytridiomycosis, there is still much that remains unknown. The exact mechanism by which *B. dendrobatidis* causes mortality is not known, but there are currently three possible mechanisms hypothesized. Firstly, the chytrid might release toxins, such as proteolytic enzymes, which are absorbed to cause systemic poisoning. Secondly, epidermal hyperplasia may impair cutaneous respiration and/or osmoregulation (Berger *et al.* 1998, 2005). Thirdly, a combination of both of these mechanisms might be involved (Daszak *et al.* 1999). The absence of any specific internal lesions suggests that the ultimate cause of death probably is either metabolic or toxic (Berger *et al.* 1999).

Although several life-history (e.g., low fecundity) and ecological (e.g., riparian, montane habitat) factors have been shown to correlate with population declines due to chytridiomycosis, these might be solely indicators of a



Batrachochytrium dendrobatidis *infection in the superficial, keratinized layer of skin sloughed from an adult North American bullfrog. Note focal thickening of the sloughed skin with numerous subspherical empty sporangia. One sporangium still contains zoospores (arrow). © Andrew Cunningham, ZSL.*

population's ability to respond to any stochastic factor (amphibians in riparian, montane habitats tend to have small and restricted ranges). Infection with *B. dendrobatidis* is highly variable between species: some species (e.g., *Rana catesbeiana*, *Xenopus laevis*) become infected, but show no evidence of disease, while others (e.g., *Atelopus* spp.) appear to be highly susceptible to infection, with very high mortality rates. However, within a species, there are differences in response, depending on variables such as dose of exposure, temperature and humidity. Therefore, a chytrid-positive population might appear to be resistant, only to decline markedly following a change in environmental conditions.

Addressing the threat of chytridiomycosis is not easy. We are used to tackling species threats by introducing or increasing protection measures of the animals and/or their habitats. Pathogens respect neither the law nor protected areas. In fact, many of the most devastating effects of chytridiomycosis have occurred in pristine and protected areas, such as rainforest reserves in Australia and Central America. Although *B. dendrobatidis* can be killed by a range of antifungal medications, it is both impractical and ecologically dangerous to attempt such treatments in the wild. The disease and causative agent were unknown until less than 10 years ago and there is still much to learn about the biology, ecology and distribution of the pathogen. Currently, our only defense is to bring vulnerable species into captivity until alternative approaches are devised. These are massive challenges to the zoo and conservation research communities. If we are to avoid losing a substantial proportion (the majority?) of the world's amphibians in the face of this daunting threat, these communities need to raise their game to a new level of cooperation along the lines of a Manhattan project-style response for amphibian conservation.

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ESSAY 4.6. CLIMATE CHANGE AND AMPHIBIAN DECLINES

Evidence that climate change is currently affecting life on earth has become overwhelming in the last few years. Although some continue to question the link between global warming and human activity, the rate of current trends in temperature shifts is vastly different from past global climate change events. For example, in lower elevation cloud forests in the Andes, the warming trend experienced from the 1970s to the present is 18 times faster than at the end of the last ice age (Bush *et al.* 2004). Species of plants and animals in many different taxonomic groups and regions of the world are already responding to warming, by shifting their ranges uphill or towards the poles and tracking cooler environments (Walther *et al.* 2002). The timing of seasonal cycles, such as flowering in plants and migration in birds, has also been shifting with the changing climate (Root *et al.* 2003). Spawning dates and breeding migrations in a number of amphibian species have already become significantly earlier (Root *et al.* 2003). Although these changes might appear trivial, they do alter the composition and dynamics of communities, with complex and unpredictable outcomes. For example, in Britain, newts are now arriving much earlier at breeding ponds, allowing their predatory larvae to be much larger by the time frogs arrive. This may be detrimental for frog species that now deposit their eggs and tadpoles into pools full of hungry newt larvae (Beebee 1995). Along with changes in species' ranges and phenology, current models predict a great loss of species in the future due to a warmer and more extreme climate (Thomas *et al.* 2004). In fact, climate change may already be causing extinctions.

Declines and disappearances of amphibian populations have become increasingly apparent in the past 20 years. Some declines appear to be explained by clear anthropogenic effects such as habitat loss, while others, with less apparent causes, have been classified as "enigmatic" (Stuart *et al.* 2004). Research activity has increasingly focused on determining the causes of these declines. High-elevation species seem to be most affected, and based on the fate of known species it appears that many have probably disappeared prior to being described. In the Neotropics, harlequin frogs of the genus *Atelopus* appear to have been most affected by "enigmatic declines". A number of undescribed *Atelopus* species collected by South American herpetologists are currently awaiting description. In the short time since these species were collected, scientists have returned to their original collection sites only to find that most of these undescribed species have vanished from their apparently pristine environments. Many more species are likely to have become extinct before even being collected. For instance, in many countries, most historical collection sites are directly adjacent to a highway or rural road, while vast tracts of land remain almost entirely unsurveyed. This makes it likely that many species unknown to science have already been lost. The situation is even worse when we take molecular evidence into account. Cryptic species that looked extremely similar to each other were probably hidden among some of the widespread species. We may never know how many species we have truly lost.

Could amphibian disappearances be attributed to global warming patterns? Skeptics have voiced critical opinions on this idea. Amphibians have been on earth for at least 280 million years, persisting through at least 60 glacial periods in the last 12 million years alone. So why would the recent temperature shifts be more threatening to amphibians than the ever-changing environment they evolved in? The answer may be found in the interaction between climate change and another variable – disease.

Climate change is already impacting human health by facilitating the spread of disease, causing an estimated 150,000 deaths a year (Patz *et al.* 2005). As with humans, a synergistic interaction between temperature change and infectious disease may explain many of the recent disappearances of amphibians. One disease for which this synergism may be important is the chytrid fungus *Batrachochytrium dendrobatidis,* which infects the skin of amphibians, causing the disease chytridiomycosis. Outbreaks of this disease have occurred in apparently naïve populations, and are clearly linked to the extirpation of frog communities in the immediate range of harlequin frogs (Lips *et al.* 2006). Approximately 80% of missing harlequin frog species vanished directly after a relatively warm year (Pounds *et al.* 2006; see Figure 1). The probability of this correlation occurring by chance is less than one in a thousand. In the laboratory, *B. dendrobatidis* grows best at temperatures between 17 and 25°C, but grows more slowly outside this range, and may not cause disease at temperatures over 30°C (Piotrowski *et al.* 2004). Even short periods at body temperatures of 37°C can clear frogs of infections by the pathogen (Woodhams *et al.* 2003). Such temperatures may be experienced by frogs after a short period in direct sunlight, but cannot be attained under heavy cloud cover. Although it has been suggested that the probability of population declines increases with altitude, this does not seem entirely

Atelopus zeteki *(Critically Endangered) from El Cope, Panama, taken about nine months before the population crash happened at that site. © Ross A. Alford* true for harlequin frogs. Pounds *et al.* (2006) demonstrate that patterns of extinction in harlequin frogs vary at different altitudes, and suggest that they are caused by interactions among temperature, atmospheric moisture, cloud cover, and host-pathogen dynamics. This hypothesis could be tested in other regions of the world, such as Australia, where the patterns of declines in amphibian populations show many parallels with those in the Neotropics. In eastern Queensland, Australia, at least 14 species have experienced declines in recent decades, with six species disappearing altogether, and others becoming locally extinct at high-elevation sites. *Batrachochytrium dendrobatidis* has been implicated in most of these declines. In these areas, where *B. dendrobatidis* now appears to be endemic, patterns of infection and mortality are consistent with the climate-linked epidemic hypothesis, with infection levels and mortality highest during cooler months (Berger *et al.* 2004; Retallick *et al.* 2004; McDonald *et al.* 2005; Woodhams and Alford 2005). Future predictions for amphibians in the region are grim, with 13 to 68% of frog species endemic to Queensland predicted to become extinct under future climate scenarios (Thomas *et al.* 2004). This prediction is based on the effects of changing climatic conditions alone. The true impacts of climate change may be far more complex and potentially detrimental when acting in synergism with disease.

What seems to be clear is that amphibian extinctions are strongly correlated with the changing climate. The disappearance of frogs may be an early warning of a new episode of mass extinction, and this time, there is no cataclysm to blame, only ourselves.

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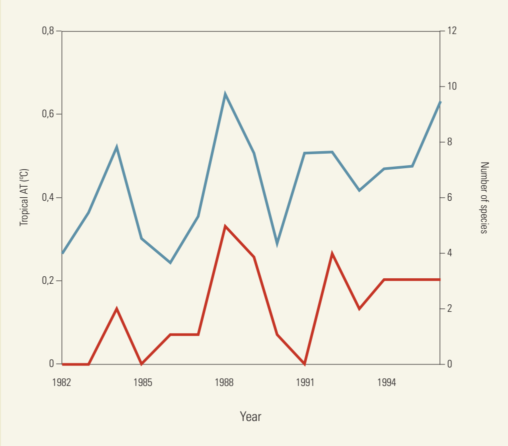

Figure 1. *Last year of observation in harlequin frog species for which there is sufficient population data (red line) and air temperature for the tropics (ºC) of the preceding year (blue line). Reproduced, with permission of authors, from Pounds* et al. *2006 (*Nature ***439****:161-167).*

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ESSAY 4.7. THE STATUS OF THE CHINESE GIANT SALAMANDER *ANDRIAS DAVIDIANUS*

The Chinese Giant Salamander *Andrias davidianus*, is the largest living amphibian, with adults reaching a total length of more than 200cm and a weight of 50kg (Peng *et al.* 1998). Although very similar to its congener, the Japanese Giant Salamander *Andrias japonicus*, the Chinese Giant Salamander differs in the arrangement of tubercles on the head and throat, which are mostly in pairs, and much smaller and fewer than those of its Japanese cousin. The snout is also less rounded and the tail a little longer in the Chinese species. The species is referred to locally as *wawayu* (baby fish), because its call resembles a baby's cry.

Formerly widespread in China, most local wild populations of the Chinese Giant Salamander have declined greatly in both range and number since the 1950s, largely due to habitat fragmentation or loss, and as a result of overharvesting for human consumption. Recent surveys show that the Chinese Giant Salamander is distributed in a few mountainous areas in the middle and lower tributaries of the Yangtze, Yellow and Pearl Rivers, across the 17 provinces of Henan, Shaanxi, Shanxi, Gansu, Qinghai, Sichuan, Chongqing, Guizhou, Hubei, Anhui, Zhejiang, Jiangxi, Hunan, Fujian, Yunnan, Guangdong and Guangxi (Wang *et al.* 2004). Many populations are now on the verge of extinction, and some are already extinct (Zhao 1998; Zhang and Wang 2000). Today, because of this continuing, drastic, population decline the Chinese Giant Salamander is listed as Critically Endangered on the IUCN Red List of Threatened Species.

Although habitat loss is certainly a threat, uncontrolled harvesting is the primary reason for the steep decline in numbers of Chinese Giant Salamander. Before the wildlife protection act was declared by the Chinese government in 1988, the Chinese Giant Salamander was a legal fishery product in China. Indeed, there was already a marked decline in the number of salamanders being collected from the wild by the 1970s. For example, a traditional company in Taibai county of Shaanxi province reported that, while demand remained high, the quantity of Chinese Giant Salamander purchased declined from 3,813kg in 1973 to 1,300kg in 1979, presumably in response to a reduction in wild stocks. Likewise, from the 1950s to the 1980s, the amount purchased of this species had declined more than 80% in some areas in Hunan and Anhui Provinces (Wang *et al.* 2004). In addition, whereas the salamander was found in 28 counties of north-eastern Sichuan Province in the 1970s, it appears to have disappeared from 11 of them by the middle of the 1980s. Western Hunan Province had 10 counties with salamanders in the 1960s, but the species could only be found in five of them in the 1980s (Liu 1989).

Despite protection by the Chinese Government since 1988 (the Chinese Government has declared the giant salamander a Class II Protected Species), illegal collection of Chinese Giant Salamander from the wild is still a leading threat widely contributing to population declines, and in many counties the poaching has actually increased during recent years. Hunters now use pesticides, electrical shock tools, explosives, and other modern methods, instead of traditional bow-hooks to capture salamanders. The increasing use of such unsustainable methods has resulted in very serious declines in salamander populations. Furthermore, the species is in danger of losing its title of "world's largest amphibian", as the weights of giant salamanders being captured today appears to be much lower than formerly, presumably due to the increased hunting pressure. In Sangzhi County in Hunan Province most individuals weighed *c.* 35-40kg; all individuals captured in the same locality during the 1970s were <5kg (Liu 1989). According to our field surveys, and questionnaires to local people in the main distributions of the salamander in six provinces from 2000 to 2001, illegal poaching is still prevalent across the range, and is even prevalent within protected areas. For example, more than 100kg of salamanders were collected per year in Dabie mountain area of Anhui Province (given weights of 0.5-1.0kg, this represents around 7-100 animals), and the poachers could have captured about 50kg (30-50 animals) worth of giant salamander per year in recent years in Hupingshan National Natural Reserve. Three canoes with over 150 bow-hooks were seen in the main river of Yongshun Chinese Giant Salamander reserve of Hunan Province.

As the Chinese Giant Salamander has a great economic value mostly as luxury food, this species has long been excessively exploited by local people. Because of the high demand in some cities such as Guangzhou and other provincial capitals, the value of salamander meat is increasing steadily in local black markets. The price in China has risen from around US$5 per kg in the early 1980s to over US$350 in recent years. High prices are strong incentives for harvesting salamanders from the wild, and combating illegal harvesting and trade has become extremely difficult.

In order to protect the wild populations of Chinese Giant Salamander, 21 nature reserves have been established in Henan, Jiangxi, Chongqing, Shaanxi, Guizhou, Guangdong, and Hunan Provinces since the 1980s (and see Table 1), but many of these reserves have very limited funds available to effectively conserve the salamanders. Sadly, because of funding difficulties four of these reserves have now been degazetted.

To date, about 100 legal Chinese Giant Salamander farms have been established throughout the species' range. Most of them were set up during the 1990s, directly aimed at supplying the ever-growing food market, and more than 20 farms have bred the giant salamanders and successfully reared young to maturity. During 2005, over 32,000 larvae were bred from more than 6,000 parents in seven farms. But, at present, even sustainable breeding programmes are insufficient to meet market demands. To date, only a few restaurants in Beijing, Hunan and Guangdong have been approved by the government to sell Chinese Giant Salamander, with the result that most trade of this animal has been driven to the black market (Zhang, pers. obs.). In addition, it certainly seems possible that a number of farms have obtained adult salamanders illegally from the wild, and this in itself may pose a threat to remaining wild populations.

The Chinese Giant Salamander Andrias davidianus *(Critically Endangered) is the largest living amphibian, with adults reaching a total length of more than 200cm and a weight of 50kg. © Kejia Zhang*

Table 1. *Chinese Giant Salamander reserves in China with location, grade, area and year established (updated from Wang* et al. *2004).*

Reserve	Location	Grade	Area (ha)	Established year
Lushi Giant Salamander Reserve	Lushi, Henan	Provincial	184,350	1982
Xixia Giant Salamander Reserve	Xixia, Henan	Provincial	131,040	1982
Qingyaoshan Giant Salamander Reserve	Xinan, Henan	Provincial	9,000	1988
Songxian Giant Salamander Reserve	Songxian, Henan	Provincial	600	1998
Luanchuan Giant Salamander Reserve	Luanchuan, Henan	Provincial	800	1996
Youyang Giant Salamander Reserve	Youyang, Chongqing	County	4,000	1989
Taibai Xushuihe Giant Salamander Reserve	Taibai, Shannxi	Provincial	5,740	1986
Lingkou Giant Salamander Reserve	Luonan, Shannxi	Provincial	5,715	1998
Zhuxi Giant Salamander Reserve	Zhuxi, Hubei	Provincial	800	1986
Zhongjianhe Giant Salamander Reserve	Xianfeng, Hubei	Provincial	264	1994
Dachenshan Giant Salamander Reserve	Loudi, Hunan	County	100	1987
Sangzhi Quanhe Giant Salamander Reserve	Sanzhi, Hunan	County	4,810	1983
Yongshun Liangcha Giant Salamander Reserve	Yongshun, Hunan	-	24,400	1988
Chenxi Longmen Giant Salamander Reserve	Chengxi, Hunan	County	1,700	1984
Zhangjiajie Giant Salamander Reserve	Zhangjiajie, Hunan	National level	14,285	1998
Qianxi Giant Salamander Reserve	Qianxi, Guizhou	County	1,000	1986
Jingan Liaohe Giant Salamander Reserve	Jinan, Jiangxi	County	100	1980
Guishan Giant Salamander Reserve	Heyuan, Guangdong	Municipal	1,199	2001
Nuoshuihe Giant Salamander Reserve	Tongjiang, Sichuan	Provincial	9,480	1998
Chuanxihe Giant Salamander Reserve	Dayi, Sichuan	County	-	2004
Wenxian Giant Salamander Reserve	Wenxian, Gansu	Provincial	21,160	2004

The many problems outlined above suggest that wild populations of the Chinese Giant Salamander are on the verge of extinction, particularly if no effective conservation measures are taken in the immediate future. The development and enforcement of a comprehensive conservation strategy and action plan is now urgently needed to prevent the extinction of this extraordinary amphibian.

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ESSAY 4.8. AMPHIBIANS AS INVASIVE ALIEN SPECIES

While only a small proportion of the species that are moved around the world with human movements and global trade actually cause harm, those that do – termed invasive alien species – are devastating. Such "biological invasions" are now considered one of the biggest factors in biodiversity loss and extinctions (Baillie *et al.* 2004). Many threatened amphibians are heavily impacted by invasive alien species. However, amphibians themselves can also be invasive. The list of "100 of the world's worst invasive alien species" includes three amphibians, as well as a fungal disease agent, for which invasive amphibians are vectors of spread (Lowe *et al.* 2000; and see www.gisd.org).

Judas' kiss: the role of invasive amphibians in the spread of frog chytrid fungus

Amphibian species have been reported as declining since the 1970s, and in many of them the fungal disease chytridiomycosis is implicated. Moreover, of the recorded nine recent extinctions of amphibians since 1980, eight were sudden disappearances in suitable habitats and they are thought to be the result of this disease, probably operating in synergy with climate change. At first, this may seem to be unrelated to the issue of invasive species, but in fact, it perfectly illustrates the complexity of biological invasion issues: not only is the pathogen itself an invasive alien species, but its spread is facilitated by invasive alien species that are amphibians!

The origin of the virulent pathogen *Batrachochytrium dendrobatidis* is not known with absolute certainty, but a recent study has led to the conclusion that in all likelihood it originated in Africa. Hence, the impacts on amphibian populations in the rest of the world result from the unintentional introductions of a pathogen as an invasive alien species. In an ironic twist of fate, several invasive frog species play a role in the exportation of the pathogen out of Africa, its 'escape" into the wild and its ongoing spread and impact on threatened amphibians. It is thought to have started with the export, out of Africa, of the African Clawed Frog (*Xenopus laevis*) for use in laboratories. This frog was a carrier of chytridiomycosis, and the establishment of feral populations of this species in countries where it had been moved to, allowed the pathogen access to other species, such as the American Bullfrog *Rana catesbeiana* which now is considered to be one of the main vectors of the disease (Weldon *et al.* 2004). The bullfrog, native in parts of the USA and Canada, is itself a highly invasive species, and has been introduced to Hawaii, parts of western USA and south-western Canada, Mexico and the Caribbean, South America, Europe and Asia (GISD 2006a). It has been traded internationally as a food item, and within countries it can spread when populations held for culinary use escape and establish. Frog species in the pet trade are also potential agents of spread of the disease and infected amphibians have been identified in European and US zoos. In Australia, chytridiomycosis has been found in Cane Toads (*Bufo marinus*), a recently introduced invasive alien species. Chytrid can persist in contaminated water or mud and it can hence also be spread by wet or muddy boots, vehicles, cattle and other animals moving among aquatic sites. Nevertheless, invasive alien frogs and toads have acted in an (involuntary) 'Judas' role, exposing many native species of amphibian around the world to the pathogen, with disastrous results.

Frog eats frog

The American Bullfrog is not only a vector for disease, but is also a highly invasive alien species in its own right, affecting native species, amphibian and otherwise, through competition or direct predation. In British Columbia (Canada), for example, it has been recorded in competition with, and predating upon, the Red-legged Frog (*Rana aurora*), and in Puerto Rico there have been reports of bullfrogs preying on several bird species, including White-cheeked Pintail (*Anas bahamensis*) (GISD 2006a). In the United States, its impacts include: competition with the Relict Leopard Frog (*Rana onca*, EN), which was once thought to be extinct, in Arizona and Nevada (Bradford *et al.* 2004); predation on both larval and juvenile Red-legged Frogs in California (Doubledee *et al.* 2003); and competition with and predation on the Oregon Spotted Frog (*Rana pretiosa*, VU) in Oregon (Pearl *et al.* 2004).

There goes the neighbourhood

The Caribbean Treefrog, also called the Common Coqui (*Eleutherodactylus coqui*) is a relatively small treefrog native to Puerto Rico. While there are ecological concerns about its introduction into Hawai'i, it also creates a nuisance to people: it is their loud call that is the main reason that many Hawai'ians consider the species as a pest. It is feared that the high-pitched call of the frog may affect the tourism industry and there are also concerns that property value may be affected due to the high biomass of frogs on infested sites (Kraus and Campbell 2002; GISD 2006b).

Cane toad conquest

The Cane Toad is native in parts of South and Central America and parts of the Caribbean. It has been introduced widely throughout the world as a biological control agent for various insect pests of sugarcane and other crops. Its alien range now includes many countries, including parts of the Caribbean where it is not native, and where, for example, it has been implicated in the decline of the endemic Bermuda Skink (*Eumeces longirostris*) (Davenport *et al.* 2001). It has also been introduced in parts of Asia, Australia and the Pacific. The Cane Toad has become a major invasive species in most of its introduced range. It competes with native amphibians and other animals for food and breeding habitat, and also directly preys on them. In fact, it has been quoted as eating "almost any terrestrial animal" (Hinkley 1962). In addition, the toad's toxicity means that many native predators are killed. For example, in Australia native snakes have been found dead with the Cane Toad in their mouths or guts, and in Japan's remote Iriomote Island, it is feared that the recent arrival of Cane Toads may result in the poisoning of the threatened Iriomote Cat (*Prionailurus iriomotensis*) (GISD 2006c).

In Australia, Cane Toads were introduced to Queensland in 1935 and they have since expanded their range to encompass more than a million square kilometres of tropical and subtropical Australia. When researchers radio-tracked toads at the "invasion front" they found astonishing locomotor performance, with animals moving up to 1.8km per night during the rainy months. As is the case with many anurans, toads with longer legs can move faster than those with shorter legs. This turned out to be happening at a grand scale in Australia: longer-legged toads were disproportionately common among the first wave of arrivals at any new site. In general, toads at the invasion front were longer-legged than toads from older populations, confirming that the invasion process has been assisted by the evolution of improved dispersal ability among toads at the front. This means that it would be expected that over many generations, rates of invasion will be accelerated owing to rapid adaptive change in the invaders. The annual rate of progress of the toad's invasion through tropical Australia has increased about five-fold since the toads first arrived. In other words, an already strong invader is actually in the process of getting even better at it (Philips *et al.* 2006). This should be a salutary reminder that, as with all alien invasive species, prevention of introduction is the best option, and any management should be undertaken as soon as possible, before the invader has had time to evolve into a more dangerous adversary.

Maj de Poorter

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An African Clawed Toad Xenopus laevis *(Least Concern) with a fish in its mouth. Chytridiomycosis was detected in museum specimens of this species dating back to 1938, and one hypothesis posits that the international trade in this species may have introduced this fungal disease to other regions of the world. © Carlos Garin Lobos*

The Cane Toad Bufo marinus *(Least Concern), a native of Central and South America, has been widely introduced in the Caribbean, the Philippines, Japan, parts of Melanesia and the Pacific Islands and Australia. It was introduced to Australia in 1935 to control sugar cane pests (which it failed to do) from whence its name derives. © Craig Morley*

In recent years, Eleutherodactylus coqui *(Least Concern), a species native to Puerto Rico, has become infamous in the Hawaiian islands, where it probably arrived in plant pots and bromeliads. There, it has spread widely (the Hawaiian archipelago has no native amphibians) where they reportedly annoy the local people when they sing loudly by windows and in gardens, at night. © Alejandro Sanchez*

CHAPTER 5. AMPHIBIANS OF THE AFROTROPICAL REALM

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THE GEOGRAPHIC AND HUMAN CONTEXT

The Afrotropical Realm includes all of mainland Sub-Saharan Africa and the southern Arabian Peninsula[1], as well as several large offshore islands: Zanzibar and Pemba; Madagascar; the western Indian Ocean islands of the Seychelles (including Aldabra), Mauritius (including Rodrigues), Réunion, Mayotte, and the Comoros; the Gulf of Guinea islands (Bioko, Príncipe, São Tomé and Pagalu); Socotra; and the Cape Verde Islands. Although Africa finally separated from the rest of the southern land-mass of Gondwanaland some 100 Ma, the African, Arabian and Eurasian plates abutted at least at the end of the Oligocene, and it is only from about 15-10 Ma that Africa has been an isolated land mass (when the African and Arabian land masses rifted apart; see Kingdon 1989; Goudie 2005). The island of Madagascar, on the other hand, separated from the African mainland between 165-140 Ma and has been isolated (as an island) from all other land masses for 87-91 million years (Storey *et al.* 1995; Torsvik *et al.* 2000).

An extensive process of rifting which began about 30 Ma has left mainland Africa very diverse topographically, with many high mountain ranges, especially on the east of the continent, and with rift valleys that include some of the deepest lakes in the world. Much of Africa is still volcanically active, including Mount Kilimanjaro, its highest peak, soaring some 5,895m above sea-level. A combination of intra-plate hotspots, extensive Cenozoic doming (45 Ma), vulcanism and coastal upwarp has created the world's largest plateau. This is characterized by a "basin and swell" topography unique to the interior of the African continent, and stretching from South Africa to East Africa, with high points including Mount Mulanje (3,002m) in southern Malawi and Mount Rungwe (2,691m) in southern Tanzania (Beentje *et al.* 1994; Goudie 2005). East and North-east Africa are bisected by the 6,000-km-long Great Rift (or Gregory Rift), the "passive" margin between the African and East African Plates. This massive feature is visible from space and runs from the Luangwa Valley in Zambia, northe-ast through Ethiopia, where it meets the Saudi Arabian Plate and continues north-west to the Caucasus Mountains.

Not surprisingly, the region is ecologically diverse, with an enormous range of vegetation types from deserts to woodlands and grasslands to rainforests. In West Africa, the agriculturally productive Guinea and Sudanese savannah regions slowly merge into the lowland forests stretching across West Africa. A little further to the east, the highly fragmented, lower Guinea rainforests of Nigeria and western Cameroon open into the vast, lush, relatively intact tropical rainforests of the Congo Basin. Apart from the chain of volcanic mountains centred on western Cameroon and extending into the sea as the Gulf of Guinea islands, West Africa has very few uplands (with the exception of Mount Nimba, and the Loma and other nearby mountains in Sierra Leone, Guinea and Liberia). The eastern edge of the Congo Basin is flanked by the Albertine Rift, a series of high, block-faulted mountain chains that separates the Congo Basin rainforest of Central Africa from the forest/savannah mosaic habitats of East Africa, most famous for their teeming herds of wildebeest and zebra.

To the north the Great Rift cuts through the Ethiopian Highlands, home to more than two-thirds of Africa's unique Afro-alpine habitat, while to the south-east of the Great Rift are the Eastern Arc Mountains that continue into the Southern Highlands of Tanzania south to Mount Mulanje in Malawi and the Chimanimani Highlands of Zimbabwe. Patches of forest (now highly fragmented) fringe the coast of much of eastern Africa, from the Juba and Shabelle River Valleys in Somalia south to south-eastern South Africa. In the south-western part of South Africa, the unique Mediterranean fynbos vegetation is dominant, with its remarkable floristic endemism, and further north the Succulent Karoo becomes dominant along the west coast of South Africa.

Africa has a low human population density (approximately 30 people per square kilometer in 2005), of which over 60% live in rural areas, but a high population growth rate (over 2.1% per annum, though this is decreasing). Historically, the region has been subject to relatively low levels of anthropogenic disturbance, related not only to low human population densities, but also to widespread poverty (gross income per capita was around US$600 in Sub-Saharan African in 2004). However, 35% of the continent's Gross Domestic Product is concentrated in South Africa, where the human impacts on natural ecosystems and biodiversity have been more severe than in most of the region. Economic growth rates in Africa have been amongst the lowest in the world and still are, though there has been a recent tendency for somewhat faster growth (4.5% in 2004). Although many of Africa's natural habitats are still intact, some parts of the continent have been affected much more than others. Deforestation has been particularly severe in the Upper Guinea forests of West Africa, in the mountains and lowlands of Nigeria and western Cameroon, in many of the mountainous regions of central and East Africa, and in the East African coastal lowlands. This forest loss has been driven largely by expanding subsistence agriculture to support the burgeoning human populations, but also by commercial agriculture and logging. As mentioned above, habitat loss and fragmentation has been particularly severe in South Africa, and above all in the fynbos vegetation of the extreme south and south-west (which has been heavily impacted by invasive species and fire, and well as by general urban and agricultural development). There has also been extensive habitat degradation in the semi-arid Sahel region, much of it driven by over-exploitation of resources for basic subsistence by growing human populations. However, in central and south-central Africa, extensive tracts of lowland forest, savannah and grassland remain largely intact. On Madagascar, habitat loss has been especially severe, with almost no natural habitat surviving on the central plateau, and much of the country characterised by very high levels of soil erosion.

GLOBAL CONSERVATION STATUS

A total of 969 amphibian species are recorded from the Afrotropical Realm, of which 240 (25%) are considered threatened (see Figure 1 for details). Although this is significantly less than the global average of 33%[2], it is still almost one-quarter of the overall amphibian fauna of the Afrotropics. As is the case globally, the percentage of threatened species is expected to increase as the status of DD species is clarified, as new species (many of which are likely to be rare, and have small ranges) are discovered, and as the taxonomic status of many species complexes is resolved.

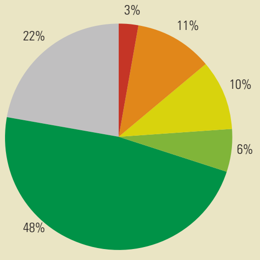
The Afrotropical realm currently accounts for about 13% (240) of all globally threatened amphibian species. When looking at the Red List Categories, the Afrotropics account for only 7% of CR species, but 14% of the EN species, and 15% of the VU species. Hence, on the basis of current knowledge, threatened Afrotropical amphibians are more likely to be in a lower category of threat, when compared with the global distribution of threatened species amongst categories. This might partly be explained by the fact that the amphibian fauna is very poorly known in many parts of the continent (for example the Albertine Rift, the Congo Basin, the Ethiopian plateau and the Upper Guinea forests of West Africa), and these are places that could have many threatened species. However, the lower than average level of threat is also likely to be genuine, in part because the fungal disease chytridiomycosis, although present in Africa (Weldon *et al.* 2004), is not so far believed to be a serious threat in the region (although there are few monitoring programmes, and further information could change this perception). Species that are threatened by this disease are more likely to experience sudden and dramatic declines, pushing them very quickly into the higher categories of threat.

Surprisingly, especially for such a poorly known region, the percentage of DD species (22%) is slightly lower than the global average (23%). As more African amphibian species are discovered and named, the percentage of DD species might increase for a period, at least until the conservation status of these species can be adequately assessed.

There have been no recorded recent extinctions of amphibians in the Afrotropical Realm. However, of the 33 CR species, three are flagged as Possibly Extinct: *Arthroleptides dutoiti* from Mount Elgon in Kenya, which has not been recorded since 1962, despite extensive searches (Lötters *et al.* 2003); *Nectophrynoides asperginis* from the Udzungwa Mountains in the Eastern Arc of Tanzania (which might have become extinct in the wild in 2004, though it still survives in captivity); and *Conraua derooi*, from the Togo-Volta Highlands of eastern Ghana and western Togo (previously not recorded since the 1960s[3]).

Figure 1. *Summary of Red List categories for amphibians in the Afrotropical Realm. The percentage of species in each category is also given.*

Red List Category	Number of species
Extinct (EX)	0
Extinct in the Wild (EW)	0
🟥 Critically Endangered (CR)	33
🟧 Endangered (EN)	107
🟨 Vulnerable (VU)	100
🟩 Near Threatened (NT)	53
🟩 Least Concern (LC)	467
⬜ Data Deficient (DD)	209
Total Number of Species	**969**



SPECIES RICHNESS AND ENDEMISM

Species Richness and Endemism Across Taxa

The 969 native amphibian species in the Afrotropical Realm represent 16% of the currently known global total of 5,915 species. Of these 969 species, 954 (or 98%) are endemic to the Afrotropics (Table 1). The overwhelming majority of African amphibians are frogs and toads (Anura), 98% of which are endemic. All 28 species of Afrotropical caecilian (Gymnophiona) occurring in the region are endemic. Members of the order Caudata (salamanders) are completely absent. A total of 618 species (64%) are members of families that are endemic to the region.

The amphibian fauna of the Afrotropical Realm has been relatively isolated from that of the rest of the world for much of its evolutionary history, and remains so today (the Saharan and Arabian deserts forming an effective, though fairly recent, barrier to most species). This isolation accounts for the high level of family and genus-level endemism within the region. For example, of the 16 families of amphibians found in the region, nine are also endemic. From the perspective of amphibian biogeography, the region is almost defined by the distribution of the African treefrogs and reed frogs (family Hyperoliidae) (Poynton 1999), which are present through nearly all of Sub-Saharan Africa, Madagascar, the Seychelles Islands, and the Gulf of Guinea islands (though absent from southern Arabia, the Comoros[4], the Mascarenes, and the Cape Verde Islands). The amphibian fauna comprises elements with both tropical and southern temperate origins (Poynton 1999).

There are 112 amphibian genera in the Afrotropical Realm, of which 105 (94%) are endemic. These endemic genera represent nearly one-quarter (23%) of the 460 amphibian genera worldwide. The Afrotropics, therefore, account for a larger proportion of the overall diversity of amphibians at the generic level than at the species level. The most species-rich endemic genus in the region is *Hyperolius* (125 species). At the opposite end of the spectrum, there are 42 monotypic genera endemic to the Afrotropical Realm, which equates to exactly

Table 1. *The number of Afrotropical amphibians in each taxonomic Family present in the region.*

Family	Native species (endemics to region)	Percentage of species in region that are endemic	Percentage of species in family that are endemic to region	Native genera (endemics to region)	Percentage of genera in region that are endemic	Percentage of genera in family that are endemic to region
Anura						
Arthroleptidae	51 (51)	100	100	3 (3)	100	100
Astylosternidae	29 (29)	100	100	5 (5)	100	100
Bufonidae	105 (97)	92	20	15 (14)	93	41
Heleophrynidae	6 (6)	100	100	1 (1)	100	100
Hemisotidae	9 (9)	100	100	1 (1)	100	100
Hylidae	1 (0)	0	0	1 (0)	0	0
Hyperoliidae	253 (253)	100	100	18 (18)	100	100
Mantellidae	158 (158)	100	100	5 (5)	100	100
Microhylidae	87 (87)	100	20	18 (18)	100	26
Petropedetidae	102 (102)	100	100	13 (13)	100	100
Pipidae	23 (23)	100	77	4 (4)	100	80
Ranidae	109 (103)	94	15	14 (9)	64	23
Rhacophoridae	4 (4)	100	1	1 (1)	100	11
Sooglossidae	4 (4)	100	100	2 (2)	100	100
TOTAL ANURA	**941 (926)**	**98**	**18**	**101 (94)**	**93**	**26**
Gymnophiona						
Caeciliidae	22 (22)	100	19	9 (9)	100	100
Scolecomorphidae	6 (6)	100	100	2 (2)	100	100
TOTAL GYMNOPHIONA	**28 (28)**	**100**	**16**	**11 (11)**	**100**	**100**
TOTAL ALL AMPHIBIANS	**969 (954)**	**98**	**16**	**112 (105)**	**94**	**23**

Boophis luteus *(Least Concern) is a treefrog in the Family Mantellidae, which is endemic to Madagascar. This species is locally abundant along streams in both pristine and degraded rainforest. © Piotr Naskrecki*

one-third (33%) of the 126 monotypic genera of amphibians worldwide. This unexpectedly high percentage is probably a reflection of the poor state of knowledge of the Afrotropical amphibian fauna; it is likely that many of these genera will prove not to be monotypic as more species are discovered. For example, recent descriptions include a second species of the previously monotypic genus *Callulina* (De Sá *et al.* 2004), a second species of *Cophyla* (Vences *et al.* 2005), a second species of *Acanthixalus* (Rödel *et al.* 2003), and a second and third species of *Alexteroon* (Amiet 2000). The seven non-endemic genera in the Afrotropics include five ranid genera (*Euphlyctis*[5], *Hoplobatrachus*, *Ptychadena*, *Rana*[6], *Tomopterna*[7]) and the widespread genera *Bufo*[8] and *Hyla*[5].

As noted already, 16 of the world's 48 amphibian families (33%) occur in the Afrotropics. The nine endemic families to the region (Arthroleptidae, Astylosternidae, Heleophrynidae, Hemisotidae, Hyperoliidae, Mantellidae, Petropedetidae, Sooglossidae and Scolecomorphidae) represent 19% of the global level of diversity of amphibians at the family level[9]. The characteristics of these families are provided in Chapter 1.

Among the non-endemic families, the majority of Afrotropical species are in the Bufonidae, the Microhylidae and the Ranidae. Of the Afrotropical Bufonidae, 68 species (65% of those occurring in the region) are within the widespread genus *Bufo*[8]. The remaining 14 genera have mostly small numbers of species, with the exception of *Nectophrynoides* (11 species). The Afrotropical toad genera of *Nectophrynoides* (endemic to eastern Tanzania) and *Nimbaphrynoides* (endemic to Mount Nimba in Côte d'Ivoire, Guinea and Liberia) are remarkable in that they include 13 of the 14 known live-bearing anurans in the world[10] (with the possibility that the poorly known, monotypic Afrotropical bufonid genera, *Didynamipus* and *Laurentophryne*, might also be live-bearing).

The Afrotropical Microhylidae species are very unevenly distributed within the region, with 56 species endemic to Madagascar (10 genera, including *Plethodontohyla* – 15 species, *Platypelis* – 11 species, *Scaphiophryne* – 10 species, and *Stumpffia* – 8 species). On the African mainland, there are 29 species in eight genera. The largest concentrations of microhylids are in South Africa (15 species, eight of which are endemic) and Tanzania (12 species, nine of which are endemic, with four endemic genera). Microhylid diversity is low in the rest of Africa, with only one species in West Africa, and none at all in the equatorial rainforest belt. The largest genera on the African mainland are *Breviceps* (15 species) and *Phrynomantis* (5 species). The Afrotropical microhylids exhibit a wide diversity of reproductive modes, including both larval- and direct-developers.[11]

The Afrotropical Ranidae species are all larval-developers, and occur throughout the African mainland, with one species naturally occurring on Madagascar. There are 14 genera, the dominant genus being *Ptychadena* (47 species), with other notable genera including *Amnirana* (11 species), *Strongylopus* (11 species), *Afrana* (10 species), and *Tomopterna* (9 species). Among the Afrotropical ranids is the largest frog in the world, the Goliath Frog *Conraua goliath*, with some individuals recorded as weighing more than 3kg.[12]

Of the remaining families, the highly aquatic Pipidae, although small in number of species (but with more than 75% of the species in the family occurring in the Afrotropics), is a very visible and abundant component of the amphibian fauna, being dominated by the generally widespread and resilient genus *Xenopus* (16 species).

The caecilian family Caeciliidae is very poorly known in the Afrotropics, as in other parts of the world. Only 21 species (in nine genera) are known, of which six species are endemic to the granitic islands of the Seychelles, though strangely none at all occur in Madagascar. The Seychelles is the only country in the world in which the order Gymnophiona forms a majority of the amphibian fauna (and see Essay 5.1). One species in the Caeciliidae is endemic to the island of São Tomé. On the African mainland, members of this family appear to occur mainly in the West African forest belt, east to Cameroon and western Democratic Republic of Congo, and in the coastal areas of East Africa and the Eastern Arc Mountains, south to southern Malawi. There is a single species present in south-western Ethiopia, and a single species (known from just one specimen) is known from the Albertine Rift highlands. Caecilians are unknown from the Congo Basin, but this is probably due to lack of sampling, and they also appear to be absent from the Kenyan Highlands (except for the northern outliers of the Eastern Arc Mountains).

Not surprisingly, the larger families – Bufonidae, Hyperoliidae, Mantellidae, Microhylidae, Petropedetidae – have the largest absolute numbers of globally threatened species (Table 2). The percentage of threatened species ranges greatly between the families, from 0% for the Hylidae, Rhacophoridae and Scolecomorphidae to 100% for the endemic Sooglossidae of the Seychelles (all four of the species have tiny ranges). The percentage of threatened species is also very high in the Astylosternidae (73%), reflecting the poor state of forest conservation in the mountainous regions of Cameroon. The percentages are also high (>30%) in the Bufonidae, Heleophrynidae, and Microhylidae. In the Bufonidae, only 11 of the 68 species of Afrotropical *Bufo* (16%) are globally threatened, but 27 of the remaining 37 species in other genera (80%) are threatened. The Bufonidae are also noteworthy in that 30 of the 38 threatened species fall in the Critically Endangered and Endangered categories, underlining how urgent the conservation needs are in this family.

Certain families have lower levels of threat, notably the Pipidae, Hemisotidae and Ranidae[13], all of which have a high proportion of adaptable species in the Afrotropics. The results for the Arthroleptidae are hard to interpret because of the major taxonomic uncertainties in this family (31% of the species are DD). There is very little information on the threat levels to Afrotropical caecilians (39% DD); two of the three threatened species occur in Seychelles, and the other in Kenya, but almost nothing is known of the conservation status of most of the West African species.

Geographic Patterns of Species Richness and Endemism

A map of overall species richness of amphibians in the Afrotropical Realm (Figure 2) shows that species richness is lowest in arid regions, such as the Sahel, the Horn of Africa, and south-west Africa. However, the apparent region of species paucity on the southern Congo Basin is almost certainly an artefact reflecting the very limited herpetological work in that part of Africa.

Although the regions with the highest known species richness, such as south-western Cameroon and eastern Madagascar are genuine reflections of amphibian diversity, these are also the rainforest regions that have received the most research attention from herpetologists. Other regions, such as the high mountains of the Albertine Rift of eastern Democratic Republic of Congo, Rwanda, Burundi and south-western Uganda, are likely to be richer in species than the current data indicate. Some regions showing higher species richness, such as the Eastern Arc Mountains of Tanzania, and Mount Nimba in Liberia, Guinea and Côte d'Ivoire, are likely to represent genuine patterns, whereas others (for example, in the Upemba region of southern Democratic Republic of Congo and the Taï National Park in south-western Côte d'Ivoire) are probably a reflection of locally intensive survey efforts.

There are seven major concentrations of threatened species (Figure 3a): the Upper Guinea forests from Sierra Leone to Togo; south-eastern Nigeria and south-western Cameroon; the mountains of the Albertine Rift; the Ethiopian Highlands; the Eastern Arc Mountains; southern South Africa (especially in the south-western Cape); and eastern Madagascar (especially in the northern and southern extremities of the eastern rainforest zone). These concentrations of threatened species correlate with those for other taxa (Stuart and Collar 1988; Baillie *et al.* 2004). Smaller concentrations of threatened amphibians are found in: São Tomé, the Kenyan Highlands; southern Malawi (around Mount Mulanje); eastern Zimbabwe (the Chimanimani mountains, in particular) and adjacent Mozambique; and the Seychelles Islands. These geographic concentrations reflect the parts of the region where amphibians have naturally small ranges, and where habitat destruction is ongoing. However, at least some of the threatened species in the Upper Guinea forests were once more widespread, but have declined due to extremely severe habitat destruction. Because of the relatively small number of CR species, there are few significant concentrations of CR species, and the overall pattern is similar to that for threatened species (Figure 3b).

Species Richness and Endemism within Countries

Amphibians occur naturally in every mainland country in Sub-Saharan Africa and southern Arabia (Figure 4). They are also present on Madagascar, and are indigenous to the following

Table 2. *The number of species within each IUCN Red List Category in each Family and Order in the Afrotropical Realm. Introduced species are not included.*

Family	CR	EN	VU	NT	LC	DD	Total number of species	Number threatened or Extinct	% threatened or Extinct
Anura									
Arthroleptidae	3	9	2	3	18	16	51	14	27
Astylosternidae	2	11	8	2	5	1	29	21	72
Bufonidae	9	21	8	2	49	16	105	38	36
Heleophrynidae	2	0	0	0	4	0	6	2	33
Hemisotidae	0	0	1	0	4	4	9	1	11
Hylidae	0	0	0	0	1	0	1	0	0
Hyperoliidae	1	19	29	17	133	54	253	49	19
Mantellidae	7	12	16	12	77	34	158	35	22
Microhylidae	3	13	16	2	36	17	87	32	37
Petropedetidae	3	13	8	10	39	29	102	24	24
Pipidae	1	1	0	1	15	5	23	2	9
Ranidae	1	7	7	4	68	22	109	15	14
Rhacophoridae	0	0	0	0	4	0	4	0	0
Sooglossidae	0	0	4	0	0	0	4	4	100
TOTAL ANURA	**32**	**106**	**99**	**53**	**453**	**198**	**941**	**237**	**25**
Gymnophiona									
Caeciliidae	1	1	1	0	11	8	22	3	14
Scolecomorphidae	0	0	0	0	3	3	6	0	0
TOTAL GYMNOPHIONA	**1**	**1**	**1**	**0**	**14**	**11**	**28**	**3**	**11**
TOTAL ALL AMPHIBIANS	**33**	**107**	**100**	**53**	**467**	**209**	**969**	**240**	**25**

Grandisonia sechellensis *(Least Concern) is known only from the islands of Mahé, Praslin and Silhouette in the Seychelles. The Seychelles is the only place in the world where caecilians form the majority of the amphibian fauna, and this species is sympatric with five other caecilian species. © Renaud Boistel*

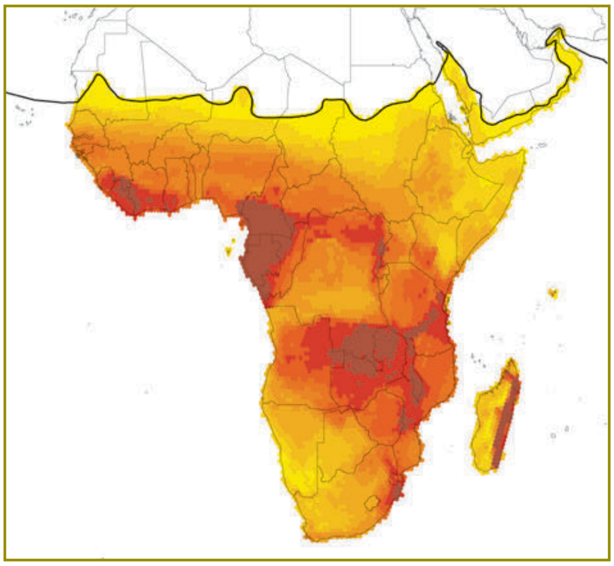


Figure 2. *The species richness of amphibians in the Afrotropical Realm, with darker colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes; maximum richness equals 123 species.*

islands: Seychelles (on most of the granitic islands, but not on the coral atolls), Zanzibar, Pemba, Mafia, Bioko, Príncipe and São Tomé (but apparently not on Pagalu, Socotra, the Comoros[4], the Mascarenes or the Cape Verde Islands).

Madagascar has been intensively studied (Blommers-Schlösser and Blanc 1991; Glaw and Vences 1994; Andreone *et al.* 2005) and has the largest number of species of any country in the Afrotropical Realm (226 species), and 70% of these are in the endemic family Mantellidae (see also Essay 5.2). The only other country with more than 200 species is the Democratic Republic of Congo, and only four other countries have more than 100 species (Cameroon, Tanzania, South Africa, and Nigeria), although, if including species awaiting description, Cameroon has more than 200 species (J.-L. Amiet pers. comm.; see Essay 5.3).

However, these figures need to be treated with considerable caution. The rate of new species' descriptions in Madagascar has been very high over the last decade, with the number of described species from the country doubling since 1991 (compare Blommers-Schlösser and Blanc [1991] with Figure 4). However, the rate of species descriptions in recent years from the African mainland has been much slower than from Madagascar, and this is largely a reflection of the very limited amount of herpetological work that has been conducted on the continent in recent decades. Only the work of Schiøtz (1967, 1975, 1999) focusing on the Hyperoliidae, and that of Tandy and Keith (1972) focusing on African *Bufo*, has taken a continental approach to the amphibian fauna. In particular, there has been very limited work carried out in the Congo Basin since the late 1950s in what might be expected to be one of the most diverse parts of the region. Similarly, with the exception of a small amount of work in Uganda (Drewes and Vindum 1994; Vonesh 2001), the Albertine Rift has received no attention for a similar period of time, despite the fact that this area has higher species richness and endemism among vertebrates than any other part of mainland Africa (Stuart and Collar 1988; Brooks *et al.* 2001). There has been much greater focus on the amphibian fauna of Cameroon (Perret 1966; Amiet 1983, 1989), but serious exploration of the fauna of West Africa only resumed in the mid 1990s (Rödel 2000; see Essay 5.4). Apart from some

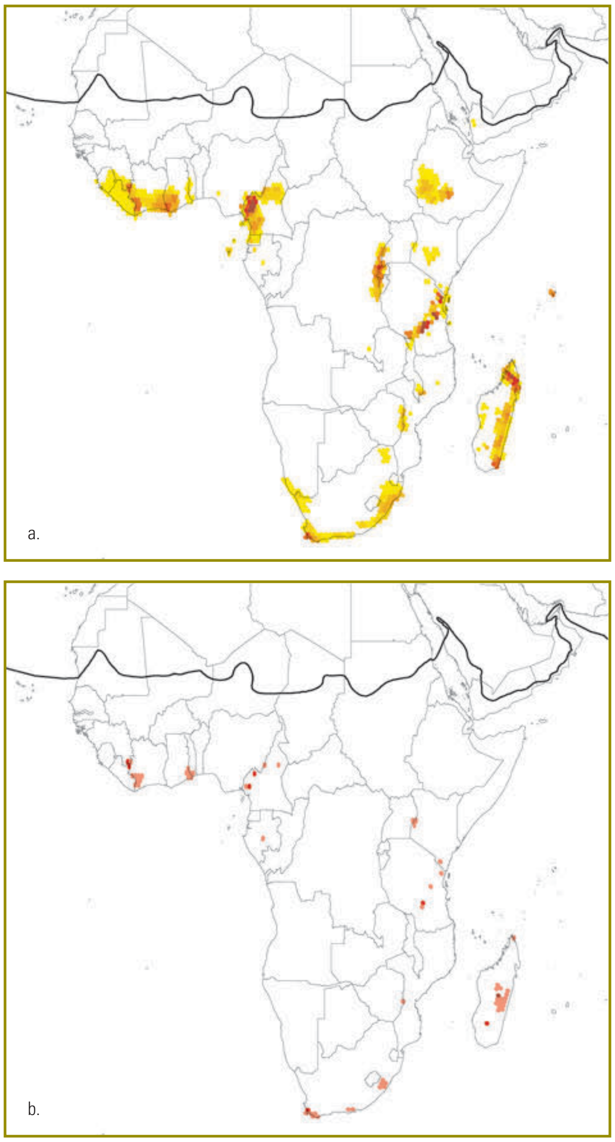


Figure 3. *a) The richness of threatened amphibians in the Afrotropical Realm, with darker colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes; maximum richness equals 31 species. b) The richness of CR amphibians in the Afrotropical Realm, with darker colours corresponding to regions of higher richness. Maximum richness equals three species.*

Bufo togoensis *(Near Threatened) is a toad from the Upper Guinea forests of West Africa, ranging from eastern Sierra Leone to western Togo. It lives only in primary forest, usually in close association with the streams in which it breeds, and is affected by ongoing deforestation throughout its range. © Piotr Naskrecki*

Figure 4. *The number of amphibians present in and endemic to each Afrotropical country. *denotes countries not entirely within the Afrotropical Realm, hence only the species whose ranges fall within the region are included.*

Figure 5. *Percentage of species endemic to each Afrotropical country. Countries with no endemic species are not included. *denotes countries not entirely within the Afrotropical Realm, hence only the species whose ranges fall within the region are included.*

Figure 6. *The number of threatened amphibians present in and endemic to each Afrotropical country. Countries with no threatened species are not included in the diagram. *denotes countries not entirely within the Afrotropical Realm, hence only the species whose ranges fall within the region are included.*

Figure 7. *Percentage of native species that are threatened. Countries with no threatened species are not included in the diagram. *denotes countries not entirely within the Afrotropical Realm, hence only the species whose ranges fall within the region are included.*

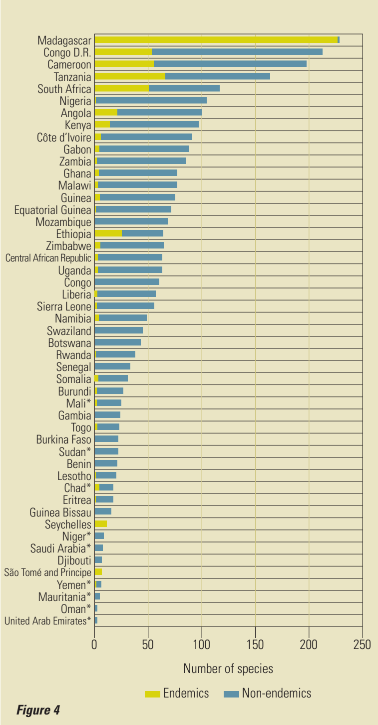


Figure 4

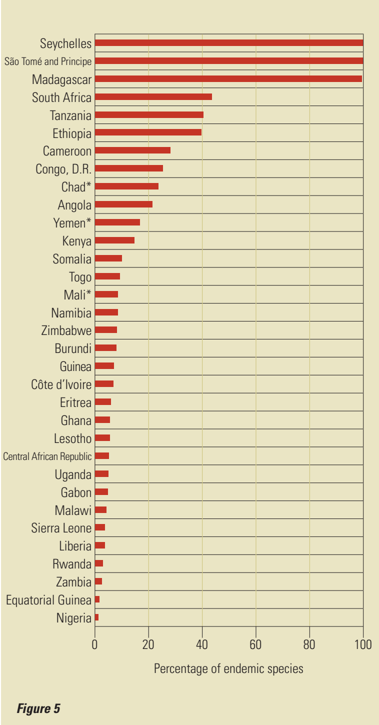


Figure 5

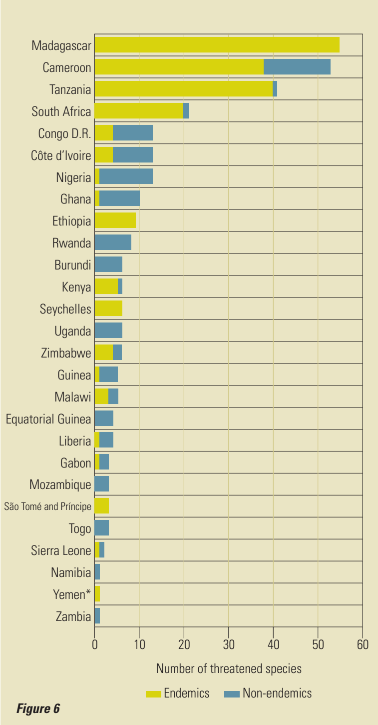


Figure 6

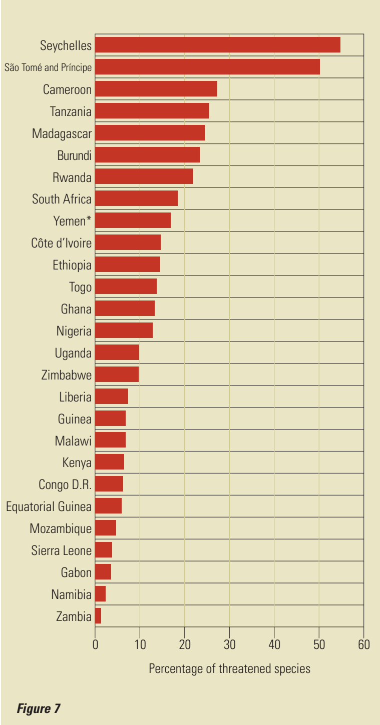


Figure 7

Kassina cochranae (Near Threatened) is in the endemic Afrotropical Family Hyperoliidae. It is an arboreal, forest-dwelling species known from the forest zone of Sierra Leone, Liberia and Guinea. Certain populations are probably suffering from severe deforestation as a result of agricultural expansion, logging and growing human settlements. © Piotr Naskrecki

preliminary work in Ethiopia (Largen 2001) and Somalia (Lanza 1990), work in eastern Africa has been very limited, although there has been some recent attention on Tanzania (e.g., Poynton 2003), and a field guide to the amphibians of East Africa, covering Kenya, Tanzania and Uganda (Channing and Howell 2006).

The frogs of the southern third of the African continent are probably somewhat better known, thanks to a number of detailed studies, for example: Poynton (1964) and Channing (2001) covering the whole region; Wager (1986), Lambiris (1989a), Passmore and Carruthers (1995), and Minter *et al.* (2004) in South Africa, Lesotho and Swaziland; Channing and Griffin (1993) in Namibia; Lambiris (1989b) in Zimbabwe; Broadley (1971) in Zambia; Stewart (1967) in Malawi; Poynton (1966) in Mozambique; and the classic *Amphibia Zambesiaca* works of Poynton and Broadley (1985ab, 1987, 1988, 1991). However, even in South Africa, which is by far the most studied country in the region, new species continue to be described (for example, Turner *et al.* 2004).

In reality, our understanding of the country-level species richness of amphibians in the Afrotropics is still very incomplete. Future investigations will doubtless result in increases in the numbers of species in every country; however, based on the known species richness of other groups such as birds, these increases are likely to be greatest for the Democratic Republic of Congo, Nigeria, Angola, Côte d'Ivoire, Gabon, Ghana, Guinea, Equatorial Guinea, Mozambique, Ethiopia, Central African Republic, Uganda, Congo, Liberia, Sierra Leone, Rwanda, Burundi, Togo, Sudan, Benin[14], and Chad. Meanwhile, Madagascar, Cameroon and Tanzania, which have received the most herpetological attention (after South Africa) in recent years, show no signs of slowing in their rates of new species' descriptions.

Not surprisingly, endemism (in terms of relative proportions; Figure 5) is much higher in island nations. Madagascar has far more endemics than any other country, with all but one of the native species, the Mascarene Ridged Frog *Ptychadena mascareniensis* (LC), being found nowhere else[15]. In both Seychelles and São Tomé and Príncipe, the level of endemism is 100%.

Table 3. *The habitat preferences of amphibians in the Afrotropical Realm.*

Habitat type	Number of species in each habitat	% of all species occurring in the habitat	Threatened and Extinct species	% of species occurring in habitat that are Threatened or Extinct
Forest	648	67	208	32
All tropical forest	624	64	201	32
Lowland tropical forest	495	51	114	23
Montane tropical forest	322	33	137	43
Savannah	227	23	7	3
Grassland	267	28	52	19
Shrubland	213	22	29	14
Secondary terrestrial habitats	415	43	74	18
Flowing freshwater	380	39	112	29
Marsh/swamp	223	23	38	17
Still open freshwater	375	39	53	14
Arid and semi-arid habitats	41	4	1	2

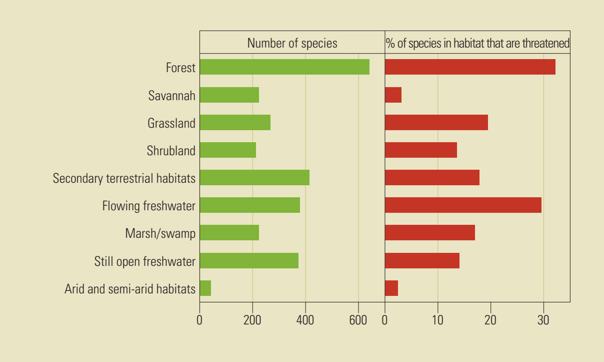


Figure 8. *The habitat preferences of Afrotropical amphibians. The plot on the left-hand side shows the number of species in each habitat type. On the right-hand side, the percentage of these species which are threatened is given.*

Hyperolius puncticulatus (Least Concern), one of at least 125 treefrogs in the genus Hyperolius*, ranges from coastal Kenya, through eastern and southern Tanzania (including the island of Zanzibar) to the highlands of Malawi. The males of this species call from vegetation around pools, where they breed. © Alan Channing*

On the African mainland, Tanzania has more endemic species than any other country (see Essay 5.5). More than 50 endemic species are also known from Cameroon, the Democratic Republic of Congo, and South Africa. In terms of percentage of the fauna being endemic, the highest endemism on the African mainland is found in South Africa, Tanzania and Ethiopia (all have around 40% of species endemic). Although the actual numbers and percentages will change as new information becomes available, the overall patterns are concordant with those of other taxonomic groups, and are almost certainly real.

Threatened species occur in 27 of the 49 countries in which there are native amphibians (Figure 6). In fact, threatened species are concentrated in relatively few countries. Only four countries, Madagascar, Cameroon, Tanzania and South Africa, have more than 20 globally threatened species. The top three countries, Madagascar, Cameroon and Tanzania, are undoubtedly genuine centres of threatened species, but the number is almost certainly grossly under-estimated for the Democratic Republic of the Congo. Here there are likely to be many threatened species, probably many of them still undescribed, in the mountains around the Albertine Rift (where there is also severe forest loss due to expanding subsistence agriculture). The percentage of threatened amphibian species is highest in the island nations of Seychelles and São Tomé and Príncipe (Figure 7). The highest percentage on the African mainland is 27% for Cameroon, a reflection of the poor state of forest conservation in the mountainous regions of the country. In many countries, the percentage of threatened species can be expected to rise as new species discoveries are made or crucial habitats are destroyed.

Assessments of the conservation status of Afrotropical amphibians at national level have been carried out only for South Africa, Lesotho and Swaziland (Branch 1988; Monadjem *et al.* 2003; Minter *et al.* 2004).

There are only 33 Critically Endangered Afrotropical species, nine of which occur in Madagascar, seven in Cameroon and five in Tanzania. Outside these three countries, there are three Critically Endangered species in South Africa, two each in Côte d'Ivoire and Kenya, and one each in Gabon, Ghana, Guinea, Liberia, Togo and Zimbabwe. However, the numbers in West Africa are very likely to increase during the coming years, both because of newly discovered species and because of destruction of forest and mountain habitats.

HABITAT AND ECOLOGY

Habitat Preferences

Two-thirds of Afrotropical amphibians occur in forests, and over 40% are believed to be able to survive in secondary terrestrial habitats (Table 3; Figure 8). Similar percentages make use of flowing water and of standing, open water habitats, but marshes and swamps appear to be used by fewer species. Forest-dwelling amphibians are more likely to be threatened than those occurring in any other habitats, with almost one-third of them being globally threatened. Almost 30% of amphibians associated with flowing water (generally streams) are threatened. Consequently, forest-associated amphibians that live along streams are particularly likely to be threatened, a combination that has also been associated with rapid declines worldwide (Stuart *et al.* 2004).

For tropical forests overall, 32% of Afrotropical species are globally threatened. However, in montane tropical forest, 43% of known species are threatened, compared with 23% in lowland tropical forest. These figures probably reflect smaller range sizes of montane species, and the lack of effective habitat conservation measures in many mountainous parts of the region.

Amphibians occurring in savannah and arid habitat are particularly unlikely to be threatened. Africa has 47% of the world's 484 savannah-associated amphibians, and 44% of the world's 94 arid-habitat species, but only 14% of the global total of 4,712 forest-dwelling species. Many of these "species" are in fact complexes of several species, and when these are disaggregated, the number of savannah amphibians will increase. In addition, the number of threatened savannah species can also be expected to increase as their habitats shrink and dry out (these habitats are especially vulnerable to climate change) and their ranges become smaller.

Reproductive Modes

Larval development is by far the most common reproductive mode in the Afrotropics (85% of species), compared with 10% for direct development and 2% live-bearing (this compares with the global picture of 68% larval development, 30% direct development, and 1% live-bearing) (Table 4). Although live-bearing is uncommon, the Afrotropics account for 36% of the world's known live-bearing amphibians, and all but one of the world's known live-bearing frogs and toads. However, it should be noted that the reproductive mode of many species is unknown, and more terrestrial breeders are likely to be identified (Rödel and Ernst 2002; Rödel *et al.* 2002).

In the Afrotropics, the percentage of globally threatened direct-developing amphibians is only slightly higher than for larval-developing species (at a global level, direct-developing species are much more likely to be threatened). The high percentage of threatened live-bearing species in the Afrotropics is a reflection of the high levels of threat to species in the genera *Nectophrynoides* and *Nimbaphrynoides*, many of which have very small ranges in fragile, primarily montane, and poorly protected, habitats.

MAJOR THREATS

As in other parts of the world, habitat loss is overwhelmingly the major threat to amphibians in the Afrotropics (Table 5; Figure 9), affecting over 90% of the threatened species. Other commonly recorded threats include invasive species, fire and pollution. Over-utilization appears to be a minor threat in the region (at least based on current knowledge), and disease, which is a very important factor in other parts of the world, is cited as a threat to only 2% of threatened species in the Afrotropics (although the amount of information on the chytrid fungus, and its pathogenicity, is very limited in the region).

In terms of the types of habitat loss that are impacting threatened amphibians in the Afrotropics, expanding croplands, vegetation removal (mainly logging), and urbanization / industrial development are approximately equivalent, and each is affecting more than 70% of threatened species. Livestock grazing has less impact (probably because it is more prevalent in regions of lower amphibian species richness, and in any case much of Africa has long been grazed by large wild mammals), and tree plantations also appear not to be a significant threat in most places (although this is a serious threat in South Africa and Swaziland). In

Reproductive mode	All Species	Threatened or Extinct Species	% Threatened or Extinct
Direct development	100	26	26
Larval development	819	190	23
Live-bearing	21	10	48
Not known	29	14	48

Table 4. *Afrotropical amphibians categorized by reproductive mode.*

Threat type	Threatened species	% Threatened species
Habitat loss	221	92
Agriculture – Crops	191	80
Agriculture – Tree plantations	18	8
Agriculture – Livestock	79	33
Timber and other vegetation removal	179	75
Urbanization and industrial development	177	74
Invasive species	52	22
Utilization	15	6
Accidental mortality	1	0.4
Pollution	30	13
Natural disasters	3	1
Disease	4	2
Human disturbance	1	0.4
Changes in native species dynamics (excluding disease)	2	1
Fire	50	21

Table 5. *The major threats to globally threatened amphibians in the Afrotropical Realm. Only present threats to species are tallied.*

parts of West Africa, planned mining activities might become increasingly serious as threats to important sites for amphibians (for example, in Guinea and Ghana).

A total of 84 species (18 of which are threatened) are recorded as being used for some or other purpose in the region (Table 6). The most commonly recorded reason for harvesting Afrotropical amphibians is for the international pet trade (especially in Madagascar), followed by human consumption (although the number of species used as human food is probably greatly under-recorded). Much of the harvesting of amphibians in the region is not considered to constitute a major threat to the species. Of the 84 species being harvested, utilization is considered to be a threat for 32 (of which only 15 are threatened species for which harvesting is believed to be contributing to deterioration in their status).

POPULATION STATUS AND TRENDS

Estimates of Population Trends

A summary of the inferred population trends of Afrotropical amphibians is presented in Table 7. For nearly all species, these trends are inferred from trends in the state of the habitats on which the species depend. Species with decreasing populations are typical forest-dependent species that can tolerate little disturbance to their habitats. The percentage of decreasing and increasing species in the Afrotropics is very similar to the global results. However, the percentage of species where the situation is stable is slightly lower, and the percentage for which it is unknown is slightly higher than the global averages (27% and 30%, respectively).

"Rapidly Declining" Species

The Afrotropics appears to have been shielded to some extent from the amphibian declines that are taking place in some other regions, with only 30 (6%) of the 470 globally "rapidly declining" species occurring within the region (a full list of all "rapidly declining" species is provided in Appendix IV and includes their occurrence within each of the realms). Most of the "rapidly declining" species are threatened primarily by the reduction of suitable habitat. Twelve of these are forest-obligate species from the Upper Guinea region of West Africa (see Essay 5.4), where habitat loss has been particularly severe. Another six are endemic to South Africa, where urbanization and agricultural intensification in key habitats has been relatively more severe than on the rest of the continent (see Essay 5.6). The remaining eight species are scattered widely across the continent in Cameroon, Gabon, Kenya, Madagascar (two species), São Tomé and Príncipe, Tanzania, and Zimbabwe.

The Afrotropics have three "rapidly declining" species, affected by severe over-harvesting. Two of these, *Mantella cowanii* (CR) and *Scaphiophryne gottlebei* (CR), both from Madagascar, appear to have declined due to over-collection for the international pet trade (Andreone *et al.* 2006). In the case of *Mantella cowanii*, it declined initially because of the loss of most of its habitat, but subsequently the remnant populations were hit by over-harvesting. The third species, the Goliath Frog *Conraua goliath* (EN) from Cameroon and Equatorial Guinea, has declined mainly due to over-harvesting for human consumption, though there is also some international trade.

So far, only one "rapidly declining" species undergoing an enigmatic decline has been recorded in the Afrotropics, namely the Kihansi Spray Toad *Nectophrynoides asperginis* (CR). This species, endemic to the spray zone of one waterfall in Tanzania, decreased initially because of the damming of an upstream river. However, its final catastrophic decline to probable extinction is believed to have been caused by the fungal disease chytridiomycosis (Krajick 2006), which has been implicated or suspected in most of the enigmatic declines worldwide. Globally, enigmatic declines account for 48% of the "rapid declines" worldwide, but for only 3% so far in the Afrotropics, though it is possible that additional enigmatic declines have not yet been detected. One suspected case concerns *Arthroleptides dutoiti* (CR) in Kenya. This species has the ecological characteristics of other species that have succumbed to chytridiomycosis elsewhere in the world, and now appears to be absent from former sites, even though suitable habitat remains. It is not listed as an enigmatic decline species here, as its decline might have taken place prior to 1980.

Leptopelis parkeri *(Vulnerable), a treefrog in the Family Hyperoliidae, is endemic to several mountain blocks in the Eastern Arc chain of Tanzania. It is a species of closed, intact rainforest, not surviving in seriously disturbed habitats outside forest, and is threatened by habitat loss as a result of expanding human settlements and agriculture, and the harvesting of wood. © David Moyer / Wildlife Conservation Society*

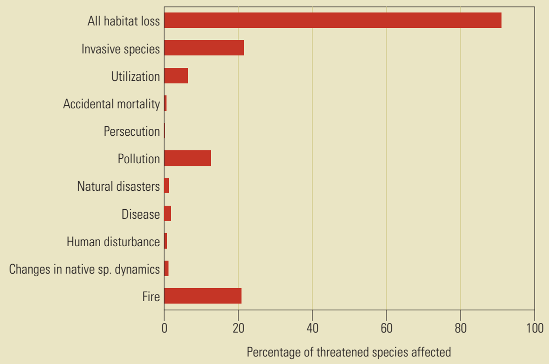


Figure 9. *The major threats impacting threatened amphibians in the Afrotropical Realm.*

Purpose	Subsistence	Sub-national/ National	Regional/ International	Number of species
Food – human	24 (4)	5 (2)	1	25 (4)
Medicine – human and veterinary	3	1	1	3 (0)
Pets, display animals	0	1	61 (15)	61 (15)
Research	0	1	1	2 (0)

Table 6. *The purposes for which amphibians are used in the Afrotropical Realm. The numbers in brackets are the number of species within the total that are threatened species.*

Population Trend	Number of species	% of species
Decreasing	425	44
Stable	221	23
Increasing	8	1
Unknown	315	33

Table 7. *The population trends for all extant Afrotropical amphibians.*

Family	Number of species in "rapid decline"	Percentage of species in family in "rapid decline"
Arthroleptidae	3	6
Bufonidae	5	5
Hemisotidae	1	11
Hyperoliidae	6	2
Mantellidae	1	6
Microhylidae	2	2
Petropedetidae	7	7
Ranidae	5	5

Table 8. *The number of species in "rapid decline" in the Afrotropical Realm by Family .*

The aptly named Tomato Frog Dyscophus antongilii *(Near Threatened) of the Family Microhylidae is endemic to north-eastern Madagascar. Although it is an adaptable species, being found in a variety of habitats from primary rainforest to disturbed urban areas, the pollution of waterbodies is a potential threat to this species. © Russell A. Mittermeier*

Endnotes

1 We follow the WWF biogeographic realms in this chapter, but recognize that this is not ideal for amphibians, especially with regard to the inclusion of the Arabian Peninsula within the Afrotropical Realm. The small Arabian amphibian fauna is generally of Palaearctic origin.

2 P<0.01 (binomial test)

3 At the time of writing, this species had been rediscovered in the Togo Hills (Leache *et al.* 2006), and been found outside its former range in the Atewa mountains (M.-O. Rödel, pers. comm.).

4 Although no amphibians have been found on the islands that make up the country Comoro, two undescribed species are present on the French island of Mayotte, which is part of the Comoro Archipelago (Vences *et al.* 2003). Because they are undescribed, they are not included in this analysis.

5 The genera *Euphlyctis* and *Hyla* occur only in the southern Arabian peninsula within the Afrotropical Realm, and not on the African continent south of the Sahara.

6 The only evidence for the occurrence of the genus *Rana* in Africa is the doubtfully valid *Rana demarchii* of unknown provenance in Ethiopia (Largen 2001).

7 The genus *Tomopterna* occurs marginally in the Palaearctic, as it is present in parts of the Sahara region; the genus is, however, essentially Afrotropical.

8 Frost *et al.* (2006) split the genus *Bufo* in Africa.

9 Frost *et al.*'s (2006) rearrangement results in 19 families in the Afrotropics, of which nine are endemic: Arthroleptidae; Brevicipitidae; Heleophrynidae; Hemisotidae; Hyperoliidae; Mantellidae; Ptychadenidae; Phrynobatrachidae; and Pyxicephalidae. However, in this section we follow the former taxonomic arrangement of families based on Frost (2004).

10 The only other species is the apparently extinct *Eleutherodactylus jasperi* from the Neotropics.

11 Frost *et al.* (2006) separate the genera *Breviceps*, *Balebreviceps*, *Callulina* and *Probreviceps* into a new family endemic to the Afrotropics: Brevicipitidae. Loader *et al.* (2004) consider that the genus *Spelaeophryne* also belongs with the brevicipitine group. Under this arrangement, all the African mainland species remaining in Microhylidae are larval developers.

12 Under the new arrangement by Frost *et al.* (2006), the genus *Amnirana* is the only remaining member of the Ranidae in the Afrotropics. The genus *Conraua* is moved to Petropedetidae, and *Euphlyctis* and *Hoplobatrachus* are transferred to the predominantly Indomalayan Dicroglossidae. *Ptychadena*, *Hildebrandtia* and *Lanzarana* are transferred to a new endemic Afrotropical family, Ptychadenidae, and the remaining Afrotropical genera previously considered to be in Ranidae are transferred to the endemic new family Pyxicephalidae.

13 It should be noted that the species of Ranidae that have been separated by Frost *et al.* (2006) as Pyxicephalidae have a clear center of endemism and species richness in southern Africa; these species appear to be on average more strongly threatened than other frogs in South Africa (Van der Meijden *et al.* 2006).

14 Indeed, since we concluded this analysis, Nago *et al.* (2006) added 17 new country records of amphibians from Benin.

15 However, Vences *et al.* (2004) show that even the *Ptychadena mascareniensis* on Madagascar represent a different species from the animals on the African mainland, but as the formal taxonomic amendments have not yet been made, we have not included this change in our analysis. When the formal taxonomic change is made, 100% of the amphibian species occurring on Madagascar will be considered to be endemic.

Unlike most other regions, the Afrotropical "rapidly declining" species show no distinct taxonomic pattern (see Table 8), with small percentages (less than 7% of the species) in all of the larger families.

KEY FINDINGS

- A total of 969 species are recorded from the Afrotropical Realm, of which 240 (nearly 25%) are considered threatened.
- At the species level, 954 amphibians (99% of those present) are endemic to the Afrotropics; of the 16 families found in the region, nine are endemic, and of 112 amphibian genera occurring, 105 are endemic.
- The percentage of threatened species is very high in the family Astylosternidae (72%), reflecting the poor state of forest conservation in the mountainous regions of Cameroon. On the other hand, certain families have lower levels of threat (Pipidae, Hemisotidae and Ranidae), all of which have a high proportion of adaptable species in the Afrotropics.
- Geographic concentrations of threatened species occur in the Upper Guinea forests from Sierra Leone to Togo; south-eastern Nigeria and south-western Cameroon; the mountains of the Albertine Rift; the Ethiopian Highlands; the Eastern Arc Mountains; eastern and southern South Africa (especially in the south-western Cape); and eastern Madagascar (especially at the northern and southern tips).
- Madagascar has the largest number of species of any country in the Afrotropical Realm (226 species). Only five other countries have more than 100 species (Democratic Republic of Congo, Cameroon, Tanzania, South Africa, and Nigeria), with all except Nigeria having more than 50 endemics. Madagascar, Cameroon, Tanzania and South Africa each have more than 20 globally threatened species. Madagascar has many more endemics than any other country.
- Among species occurring in tropical forests, 43% of species in montane tropical forest are threatened, compared with 23% in lowland tropical forest, probably reflecting smaller range sizes of montane species, and the lack of effective habitat conservation in montane regions. Africa has 47% of the world's 484 savannah-associated amphibians (yet only 3% of these species are threatened) and 44% of the world's 94 arid-habitat species (2% threatened).
- Habitat loss, primarily due to expanding croplands, vegetation removal (mainly logging), and urbanization/industrial development, is affecting over 90% of the threatened species in the region. Other commonly recorded threats include invasive species, fire and pollution; disease is cited as a threat to only 2% of threatened species.
- Only 6% of the 470 globally "rapidly declining" species occur within the region; 12 of these species are forest-obligate species from the Upper Guinea region of West Africa, where habitat loss has been especially severe.
- No amphibian extinctions have yet been recorded from the Afrotropics, but three species are possibly extinct.

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Scaphiophryne gottlebei *(Critically Endangered) is restricted to two localities near Isalo in south-central Madagascar. Like other members of the Family Microhylidae, it digs itself into the ground, as shown in this photograph. Over collection for the international pet trade could be a significant threat to this restricted-range species. © Franco Andreone*

ESSAY 5.1. SEYCHELLES AMPHIBIANS

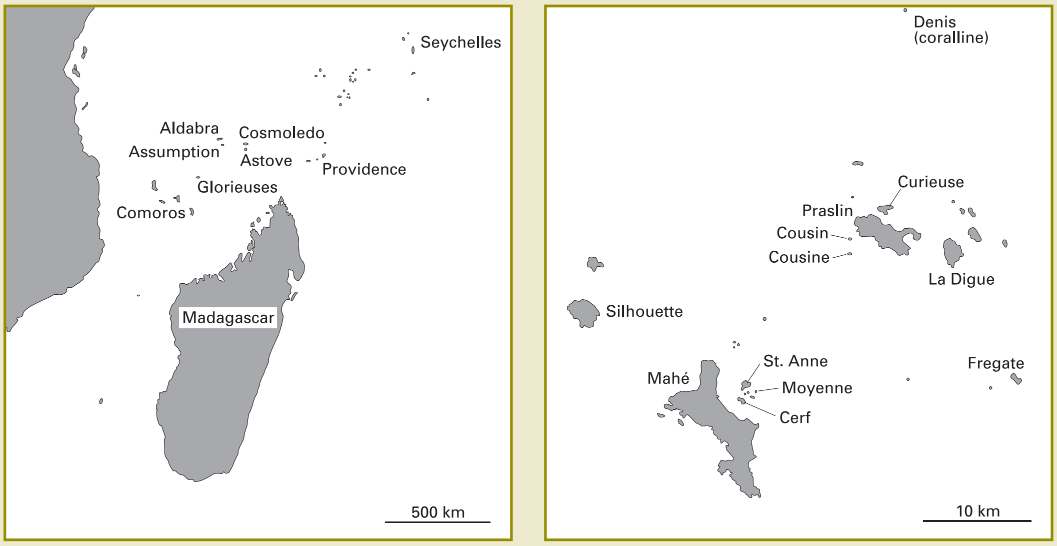

Figure 1. *Map of the Seychelles Islands.*

Due to their permeable skin few amphibians are able to tolerate dry or salty conditions, a characteristic that has prevented most species from colonising oceanic islands. The most diverse oceanic island amphibian fauna is found in the Seychelles, an archipelago of about 115 granitic and coralline islands in the Indian Ocean, some 1,600km east of mainland Africa, and northeast of the island of Madagascar (Figure 1). Eleven native amphibian species have been recorded from the Seychelles islands, comprising both recent colonists and ancient endemics. Recent colonization by one species, the Mascarene Grass Frog *Ptychadena mascariensis* (LC), is probably the result of human introduction (Vences *et al.* 2004) in the 1800s, whilst the endemic Seychelles Treefrog *Tachycnemis seychellensis* (LC) is believed to be descended from a natural colonist from Madagascar (Vences *et al.* 2003). The remaining species are all ancient endemics that have probably existed on the island since their isolation from the Indian landmass some 65 million years ago. These species comprise the endemic frog family Sooglossidae and seven species of burrowing caecilians (Order Gymnophiona).

Sooglossidae are an exceptional family in several respects. Four species are currently recognized in two genera, although recent morphological and molecular data suggests that a further three species remain to be described and that the genera need to be redefined. They are all small frogs, with Gardiner's Frog *Sooglossus gardineri* (VU) among several species up for contention as the world's smallest frog (with adults being as small as 9mm in length). All sooglossids are found in the damp forests of the two highest islands, Mahé and Silhouette. These habitats have only seasonal or fast-flowing stems, and the sooglossids have abandoned the normal frog life-cycle in favour of terrestrial development. The Seychelles Frog *Sooglossus sechellensis* (VU) lays its eggs on land and the female carries the tadpoles until they develop into frogs. *Sooglossus gardineri* is even more specialized, with the male guarding terrestrial eggs that hatch into 3-mm long froglets; the entire tadpole stage is passed within the egg. Thomasset's Seychelles Frog *Nesomantis thomasseti* (VU) has recently been discovered to have a very similar breeding strategy, but nothing is known of the reproductive behaviour of the Seychelles Palm Frog *S. pipilodryas* (VU). This latter species is the most recently described of the Seychelles amphibian species, having been discovered in 2000 (Gerlach and Willi 2002). It lives in the axils of endemic palms where it lay protected from discovery by the dense spines of the palm leaves. It is the only arboreal sooglossid, the other species all being associated with crevices in boulder fields or the leaf-litter and root-mat of the forest floor.

The caecilian fauna of the Seychelles islands comprises six species in three endemic genera. Not surprisingly, and as with caecilians in general (see Essay 1.3), these are the least well known of all Seychelles amphibians. Their burrowing habits make them difficult to locate and study. For most species, their distributions are reasonably well defined and there are some observations of breeding habits. Different species appear to show the full range of reproductive strategies, form aquatic larvae, thorough to terrestrial larvae and direct development. The limited ecological data available indicate that *Grandisonia alternans* (LC) is a widespread species occurring in all habitats and *Hypogeophis rostratus* (LC) is a similar generalist, although more associated with lowland habitats. In contrast, *Praslina cooperi* (VU) and some of the small *Grandisonia* species appear to be specialists of the high forest. Current research into this group is attempting to develop monitoring methods and to identify aspects of their ecology that are of importance to their conservation.

Half of Seychelles amphibians are threatened due to their naturally restricted ranges and deteriorating habitats (five species are categorised as Least Concern, 5 Vulnerable and one Endangered). The sooglossid frogs and the caecilian *Praslina cooperi* have particularly restricted ranges, being associated only with the damper rain-forests. Habitat deterioration is a significant threat to the caecilian *Grandisonia brevis* (EN), which has a restricted range and occurs in habitats that are suffering from ongoing invasion by alien plant species. In addition, there is some suggestion that changes in rainfall patterns may have impacts on some species, which may result from mid-year declines in rainfall restricting the activity and distribution of the rain-forest specialists (Gerlach 2000). Losses of several areas of marsh habitats have probably caused population declines in some species, such as another caecilian *Grandisonia alternans* (Gerlach 2000).

There have been a number of successful conservation programmes in Seychelles, concentrating mainly on birds. Critically Endangered species have been rescued from extinction by limited habitat management, but mostly by inter-island transfers. These programmes have been to the benefit of species such as the Seychelles Magpie-robin *Copsychus seychellarum* and the Seychelles White-eye *Zosterops modesta*. Such options are not available for the amphibians due to their close dependence on their high forest or marsh-land habitats. Consequently, preservation of their habitat is essential; most species are present in protected areas, although habitat management is still required to control the spread of invasive plant species. The island with the highest diversity of amphibians (Silhouette) is currently unprotected and designation of this island as a national park would significantly enhance amphibian conservation in Seychelles.

To date, there has been no evidence of any sudden amphibian decline in Seychelles, although the potential impact of an invasion by chytridiomycosis would be considerable. Monitoring programmes are in place for the frogs, and are being developed for the caecilians. Updates on research and conservation progress can be found at http://members.aol.com/jstgerlach/herps.htm

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Nesomantis thomasseti *(Vulnerable) is restricted to Mahé and Silhouette Islands in the Seychelles, and has been recorded from the Morne Seychellois National Park. © Naomi Doak*

ESSAY 5.2. THE ENDEMIC AND THREATENED AMPHIBIANS OF MADAGASCAR

Separated from mainland Africa by a sea channel of about 300km, the biodiversity of Madagascar has experienced a distinct evolutionary trajectory that has resulted in a very high degree of endemism in both its fauna and flora. Among the vertebrates, the amphibians of this large island (around 580,000km^2, the fourth in the world for size) are currently represented by more than 230 frog species[1], a number that is still preliminary and tentative, since many more remain to be discovered or are awaiting description (see Essay 1.1) (Figure 1). Remarkably, out of the entire amphibian fauna, only two species, the adaptable and widely distributed *Ptychadena mascareniensis*, which is present also in mainland Africa, and *Hoplobatrachus tigerinus*, introduced to Madagascar from southern Asia, are not considered to be endemic. Interestingly, recent molecular studies have shown that the *P. mascareniensis* populations from Madagascar are already sufficiently differentiated from those from mainland Africa, and likely represent a different species (Vences *et al.* 2003, 2004).

Malagasy amphibians are represented by four families of frogs (Gymnophiones and Urodeles being absent): Mantellidae, Microhylidae, Hyperoliidae, and Ranidae[2], with ranids being represented only by the aforementioned non-endemic *Ptychadena mascareniensis* and *Hoplobatrachus tigerinus* (Glaw and Vences 1994). Mantellidae is the most speciose group and is endemic to Madagascar and the Comoro Islands. This family includes the highly diverse genus *Mantidactylus* (with nearly 90 species), the well-known genus *Mantella*

(15 species), *Boophis* (53 species), *Aglyptodactylus* (3 species), and the monospecific genus *Laliostoma*. At the time of writing, *Mantidactylus* has been split into several genera (Glaw and Vences 2006), which differ significantly in aspects of morphology, life history and distribution: *Wakea, Blommersia, Guibemantis, Spinomantis, Gephyromantis, Boehmantis,* and *Mantidactylus*. As a general trait, *Mantidactylus* (sensu lato) and the closely related *Mantella* show peculiar reproductive features, such as the absence of amplexus and of nuptial pads in males, with eggs laid outside water, and the presence (in most species) of femoral glands, which are glandular structures on the inside of the thighs, and related to reproductive behaviour. They also exhibit a variety of life history traits, with species adapted to terrestrial, aquatic, and arboreal habitats (Andreone and Luiselli 2003). The diurnal *Mantella* species are characterized mainly by their bright aposematic colouration, small size, and accumulations of alkaloids in the skin. The *Mantella* species are, therefore, toxic, and are apparently rarely predated upon by other species, a situation similar in many respects to that of the Neotropical dendrobatid frogs (Clark *et al.* 2005).

In contrast to these frogs, amphibians in the genus *Boophis* are mainly arboreal species, breed in water, and have a typical larval development. Egg-laying usually occurs in streams, except for some species that reproduce in lentic waters (Aprea *et al.* 2004; Glaw and Vences 2006). Two further genera, *Aglyptodactylus* and *Laliostoma,* are mainly terrestrial and breed in temporary ponds, often breeding explosively during which time they form large aggregations. The genus *Aglyptodactylus* is also peculiar in having the males that assume a somehow bright yellow colouration during the breeding season (Glaw and Vences 1994, 2006).

Microhylidae are represented by 10 genera and more than 50 species with a diverse life history. The cophyline microhylids (belonging to the genera *Cophyla, Platypelis, Anodonthyla, Plethodontohyla, Madecassophryne, Rhombophryne,* and *Stumpffia*) are closely tied to rainforest habitats and have a reproduction that is characterized by the presence of parental care (for example, both the parents, or at least one of them, remain with the tadpoles during their development) and non-feeding tadpoles (Andreone *et al.* 2004). The genera *Dyscophus, Paradoxophyla,* and *Scaphiophryne* are different in this habitat preference, living mainly in open areas, but sometimes in arid and sub-arid conditions (Andreone *et al.* 2006a). Most of them are mainly terrestrial, although some species, such as *S. gottlebei* are partly rupicolous and able to climb vertical walls within the narrow canyons of the Isalo Massif (Andreone *et al.* 2005a). In particular, *Scaphiophryne* species have tadpoles that are largely filter feeding, with some peculiar specializations (see Mercurio and Andreone 2005).

The Malagasy Hyperoliidae includes the single endemic genus *Heterixalus* comprising eleven species, which inhabit grasslands and forest edges. They are quite similar in habitat preferences and general behaviour to other hyperoliids from mainland Africa (Glaw and Vences 1994).

Nine species of Malagasy frogs have been categorized as Critically Endangered according to the IUCN Red List Categories and Criteria, namely: *Mantella aurantiaca, M. cowani, M. expectata, M. milotympanum, M. viridis, Scaphiophryne gottlebei, Mantidactylus pauliani, Boophis williamsi,* and *Stumpffia helenae* (Andreone *et al.* 2005b). A further 21 species were classed as Endangered and 25 as Vulnerable. In general, the main threat affecting the local amphibian fauna is the high rate of forest loss (just less than 1% per annum; Harper *et al.* 2007) (Figure 2). The different life history traits of the amphibians are consequently mirrored by their differential ecological sensitivity and conservation needs (Andreone and Luiselli 2003). In fact, most of the Malagasy frogs inhabit the eastern rainforest, an ecosystem that allowed the rapid diversification of some groups, such as *Boophis, Mantidactylus* (sensu lato), and cophyline microhylids. The original eastern rainforest block is now severely fragmented due to deforestation, and this fragmentation has often resulted in high levels of threats among the native amphibian fauna (Figure 3). However, in some cases this loss in amphibian species richness is not immediately evident, because species have differing sensitivities to habitat alterations (Andreone *et al.* 2005b).

In addition to the threat of habitat loss, some species (e.g. those belonging to *Mantella, Scaphiophryne,* and *Dyscophus*) have been highly sought after for the international pet trade due to their biological peculiarities and remarkable colouration (Raxworthy and Nussbaum 2001; Andreone *et al.* 2006b; Mattioli *et al.* 2006). There is still a paucity of reliable data on the impact of trade on wild populations, although in some cases it is evident that collecting represents a confounding threat when the habitat is already compromised and the populations are small. This is the case, for example, for the rare harlequin mantella, *Mantella cowani,* which was collected in high numbers and survived in a very degraded environment on the high plateau of Madagascar (Andreone and Randrianarina 2003; Chiari *et al.* 2005). Fortunately, the collecting and exportation of this species, classified as Critically Endangered, are now banned, a measure that should reinforce its protection (Andreone *et al.* 2006b). Due to concerns about overharvesting for commercial trade, all frogs in the genus *Mantella* as well as the species *Scaphiophryne gottlebei* are now included on CITES Appendix II. Other species are also of conservation concern, such as the Tomato Frog, *Dyscophus antongili,* the only native species included on CITES Appendix I. Although its distribution area is wider than formerly believed (Andreone *et al.* 2006b), the habitat degradation around the town of Maroantsetra, where most known populations occur, is high. There is also evidence that the populations have apparently declined in numbers, and the species appears to have vanished from sites at which it was formerly known to occur (Chiari *et al.* 2006).

Fortunately, field surveys conducted during the last 15 years have revealed no known extinctions of Malagasy amphibians resulting from habitat loss, disease or other agents (Andreone *et al.* 2005b), as has been reported elsewhere. On the other hand, 12 highly threatened species now have their last remaining populations confined to a single site (Ricketts *et al.* 2005), and several of these sites, such as the Ankaratra Massif and Fierenana, remain unprotected. In general, the two areas with the majority of threatened species are the northern Tsaratanana-Marojejy-Masoala highlands and the southeastern Anosy Mountains (Andreone *et al.* 2005b).

Following the remarkable declaration by Malagasy president Marc Ravalomanana to triple the existing coverage of the island's protected areas network (see Figure 2), amphibians are now beginning to be considered in the identification of globally important sites for conservation (see Essay 11.3). This is all the more important since, as already noted, several highly threatened species experience no protection whatsoever. For example, of the nine Critically Endangered amphibians, six are not recorded from any protected area (Andreone *et al.* 2005b, 2006b). Amphibians also represent an excellent candidate to become a symbol for the conservation strategies in Madagascar. Indeed, it is clear that, as with lemurs, the frogs of Madagascar have the potential to become an important tool for the conservation of wildlife in Madagascar. This aspect, as well as long-term conservation planning, was the focus of a workshop (*A Conservation Strategy for the Amphibians of Madagascar*) held in Antananarivo in September 2006 specifically dedicated to the amphibians of Madagascar, and attended by more than 80 scientists and conservation practitioners.

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1 Although only some 226 species are currently classified through the Global Amphibian Assessment, several new species were recently described, including *Paradoxaphyla tiarano* from Masoalo Forest in north-eastern Madagascar (Andreone *et al.* 2006a).

2 The Ranidae were disaggregated into several families by Frost *et al.* (2006). In Madagascar, *Pthychadena* is ascribed to Ptychadenidae and *Hoplobatrachus* to Dicroglossidae. Thus, the number of families becomes five.

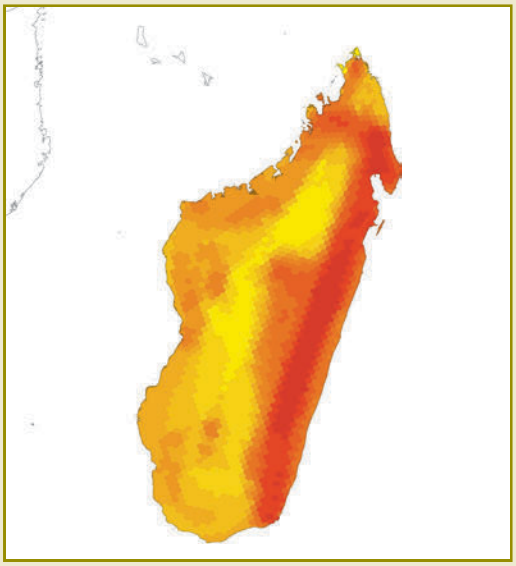

***Figure 1.** Richness map of amphibian species in Madagascar, with dark red colours corresponding to areas of higher richness. Colour scale based on 10 quantile classes. Maximum richness equals 91 species.*

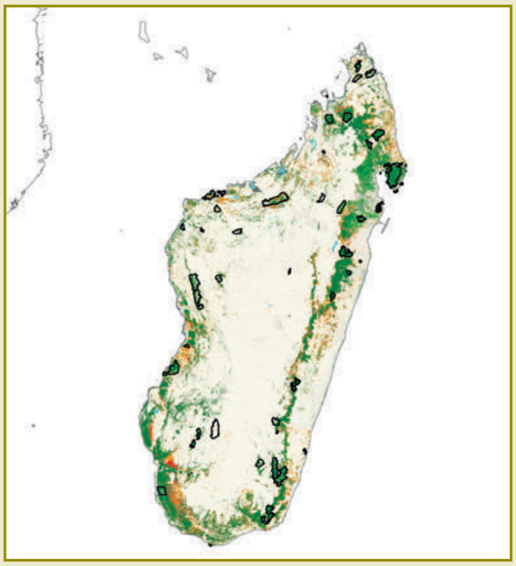

***Figure 2.** Forest cover map for Madagascar, and existing protected areas in black. Red corresponds to forest clearance between 1990 and 2000, brown to clearance between 1975 and 1990, and green to forest cover in 2000.*

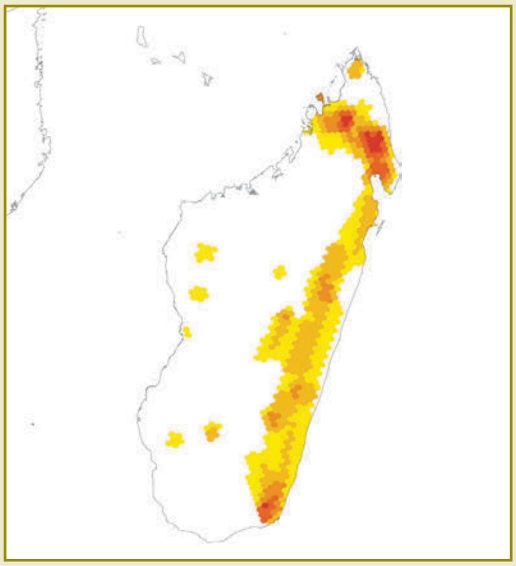

***Figure 3.** Richness map of threatened amphibian species in Madagascar, with dark red colours corresponding to areas of higher richness. Colour scale based on five quantile classes. Maximum richness equals nine species.*

ESSAY 5.3. FROG BIODIVERSITY IN CAMEROON

Around 200 species of frogs occur in Cameroon (Amiet 1989), including several unnamed taxa, but the final total could be as high as 210 due to limited knowledge of the extreme north and south-east of the country. Comparisons with the less well prospected neighbouring countries in central Africa are difficult, but the frog fauna of Cameroon is almost certainly the second most diverse in continental Africa, after the Democratic Republic of the Congo.

Components of Cameroon's frog fauna

Cameroon's frog fauna largely consists of four ecological components. The *savannah component* (*c.* 35 species) is associated with grassy and herbaceous habitats over a broad latitudinal extent, from the small savannahs near Yaoundé, north to the steppes around Lake Chad. Very few species occupy this entire area, most being distributed in latitudinal bands reflecting their different tolerances of drought. All have wide distributions outside Cameroon, and their tadpoles develop in still water.

The *montane component*, represented by about 50 species, many endemic, is restricted not only to mountains but also to high plateaus in western Cameroon. The boundary between this component and lowland faunas is between 800 and 1,200m. These species prefer forests or are indifferent to vegetation type, and for many the tadpoles develop in streams.

The *forest component* includes some 80 species that are generally confined to closed-canopy forest. These species depend mainly on ecological conditions created by a closed canopy, rather than on the exploitation history of the forest (primary or secondary), or on floristic composition. Amiet's (1989) study of the Yaoundé forest frog fauna showed that it consisted overwhelmingly of species living in leaf-litter (43%), or on vegetation (39%), with half of the water-dependent species associated with streams. This component includes many species and some genera that are, more or less, restricted to Cameroon, especially in the west.

The *"parasylvicolous" component* includes some 30 species confined to the forest zone and gallery forests in the savannah zone. These species do not live in intact forest, but in habitats that have been disturbed, either as a result of natural processes, or because of degradation by humans (Amiet 1989). Most of these species occur widely outside Cameroon, their tadpoles developing in still or slow-flowing waters.

There is also a small component of about six species that occur widely in the savannahs, and in degraded habitats in the forest zone, often in villages and large urban areas.

These components are not homogeneous, and can be subdivided into elevational zones (montane component) or latitudinal zones (savannah component). However, the limits of these zones are less clear than those that separate the components themselves.

Causes of the diversity of Cameroon's frog fauna

Several factors contribute to the high level of frog diversity in Cameroon. The first is the wide variety of natural conditions in the country. An old tourist advertisement boasts that Cameroon is "the whole of Africa in just one country", which is not an exaggeration. Diversity is boosted by interplay between climatic and geomorphological factors. The country covers over 12° of latitude, including most of the climatic gradient of western and central Africa north of the equator, from a very rainy equatorial to tropical climate (with rainfall decreasing as one goes northwards).

This pattern is modified by two major axes of relief. The first is the Cameroon mountain ridge, a series of massifs, often of volcanic origin with peaks over 2,000m, the highest being Mount Cameroon (4,095m). The ridge runs SSW-NNE, with numerous southern and western slopes exposed to the monsoon rains. The second is the Adamawa Plateau, which, at an altitude of 1,000-1,200m, crosses the entire country between 6° and 8°N, and has a relatively cool and humid climate. Thus, there is a complex patchwork of rainfall patterns in Cameroon, analysed in depth by Suchel (1972, 1988). In addition to affecting the overall climate, these high plateaus and mountain massifs also display vertical climatic zoning, resulting in the diversification of ecological conditions over very short distances.

While the diversity of current climatic conditions undoubtedly contributes to the diversity of Cameroon's frog fauna, climatic changes during the Quaternary are the main cause. These changes (see Maley 1996, 2001) resulted in repeated modifications to the distribution of bioclimatic zones, and have been a major cause of frog speciation, affecting in particular lowland forest and montane species. Lowland tropical and montane forests both experienced phases of expansion and regression. When habitats became fragmented, allopatric speciation took place in isolated areas, causing remarkable diversification in genera such as *Cardioglossa*, *Astylosternus* or *Leptodactylodon*, which include pairs and trios of closely related species. Some of these close relatives have remained allopatric, while others have become sympatric or even syntopic (Amiet 1980, 1987). However, Quaternary climatic changes are too recent to explain the presence of 15 genera, endemic, or largely endemic, to Cameroon (Amiet 1989). Most of these have tadpoles that develop in well-oxygenated, running water, a habitat that is plentiful in the hilly highlands of the west and south-west. These genera presumably evolved *in situ* during the formation of the Cameroon mountain ridge.

More recently, human impact on the environment has had favourable consequences on savannah and "parasylvicolous" species. Maintenance of savannahs by fire since the last episode of forest regression has aided the expansion of savannah species (for example, in the northern part of the southern Cameroon Plateau, which under current climatic conditions should be forest, but which is in fact dominated by savannah). In the forest zone, agricultural clearings have provided habitats favourable to "parasylvicolous" species, especially with the increasing destruction of forests since the start of the colonial period. Some "parasylvicolous" species of western origin, now quite common, were not found by the first collectors, and some of these might have reached Cameroon in the last 150 years, and continue to expand towards the east or south-east. Judging by the speed at which certain "parasylvicolous" species settle in newly opened forest sites, this hypothesis does not seem outlandish.

Geographic patterns of diversity

Figure 1 shows how the frog fauna is distributed in relation to the main bioclimatic units of the country. In regions Ic, II, Va and Vb, the numbers of species have probably been underestimated, but regions Ia, Ib and III will remain the centres of Cameroon's frog diversity. The high diversity in regions Ia and III is due to the large number of endemic and near-endemic species. Region III includes virtually all of Cameroon's montane species, none of which occur in other mountainous regions in Africa. Regions Ia and Ib include several "parasylvicolous" species (those in Ia and Ib being of "western" and "Congolese" origin, respectively). However, the higher diversity in Ia is due to the presence of several endemic species on the coastal plain, especially between the lower Sanaga and the Mungo rivers, and also south of the lower Nyong River (both probably being forest refugia during past climatic fluctuations).

Threats to Cameroon's frog fauna

The ecological conditions and the overall diversity and endemism of frogs vary across the regions of Cameroon, and this affects the threats facing the frog fauna. Moreover, future environmental changes in the context of the country's socio-economical and political situation need to be considered.

The frog faunas in regions IV, Va and Vb are not at great risk, despite these regions being greatly affected by human activity, as most of the species are adaptable. Conversely, in region II, the savannah species are, in theory at least, doomed to eventual extinction, as the forest should be expanding rapidly under current climatic conditions. However, the species in question also occur in regions IV and V, and forest species would presumably spread in region II.

The situation is much worse for the forest species in regions Ia, Ib and Ic, with the increasingly serious loss of forest, which seems inevitable due to lack of political commitment to conservation. However, frogs are less seriously affected than large mammals because, thanks to their small size, they are often able to survive in what little forest remains. They can also survive in areas of shifting cultivation where rotations allow for rapid recovery of the forest cover. Logging has limited impact as there is very little clear-cutting in Cameroon, but commercial tree plantations (such as oil palm) do have a very negative impact on forest frogs, and are especially prevalent in region Ia.

Region III has lost much forest, especially on the Bamileke Plateau. However, on the humid southern and western mountain slopes cleared forest can be replaced quickly by dense secondary vegetation suitable for many montane frogs (few species are completely dependent on intact forest). However, the tendency of the Bamileke and Banso peoples to clear large areas of habitat is alarming. For frogs living at very high elevations in open habitats, the threat level is low.

The Goliath Frog *Conraua goliath* (EN) requires particular mention as the only directly threatened frog in Cameroon. In the past it was sold in large numbers to at least one American importer for the ridiculous practice of jumping competitions. Now, these frogs, which used to be eaten only occasionally, have become prized game actively sought after, at least in the area of Nkongsamba (G. Renson, pers. comm.). Special traps have even been invented for catching this species, a victim of the current fad for bushmeat. With lack of law enforcement and endemic corruption, conservation measures are ineffective, and the future of the Goliath Frog depends on a change in food habits among local people.

The most effective measure of conservation for forest and montane frogs in Cameroon would be total preservation or restoration of a 30m-wide band of forest on both sides of water courses, whatever their size and location (including in commercial plantations). This solution, based on this author's 29 years of field research in Cameroon, would safeguard a huge portion of biodiversity in all taxonomic groups, and would contribute to quantitative and qualitative improvements in water reserves. Such a measure, if it were adopted, would require the means, and above all the political will, to implement in a resolute manner.

Jean-Louis Amiet

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Astylosternus ranoides (Endangered) is known only from western Cameroon, where it has been recorded from the Bamboutos Mountains, Lake Oku, and Mount Neshele, at altitudes of 2,000-2,600m asl. © Jean-Louis Amiet

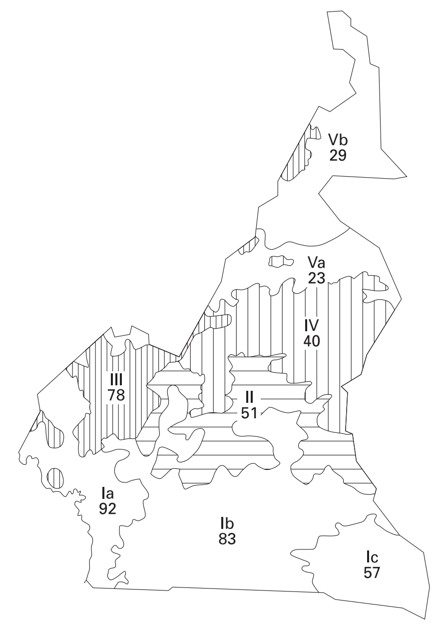

Figure 1. *Map of Cameroon showing the major bioclimatic regions, with the number of species recorded from each region. Key for bioclimatic regions: Ia: coastal plain tropical lowland forest (92 species); Ib: southern Cameroonian plateau tropical lowland forest (83); Ic: Congo basin tropical lowland forest (57); II: southern Cameroonian plateau gallery forests and Guinea savannah (51); III: Cameroon mountain ridge mountains and high plateaus (78); IV: Adamawa Plateau (40); Va: northern Cameroon Sudan savannah (23); and Vb: northern Cameroon Sudano-Sahelian savannah and Sahel (29). For methodology in defining these regions and estimating species totals, see (Amiet 1983).*

ESSAY 5.4. THREATENED ISLANDS OF AMPHIBIAN DIVERSITY IN WEST AFRICA

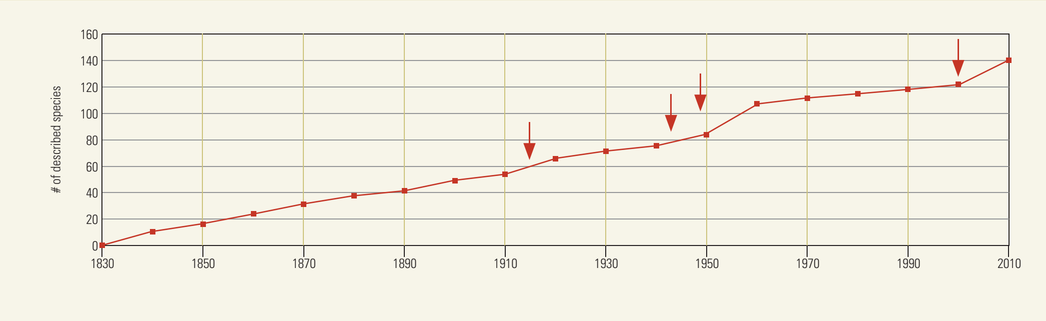

Figure 1. *Number of described West African amphibian species per decade (including known but not yet described new species for the last decade). Black arrows indicate the start of periods of more intensive survey and taxonomic work. These significant increases were mainly due to (arrows from left to right) P. Chabanaud; J. Guibé, M. Lamotte and co-workers; A. Schiøtz and J.-L. Perret and M.-O. Rödel and co-workers. With the exception of the 1960s (A. Schiøtz) new amphibian species have been described at a near constant rate of about 0.7 species per annum. Since 2000 the description rate increased to more than 1.8 species per annum and is not yet reaching any visible plateau, hence illustrating that the West African amphibian fauna still is far from being well known.*

West Africa, here defined as the region from Senegal in the west to Nigeria in the east and extending north to the southern border of the Sahara Desert, covers almost all larger African biomes, ranging from rainforests along the Atlantic Ocean's coast, over various types of savannahs to semi-deserts. In the border region of Guinea, Côte d'Ivoire, and Liberia, as well as within Sierra Leone, there are also several higher mountain ranges representing rare examples, at least in the West African context, of montane grassland.

Amphibian research in West Africa dates back to the middle of the 19th century. In general, the diversity of amphibians in West Africa is high, with around 175 amphibian species having been recorded from this region, including four caecilians and 171 anurans. While some forests may support as many as 40 different amphibian species in an area as small as 2 ha, amphibian richness is also high in some savannah formations (sometimes surpassing 30 frog species in only a few square kilometres). However, while new species have been described on a continual basis, species description curves have never attained any sort of saturation (Figure 1) suggesting that many new species remain undiscovered.

Around one-fifth of the region's amphibian fauna is considered to be threatened (34 species), including 14 species that are listed as Vulnerable, 16 Endangered, and four Critically Endangered. A further 19 species are classified as Near Threatened. The four Critically Endangered species include two species, *Nimbaphrynoides occidentalis* and *N. liberiensis*, known only from a few square kilometres on Mount Nimba's grassland mountain ridge and a very limited area in Liberia's rainforest on Mount Nimba's southern slopes, respectively. A third species, *Bufo taiensis*, is only known from four specimens collected from the region of Taï National Park in Côte d'Ivoire, while the fourth species, *Conraua derooi* (currently considered Possibly Extinct on the IUCN Red list), was described from, and only very recently rediscovered, in the southern part of the Ghanaian-Togolese mountainous borderline.

Many West African forest amphibians have very small ranges, possibly due to fluctuations in the region's forest cover (Wieringa and Poorter 2004). These fluctuations presumably also served as a catalyst for amphibian speciation and are a reason for today's high diversity. In the Pleistocene and pre-Pleistocene, rainforests were either increasing towards the north in humid periods or were shrinking to comparatively small forest refugia during drier periods (Falk *et al.* 2003). The recent distributions of West Africa's endemic frogs matches well with the rough location of these postulated forest refugia, namely south-western Ghana (Rödel *et al.* 2005), south-western Côte d'Ivoire (Rödel and Branch 2002), and the Mount Nimba area (Rödel *et al.* 2004; Figure 2).

However, new evidence lends support for a much finer grained picture, adding a few more distinct Pleistocene or Pre-Pleistocene forest remnants to the Upper Guinea highlands (Rödel *et al.* unpubl.). The Upper Guinea highlands region stretches from Sierra Leone and Guinea through Liberia to western Côte d'Ivoire, and forms part of the Guinean Forests of West Africa biodiversity hotspot (Bakarr *et al.* 2004). In order to understand West Africa's forest history and to reveal potentially overlooked centres of endemism, an accurate knowledge of the location of historical forest refugia is needed. Current research aims to locate these former forest refugia by investigating the relationships between various leaf litter frog species and populations from West African forests. The recent distribution patterns of these amphibians and the genetic divergences of populations of these frogs will help us to reconstruct the history of West Africa's forest cover (Hillers *et al.* unpubl.).

On this regional scale we have also started to analyse landscape characteristics such as climate, vegetation, altitude, and topo-diversity with respect to their potential influence on amphibian species richness. Our analyses have revealed positive correlations of species richness with rainfall, forest cover, and habitat diversity. Based on these three parameters, we have been able to model areas believed to harbour a high richness of amphibian species. These areas coincide with the aforementioned areas of former forest refugia, which hence would be not only islands of high endemism but also of corresponding high amphibian diversity (Penner *et al.* unpubl.).

Unfortunately, these areas are also among the most threatened regions in West African. South-western Côte d'Ivoire, the area with the most extensive tracts of remaining forest in the country, lost about 80% of its forests within the last 30 years (Chatelain *et al.* 1996). Guinea has little more than about 5% of its former rainforests left (UICN 1996), and many of its remaining forested mountain ranges are threatened by open-cast mining operations. Given the distributional limitations of many forest amphibians and the vast tracts of forest areas that have already been lost, it is not unreasonable to expect that several species have already gone extinct without having been discovered and described scientifically.

But even selective logging might be a severe danger to the endemic West African forest frogs. We have shown that habitat degradation markedly alters the composition of forest frog communities, and many endemic and range-restricted forest frogs do not prevail in logged or fragmented forests (Ernst and Rödel 2005). Moreover, not only does forest degradation negatively affect particular species, but it severely and non-randomly reduces the functional diversity of forest species assemblages, i.e., specific life history traits disappear (Ernst *et al.* 2006). The latter is particularly important for ecosystem renewal and reorganization following change and it provides adaptive capacity in a world of complex systems, and human-dominated environments. The loss especially concerns species with tadpoles that are dependant on larger stagnant or slow-flowing waters. In conclusion, West Africa still supports an extraordinary rich amphibian fauna, albeit restricted to steadily declining islands of diversity.

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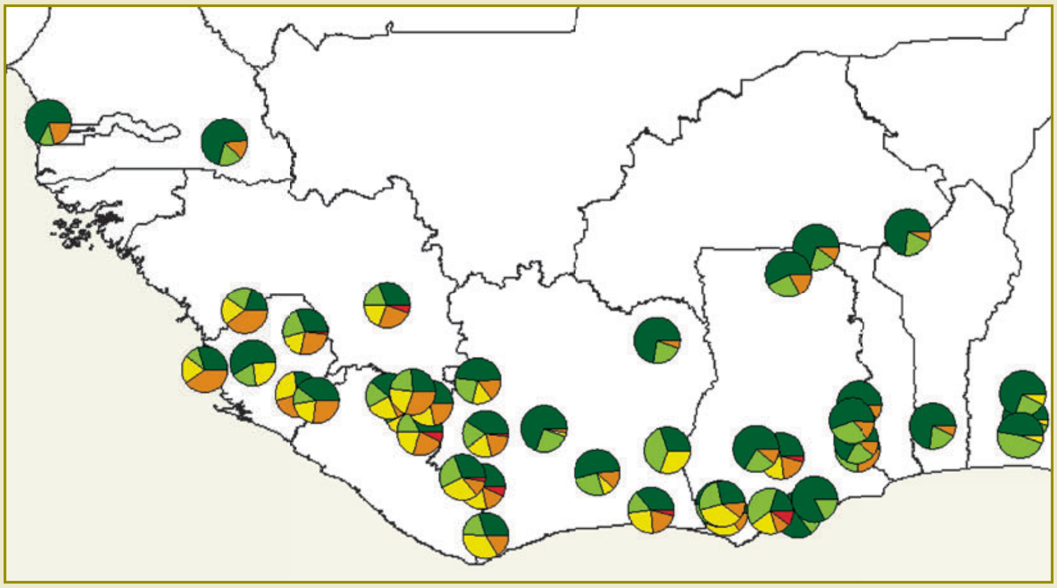
Figure 2. *Endemism of West African amphibian species. Shown are 42 well-known amphibian communities and the respective proportion of endemic species. The level of endemism ranges from local (red, e.g.* Nimbaphrynoides occidentalis, *estimated range: 111km²) and regional (orange, e.g.* Kassina lamottei, *13,002km²) endemics, to species that occur in the Upper Guinea forest zone (yellow), West Africa (clear green), Central and West Africa (green, e.g.* Phlyctimantis boulengeri, *294,445km²) to species with an almost sub-Saharan distribution (dark green, e.g.* Kassina senegalensis, *12,263,903km²).*



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ESSAY 5.5. THE AMPHIBIAN FAUNA OF THE EASTERN ARC MOUNTAINS OF KENYA AND TANZANIA

In 1983 three botanists – Jon Lovett, Roger Polhill and John Hall – were sitting together at the foot of the Uluguru Mountains discussing recent discoveries of rare plants in the Udzungwa Mountains, previously thought to be endemic to the Usambaras and Ulugurus (Lovett 1998). From the analysis they were making, it was clear that these rare forest plants were found only on the crystalline peaks of a series of isolated mountain ranges in south-eastern Kenya and Tanzania. These mountains were showing remarkable similarities in terms of species richness and composition and since they are set in a half-moon 'arc' shape, they decided to name them collectively as the Eastern Arc Mountains (Lovett 1998). The name first appeared in an article written by Jon Lovett for the Kenyan magazine *Swara*, in 1985.

The Taita Hills of Kenya and the Pare, Usambara, Nguru, Nguu, Ukaguru, Uluguru, Rubeho, Udzungwa, Malundwe and Mahenge Mountains in Tanzania comprise the Eastern Arcs. They lie within the intertropical montane region and were formed by heavily metamorphosed Pre-Cambrian basement rocks, rising to 2,635 m in elevation (Kimhandu peak in the Ulugurus). They are part of one of the Earth's richest biodiversity hotspots and amongst the most important regions in Africa for concentrations of endemic animals and plants, with at least 93 species of endemic vertebrate (Burgess *et al.* 2007).

The Danish batrachologist Arne Schiøtz published a short paper highlighting the importance of the basement hills of Tanzania (the name Eastern Arc was still to be coined) as a regional centre of amphibian endemism (Schiøtz 1981). The Eastern Arcs are home to about 94 named amphibian species, of which 57 are endemic or near-endemic. A further 17 species have been recently discovered and are awaiting formal description (all of which are probably endemic). A rough estimate, therefore, of the total number of amphibians (described and undescribed) in the Eastern Arc Mountains is 121 species, of which 74 occur are endemic or nearly so. The remarkable species richness and the high level of endemism is due to the great age of the Eastern Arc Mountains (they uplifted at least 30 million years ago), to their archipelago-like arrangement, and to the climatic influence of the Indian Ocean that kept the mountains relatively wetter and warmer than the surrounding areas during past climatic fluctuations. The high number of endemic species in small areas, the co-occurrence of recent and old lineages, and the consequent biogeographical implications make these mountains of extreme biological and conservation interest.

Historically, the Eastern Arc Mountains were probably covered by a mosaic of rainforests. These rainforests were concentrated mostly on the eastern slopes and on the upland plateaux and were interspersed with open grassland areas and with dry, semi-deciduous forests on the western slopes. The majority of endemic species occur in the wet forest that covered parts of the eastern slopes of the mountains. Although the forest environment has been well-studied, the grasslands and ecotones could represent a further frontier of batrachological exploration. At the southern tip of the Udzungwas, the so called 'Makambako gap' has long been considered the southernmost limit. However, recent cross-taxon studies are revealing that the Southern Highlands, especially the forests of Mt Rungwe and Livingstone, also contain many species previously assumed to be endemic to the Eastern Arcs. For example, amphibian species such as *Nectophrynoides viviparus* (VU), *Nectophrynoides tornieri* (VU), and *Leptopelis barbouri* (VU) demonstrate Mt Rungwe's Eastern Arc affinities (Davenport *et al.* 2003).

Recently, molecular analysis has shown that a number of genera and species in the Eastern Arc Mountains are genetically ancient. For example, DNA sequence data of caecilians, including Eastern Arc species, suggest that the origin of the caecilian fauna of Africa may 'predate the break-up of Gondwana' (Wilkinson *et al.* 2003). Similar suggestions are made concerning the microhylids and brevicipitids fauna of Africa based on DNA sequence data, which have exposed the extremely ancient age of these lineages (Loader *et al.* 2004). The present pattern of distribution and the presence of recent and old lineages could be interpreted as a consequence of stable local conditions, and to some degree the pattern can be attributed to local speciation or to local low extinction rates – in other words, long species persistence (Lovett *et al.* 2004).

Among the taxa occurring in the Arc, forest bufonids are of particular interest with a number of endemic genera and species like the extraordinary *Churamiti maridadi* (CR), with its shining skin resembling wet lichen, or the bicoloured *Nectophrynoides viviparus.* Ongoing molecular studies on forest bufonids are revealing the presence of lineages of East African origin as well as others derived from Guineo-Congolian taxa and ancient African-Asian linkages. Forest bufonids in the Arc are revealing a much more abundant species radiation than expected with several new species and genera awaiting description.

Many of the endemic species are confined to high-elevation sites and their distribution pattern may be due to relictualization. Other endemic species demonstrate intriguing and highly restricted ranges, deserving of special conservation strategies. These species display a 'single site' distribution, since they are confined to a single valley or parts of it, at certain elevations, and yet are surrounded by apparently suitable habitat. In just the Uzungwa Scarp Forest Reserve there are three strictly endemic species showing such distribution patterns: two dwarf forest bufonids, *Nectophrynoides wendyae* (CR) and *N. poyntoni* (CR), and the treefrog *Hyperolius kihangensis* (EN)(Menegon and Salvidio 2005). Another 'single site' species is the Kihansi Spray Toad *Nectophrynoides asperginis* (CR) occurring only in the Kihansi gorge, and now possibly extinct in the wild. This species is adapted to the peculiar habitat influenced by the constant spray provided by waterfalls. In this case, the small distribution is explained by the extremely peculiar local conditions in the lower Kinhasi gorge. The other three species inhabit sites with no apparent special conditions; they have been sought unsuccessfully in other suitable sites within the same forest patch. Differences thus exist between assemblages at sites at similar altitudes in adjoining mountain fragments or within single fragments, indicating a fine-scale geographic turnover in the herpetofauna of these areas.

The distinct nature of the herpetofauna species assemblages at high altitude, and the high elevational turnover of species, clearly demonstrates the importance of conserving forest at all altitudes. Areas of forest or marginal habitats, at all elevations, might also be vital in generating high species diversity, and need to be considered in the development of a holistic conservation strategy for the area. This suggests that not only is it important to conserve the forest along an elevational gradient, but it is also important to conserve fragments in geographically complex terrains, where isolated populations and therefore potentially new species may still exist, and are awaiting discovery.

Michele Menegon and Tim Davenport

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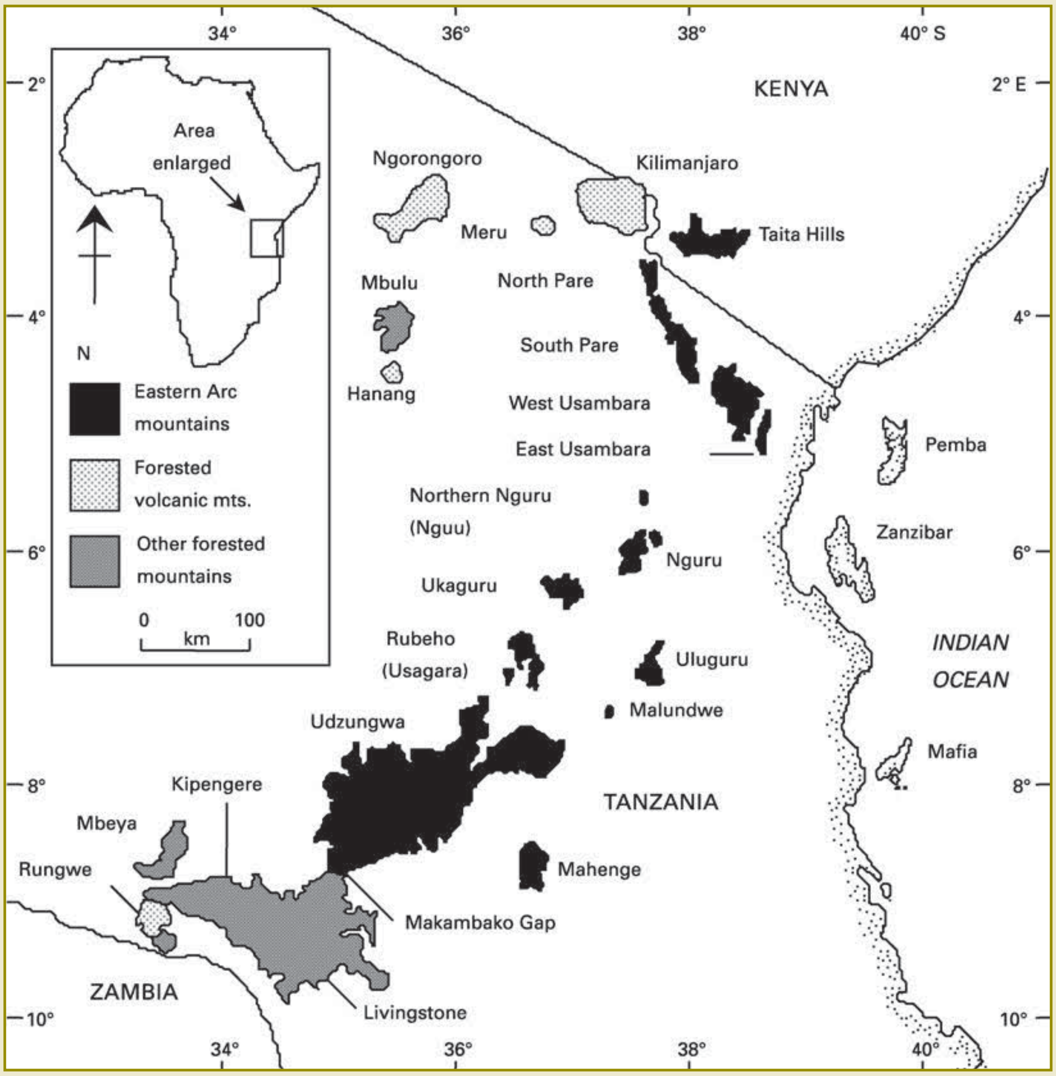

Figure 1. *Map showing the 13 blocks of the Eastern Arc Mountains of Tanzania and Kenya (reproduced, with permission, from Moyer 1993).*

ESSAY 5.6. THREATENED AMPHIBIANS OF SOUTHERN AFRICA

Although many species of amphibians have been described from Africa in recent years, amphibians as a group remain poorly known relative to other vertebrate taxa. An exception is South Africa, which has perhaps the best-studied fauna in the region, culminating in the *Atlas and Red Data Book of the Frogs of South Africa, Lesotho and Swaziland* (Minter *et al.* 2004). The larger southern African region, including Botswana, Namibia, Mozambique, Malawi and Zimbabwe, is home to 185 species of amphibians, of which 32 species (17%) have been assigned a status of conservation concern, including five as Critically Endangered, 16 as Endangered, and 11 as Vulnerable.

These threatened species have several things in common: they mostly occupy small areas, either on coastal plains, or in highland or montane grasslands or forests. The coastal areas are preferred localities for housing developments, and for farming wheat and other crops. The highlands and mountains are areas with high rainfall, and are selected for planting huge tracts of pine plantations. These threatened species evolved on highlands where there was sufficient moisture, often separated from other highlands by dry plains. The moist conditions that promoted speciation, thereby assisting the formation of a rich diversity of amphibians (see, for example, Channing *et al.* 2002, 2005; Clarke & Poynton 2005) are the same environmental conditions that are suitable for growing trees and other crops. Agriculture leads to severe habitat modification and fragmentation. All the well-known areas planted with exotic pines, such as the Amatola Mountains, the Elandsberg Mountains, and even Table Mountain in Cape Town, are home to endemic species of amphibians that are now threatened with extinction due to habitat loss and conversion. Furthermore, many of these species may be at risk of infection with the fast-spreading chytrid fungus, which is responsible for the extinction of amphibian species in many parts of the world (Daszak *et al.* 1999; Mendelson *et al.* 2006).

One-quarter of threatened species do not have normal life-cycles with free-swimming tadpoles. Instead, their tadpoles remain within the egg, and develop directly into small frogs. This negates the need for nearby pools of water, enabling these species to survive in areas where there is little chance of pools forming, such as in very sandy areas, forests and mountain tops. However, the species with tadpoles display some very unusual breeding strategies: some deposit eggs out of water, and the tadpoles must either move to water, or wait until the nest is flooded. The tadpoles of these species also display a range of adaptations. Most develop in streams or quiet pools, but the tadpoles of Broadley's Ridged Frog *Ptychadena broadleyi* (EN) live on wet rocks in forests, and both species of ghost frogs *Heleophryne* sp. have tadpoles that develop in fast-flowing rocky streams. The tadpoles hang onto rocks in these turbulent habitats by using a large sucker-like mouth. The Chirinda Toad *Stephopaedes anotis* (EN) breeds in small pockets of water trapped in tree-holes.

Protected areas have proved to be the most important conservation tactic in southern Africa, provided that the conservation area is large enough to include a viable population size of the threatened species. Protected areas that provide a haven for globally threatened amphibians include: Inyanga National Park, Chimanimani National Park and Chirinda Forest on the eastern highlands of Zimbabwe (*Afrana inyangae*, EN; *Bufo inyangae*, EN; *Arthroleptis troglodytes*, CR; *Probreviceps rhodesianus*, EN; *Stephopaedes anotis*, EN; *Strongylopus rhodesianus*, VU); Mt Mulanje Forest Reserve in Malawi (*Afrana johnstoni*, EN; *Nothophryne broadleyi*, EN; *Arthroleptis francei*, EN; *Ptychadena broadleyi*); Nyika National Park in Malawi (*Bufo nyikae*, VU), and Table Mountain National Park (*Capensibufo rosei*, VU; *Heleophryne rosei*, CR) on the Cape Peninsula of South Africa. Smaller reserves occur along the south and east coasts of South Africa, though these may not be adequate to sustain viable populations of threatened species in the region, such as Knysna Spiny Reed Frog *Afrixalus knysnae* (EN), Natal Spiny Reed Frog *Afrixalus spinifrons* (VU), and Pickersgill's Reed Frog *Hyperolius pickersgilli* (EN).

Several threatened species occur almost entirely within strictly managed, albeit different, areas. For example, the Cape Platanna *Xenopus gilli* (EN) occurs within the well-established Table Mountain National Park, with other populations in the newly proclaimed and still developing Agulhas National Park. However, even within these national parks, its security cannot be guaranteed, principally due to hybridization with the Common Platanna *Xenopus laevis* (LC) (Kobel 1981; Picker *et al.* 1996) although the extent of this problem may be limited (Evans *et al.* 1997). The Desert Rain Frog *Breviceps macrops* (VU) occurs in a narrow coastal zone along the west coast of South Africa and southern Namibia. This is a diamond mining area where access is restricted, and no development is permitted. However, the diamonds are mined by removing all the old beach sand above the bedrock. This effectively destroys the habitat where this species is found. Of course, even within many protected areas, a lack of management means that natural forest is still being removed, and agricultural activities (both subsistence and large-scale) have been reported from within these. Most (81%) threatened species occur largely (72%) or entirely (9%) outside of any conservation area.

Active protection of threatened species does occur in some cases, as in the Western Cape province of South Africa, where CapeNature was able to both thwart construction plans for a road that would have had devastating impacts on the breeding habitat of the Critically Endangered Micro Frog *Microbatrachella capensis*, and establish a new breeding site. This species is also being actively monitored by CapeNature, although continual active intervention by local authorities is required to halt the damaging effects of alien invasive plants on the breeding sites. As far as can be determined, the only threatened species that are subject to official long-term monitoring activities are Rose's Ghost Frog *Heleophryne rosei* (CR), the Micro Frog, and Cape Platanna. Among local conservation authorities, only CapeNature seems to be paying sufficient attention to the problem of threatened amphibians. In many other protected areas, including those to the north of southern Africa, it is not unusual for staff of reserves to be unaware of the importance of their reserve as a haven for a population of a globally threatened species.

Conservationists are able to determine effectively which species are threatened. We are also able to determine which species require the most appropriate conservation response, be it the establishment of a protected area or controlling invasive species. However, it seems that we are unable to initiate long-term programmes involving active management. Will we sit on the sidelines and tick off the species as they become extinct? Where there was once a rallying call from African conservationists, 'Save the Rhino!", we now need to encourage a 'Save the Frog!" campaign.

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Afrana johnstoni (Endangered) is known only from montane grassland and forest habitats on Mount Mulanje in southern Malawi. © Alan Channing

Table Mountain National Park on the Cape Peninsula of South Africa is home to the only known population of the eponymous Table Mountain Ghost Frog Heleophryne rosei *(Critically Endangered), a cryptic species found from 240-1,060m asl. © Richard Boycott*

CHAPTER 6. AMPHIBIANS OF THE AUSTRALASIAN REALM

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THE GEOGRAPHIC AND HUMAN CONTEXT

The Australasian Realm as defined here includes Australia and New Zealand, and subsumes the Papuan Sub-region incorporating the Solomon Islands, Papua New Guinea and parts of Indonesia (Papua Province on the island of New Guinea, and the Malukus, including the islands of Halmahera, Ceram, Obi, Misool, Aru, Ambon, Buru and Kai). The Oceanic Region, which includes islands in the northern and eastern Pacific Basin, is usually treated as a separate biogeographic region (Olsen *et al.* 2001), but as it has only three native amphibians occur in the region (two in Fiji and one in Palau) and their evolutionary affinities are with Australasian taxa so it is combined with Australasia for the purpose of this analysis.

The Australasian continental plate includes mainland Australia, the island of Tasmania and the southern half of the island of New Guinea. It was part of the southern landmass of Gondwana until about 96 Ma, though connections with Antarctica and South America continued until more recently. The Indo-Australian Plate started drifting northwards (with the Indian and Australasian portions separating), colliding with the Eurasian Plate to the north approximately 15 Ma, and creating the uplift that formed New Guinea's spectacular mountainous spine. Much of New Guinea, particularly the northern portions, is a complex mosaic of 'terrains', fragments of the earth that have embedded onto the mainland at different times, each with different origins and ages of impact. This incredibly complex geological history and one of the most active orogenies on earth has resulted in a spectacularly diverse topography and fauna in a relatively small area. The Torres Strait, a shallow water body that now separates Australia from New Guinea, has formed a bridge between the two land-masses on several occasions in the past during glacial periods when global sea levels were lower. The most recent land connection between Australia and New Guinea lasted until about 7,000 years ago. Tasmania was similarly connected to the Australian mainland during times of glacial maxima when Bass Strait was exposed. The islands of Wallacea form the western boundary of the region. These islands enabled cross colonization of plants between Southeast Asia and Australia-New Guinea but the deep ocean straits between islands appear to have hindered the exchange of many groups of amphibians (though some dispersal appears to have taken place due to tectonic accretion, for example allowing *Oreophryne* to reach Sulawesi from the east, and *Rana* to reach New Guinea from the west).

Around 85 Ma, a land mass known as Tasmantis broke away from Australia. All that now remains of this largely submerged landmass is New Zealand at its southern end and New Caledonia at the northern end. Located on the south-eastern boundary of the Australian plate where it converges with the Pacific plate, New Zealand consists of two main islands, called the North and South Islands, and a number of smaller islands. Its position on the boundary of two converging plates is reflected in the many active volcanoes on the North Island.

Australia is one of the flattest countries in the world. Because it lies in the middle of the Australian tectonic plate there has been very little geological activity since the plate separated from Gondwana. Instead the landscape has been moulded by constant weathering and erosion over millions of years. The highest peak is Mount Kosciuszko (2,228m) in the Snowy Mountains of New South Wales; these form part of the Great Dividing Range, which runs north-south along nearly the entire east coast of the country. This mountain range promotes significant rainfall along the east coast, but substantially prevents rainfall from the Pacific Ocean reaching the interior. Hence, the east coast includes a wide range of wet forest habitats (especially in the more mountainous areas), but the vast interior of Australia, stretching all the way to the west coast, is predominantly desert, semi-desert or savannah. The north of the country is tropical, and is dominated by savannah, eucalypt woodland, grassland, and desert habitats, with rainforests being found along parts of the east coast (mainly in mountainous regions) and in pockets scattered further west. There are significant areas of rocky escarpment country in the Kimberley and Arnhem Land. Temperate climates are found only in the south-east and south-west corners of the country. Inland droughts lasting several seasons are not uncommon as rainfall can be highly variable and patchily distributed.

The island of New Guinea is divided politically, with the eastern half of the island along with many islands off the north and east coast (including Admiralty and Bismarck archipelagos, and the islands of Bougainville and Buka in the Solomons Archipelago) forming the country of Papua New Guinea, and the western half of the island belonging to Indonesia. A wide, east-west range of mountains dominates the interior of the island, with the highest peak being snow-covered Puncak Jaya (5,030m) in Papua, Indonesia. To the north and south of the central mountains are vast lowland rainforests and complex wetland habitats. These are most conspicuously developed in the Trans-Fly region of south-central New Guinea where seasonally flooded savannah grasslands form a habitat unique in New Guinea (but typical of northern Australia).

New Zealand is geographically very isolated, the closest countries being Australia some 2,000km to the west, and New Caledonia, Fiji and Tonga, between 1,400 and 2,000km to the north. Mountains cover about two-thirds of the South Island and 20% of the North Island, the highest peak being Aoraki/Mount Cook (3,754m) on the South Island. On either side of the central mountain ridges are rolling fertile plains, and due to its southerly latitudes the country has a temperate climate. Rainfall is generally moderate to high in New Zealand.

Human population density is very low throughout the Australasian Realm. The Solomon Islands have the highest population density (17 people/km^2), followed by New Zealand (15), Papua New Guinea (11), Indonesia (Papua Province only: 6) and Australia (less than 3). Indonesia is the fourth most populous country in the world, but only 1% of Indonesians live in Papua Province, even though the landmass of Papua constitutes around 22% of the total landmass of the country. Population growth is high (over 3% per annum) in Papua Province, partly due to a high birth rate but also due to immigration from other provinces of Indonesia. The Solomon Islands and Papua New Guinea also have growth rates above 2% (approaching 4% in many coastal areas), but Australia and New Zealand have growth rates that are less than 1% per annum.

New Guinea has been subject to relatively low anthropogenic disturbance and it has been stated that around 70% of the natural environment on the island remains intact (Mittermeier *et al.* 2002), although some parts of the island have experienced serious habitat loss (and the level of loss is likely to be higher than has been realised). The extensive tropical rainforest wilderness on the island is the world's third largest rainforest block after the Amazon and Congolese forests. However, logging concessions now cover much of the lowland forest in New Guinea and nearly all of New Britain; unsustainable logging is the most immediate threat to the biodiversity of these regions. In Papua New Guinea the majority of people still practice subsistence agriculture and live in traditional societies, and the GDP per capita is low ($2,400 in 2005). The Solomon Islands has a similarly low GDP per capita ($1,700 in 2002), and Indonesia ($3,700 in 2005 averaged across the whole country, not just Papua Province) is only slightly higher.

Ceratobatrachus guentheri *(Least Concern) is an abundant direct-developing ranid frog from the Solomon Islands and Bougainville and Buka Islands in Papua New Guinea. It inhabits the forest floor in tropical rainforest, and persists in secondary forest, rural gardens and other degraded areas. © Piotr Naskrecki*

Australia has a very low human population density, but with the majority of the people living along the east and south-east coast, coupled with the high GDP per capita, habitat loss and degradation has been particularly serious in these regions. There has also been extensive habitat loss in south-western Australia (which is a Mediterranean-type system). Likewise, New Zealand has experienced significant habitat loss and degradation with natural habitats covering only 22% of the country. Invasive species have had a significant impact on native species both in Australia and New Zealand.

GLOBAL CONSERVATION STATUS

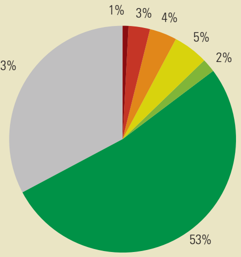
There are 544 amphibians currently recorded from the Australasian Realm, 69 (13%) of which are considered globally threatened or Extinct. This is much lower than the global average of 33%[1]. However, the number of DD species, 178 (33%), is much higher than the global average of 23%. As sufficient information becomes available to assess these species, it is expected that some of them will contribute to an increase in the percentage of threatened species in the region.

The Australasian Realm accounts for only 3% of globally threatened amphibians, which is relatively low considering that 9% of the world's amphibian species occur here. The region contains 4% of the CR, 3% of the EN and 4% of the VU species in the world.

Of the world's 34 known amphibian extinctions, three occurred in the Australasian Realm and all of them were species endemic to Australia. The only two species within the family Rheobatrachidae are now both Extinct: the Southern Gastric-brooding Frog *Rheobatrachus silus* was last seen in the wild in 1981 (Richards *et al.* 1993), while the Northern Gastric-brooding Frog *Rheobatrachus vitellinus* was last recorded in the wild in 1985 (Ingram and McDonald 1993; McDonald and Alford 1999) (see Essay 6.1). The third Extinct species, *Taudactylus diurnus*, has not been recorded in the wild since 1979 (Czechura and Ingram 1990). The reason(s) for the decline of all three species has still not been confirmed despite extensive research (Tyler and Davies 1985), but the disease chytridiomycosis (which was unknown at the time of these extinctions) must now be suspected. In addition, there are five Critically Endangered species that are considered Possibly Extinct (*Litoria castanea*, *Litoria lorica*, *Litoria nyakalensis*, *Litoria piperata* and *Taudactylus acutirostris*). This represents 4% of the global total of 130 Possibly Extinct species.

Figure 1. *Summary of Red List categories for amphibians in the Australasian Realm. The percentage of species in each category is also given.*

Red List Category	Number of species
🟥 Extinct (EX)	3
Extinct in the Wild (EW)	0
🟥 Critically Endangered (CR)	16
🟧 Endangered (EN)	21
🟨 Vulnerable (VU)	29
🟩 Near Threatened (NT)	10
🟩 Least Concern (LC)	287
⬜ Data Deficient (DD)	178
Total Number of Species	**544**



SPECIES RICHNESS AND ENDEMISM

Species Richness and Endemism Across Taxa

There are 544 amphibian species occurring in the Australasian Realm (9% of the world's total). Only one of the three orders of amphibians, the Anura, is found here but of the seven anuran families native to the region, four are endemic. The level of endemism increases at the generic level, with 90% (45 of 50) of genera endemic, and again at the species level, with 99% (538 of 544) of species endemic.

The high level of endemism is largely due to the insular nature of the region. The boundary between Australasia and Indomalaya is also defined here in a manner that minimizes the number of amphibians occurring across both regions. Whereas the boundary between the Australasian and Indomalayan realms is often taken as Wallace's line (an imaginary line running between Borneo and Sulawesi and Bali and Lombok in Indonesia; e.g. Newton 2003), the boundary is here taken to lie further to the east between Sulawesi and the Maluku islands (approximating Tyler 1999a), as this reflects amphibian distribution patterns better.

Seven of the world's 48 amphibian families are found in the region, and four of these are endemic: Leiopelmatidae, Limnodynastidae, Myobatrachidae, and Rheobatrachidae. The characteristics of these families are provided in Chapter 1[2]. There have been various taxonomic arrangements of the families defined here as Limnodynastidae, Myobatrachidae and Rheobatrachidae. Limnodynastidae and Rheobatrachidae are sometimes included as subfamilies of Myobatrachidae, with the species defined here as members of the Myobatrachidae included in the subfamily Myobatrachinae (Heyer and Liem 1976). Another taxonomic arrangement recognizes two families, separating the Limnodynastidae as a separate family from the Myobatrachidae (Zug *et al.* 2001; Davies 2003a, b; Iskandar and Colijn 2000). The Rheobatrachidae were placed in a separate family by Laurent (1980, 1986), and these three separate families are recognized here.[3]

The three non-endemic families occurring in the region are Microhylidae, Hylidae, and Ranidae. Together, these three non-endemic families contain 77% of the region's species. The family with the largest number of species in the region is Microhylidae with 197 species (all endemic), and representing 46% of the family's global species diversity. Most of these species are found on New Guinea, and comprise almost half of the total amphibian fauna on the island. There are 19 genera of the Microhylidae in the region, which represents 28% of the family's generic diversity. All of these are endemic to the region except for the genus *Oreophryne* which occurs as far west as the Philippines. The three most speciose genera are *Oreophryne* (34 species in the region) that within Australasia is restricted to the Papuan sub-region, and *Cophixalus* (35 species) and *Austrochaperina* (24 species) both of which occur in Australia and in the Papuan sub-region. All microhylids occurring in the region have a reproductive strategy in which embryonic and larval development occurs entirely within the egg capsule and they do not rely on free-standing water for breeding.

The second largest family in the region is the Hylidae[4] with 161 species, of which 159 are endemic to the region (representing 20% of the family's global species diversity). Three hylid genera, representing only 6% of the global diversity at the genus level, are represented in the region. The largest genus, and the only one not endemic to the region, is *Litoria* (124 species), which ranges across Australia and the Papuan sub-region. Two of the species in the genus occur in both the Australasian and Indomalayan regions (*Litoria infrafrenata* and *L. rubella*) and one is endemic to the Indomalayan region (*Litoria everetti*). The second largest genus, *Nyctimystes* (24 species), also occurs in Australia and the Papuan sub-region while the smallest genus, *Cyclorana* (13 species), is endemic to Australia. All hylids occurring in the region lay eggs in water where free-swimming larvae develop until metamorphosis.

The remaining non-endemic family occurring in the region is the globally widespread Ranidae, represented in the region by 59 species (55 endemic) comprising 9% of the global species diversity of the family. Within Australasia ranids are primarily found in the Papuan sub-region with only one species, *Rana daemeli*, extending its range into Australia. The three native amphibians of the Oceanic Region are members of the region's most speciose ranid genus, *Platymantis* (29 species). In total there are seven native ranid genera in the region, which is 10% of the global diversity of the family at the genus level. Four of these genera are endemic: *Batrachylodes* (8 species), *Ceratobatrachus* (1 species), *Discodeles* (5 species) and *Palmatorappia* (1 species). The species in these genera have a 'direct development' reproductive strategy like the microhylids, but species within the genera *Limnonectes* and *Rana* have aquatic larvae.[5]

There are 69 threatened or extinct species in the Australasian Realm spread across all seven families (Table 2). The family with the highest number of threatened species (24) is the Hylidae. The most diverse family in the region, the Microhylidae, has relatively few threatened species (only 12 of 197 species being threatened). Comparing the percentage of species that are threatened or extinct reveals large variation between families. Two families have 100% of their species threatened or Extinct. Both species within the family Rheobatrachidae are Extinct, and all four species within the New Zealand endemic family Leiopelmatidae are threatened (and see Essay 6.2).

The least threatened families are the Microhylidae and Ranidae, with only 6% and 7% of species in threatened categories, respectively. Both of these families have in common that they are primarily found in the Papuan sub-region, and all microhylids and the majority of ranids in the region are direct-developing species. Compared with the other families, they also have a much higher percentage of species in the Data Deficient category: 56% for Microhylidae and 29% for Ranidae. This is partly a reflection of how poorly surveyed the Papuan sub-region is for amphibians. As more research is done in the Papuan sub-region it is to be expected that the number of threatened species in these two families will increase, at least to some extent, although direct-developing species in this region do not appear to be at risk from chytridiomycosis. Microhylids in northern Australia have not declined due to this disease, even in areas where other species have disappeared.

Geographic Patterns of Species Richness and Endemism

A map of overall amphibian species richness within the Australasian Realm is shown in Figure 2. The highest species richness of amphibians is found in the tropics, where the number of species is highest in the central mountains of New Guinea and the Wet Tropics rainforests of north-eastern Queensland in Australia. In Australia amphibian species richness is concentrated in the areas of highest rainfall including the east (in particular in the temperate forest systems in the New South Wales / Queensland border area) and north coastal regions, and the south-western tip of Western Australia. Areas of lowest species richness coincide with Australia's arid interior and central southern coast. In the Papuan sub-region, Papua New Guinea has a higher documented species richness than Papua Province (Indonesia), but this is most likely an artefact of sampling because there has been substantially greater survey effort in Papua New Guinea.

The pattern of species richness illustrated in Figure 2 will require modification as survey effort is increased in poorly documented areas. Australia and New Zealand are both well surveyed for amphibians and the rate of new species descriptions is low. In comparison, the Papuan sub-region is one of the least studied regions in the world, and it is estimated that more than half of the amphibian species in New Guinea remain to be described (Günther 2006a). Many species in the Papuan sub-region are still known only from their type localities and perhaps one other locality, whereas the known range of species in Australia and New Zealand is much more likely to be representative of their actual ranges. There has been relatively little herpetological research conducted in the Solomon Islands and on the offshore islands of Papua New Guinea, and it is expected that documented amphibian diversity in these regions will increase in the future. However, there has recently been considerable survey work on the islands offshore of south-eastern Papua New Guinea and the known amphibian diversity there has increased markedly. Although most of these new additions have yet to be described, a number of new range records have been published (Kraus and Allison 2004; Kraus and Shea 2005).

The vast majority of threatened species in the Australasian Realm are endemic to Australia (see Figure 3) (and see Essay 6.3). The highest concentrations are found along the east and south-east coast, largely congruent with the areas of highest species species richness. However, the north coast, a relatively species-rich region, has no threatened species. Two factors appear to be contributing to this pattern: firstly, the fertile plains of the east and south-east coast of Australia are where the vast majority of people live, and

The Australian Lace-lid Nyctimystes dayi *(Endangered) is a treefrog (Hylidae) that is endemic to the Wet Tropics of northern Queensland, Australia. In the 1980s and early 1990s it disappeared from upland sites throughout its range, but still persists in suitable habitat at low elevations. © Jodi Rowley*

Table 1. *The number of Australasian amphibians in each taxonomic Family present in the region.*

Family	Native species (endemics to region)	Percentage of species in region that are endemic	Percentage of species in family that are endemic to region	Native genera (endemics to region)	Percentage of genera in region that are endemic	Percentage of genera in family that are endemic to region
Anura						
Hylidae	161 (159)	99	20	3 (2)	67	4
Leiopelmatidae	4 (4)	100	100	1 (1)	100	100
Limnodynastidae	50 (50)	100	100	8 (8)	100	100
Microhylidae	197 (197)	100	46	19 (18)	95	26
Myobatrachidae	71 (71)	100	100	11 (11)	100	100
Ranidae	59 (55)	91	8	7 (4)	57	10
Rheobatrachidae	2 (2)	100	100	1 (1)	100	100
TOTAL ANURA	**544 (538)**	**99**	**10**	**50 (45)**	**90**	**12**
TOTAL ALL AMPHIBIANS	**544 (538)**	**99**	**9**	**50 (45)**	**90**	**10**

Family	EX	CR	EN	VU	NT	LC	DD	Total of Order	Number threatened or Extinct	% Threatened or Extinct
Anura										
Hylidae	0	6	6	12	2	93	42	161	24	15
Leiopelmatidae	0	1	1	2	0	0	0	4	4	100
Limnodynastidae	0	1	7	2	1	37	2	50	10	20
Microhylidae	0	2	4	6	3	71	111	197	12	6
Myobatrachidae	1	6	2	4	3	49	6	71	13	18
Ranidae	0	0	1	3	1	37	17	59	4	7
Rheobatrachidae	2	0	0	0	0	0	0	2	2	100
TOTAL ANURA	**3**	**16**	**21**	**29**	**10**	**287**	**178**	**544**	**69**	**13**

Table 2. *The number of species within each IUCN Red List Category in each Family and Order in the Australasian Realm. Introduced species are not included.*

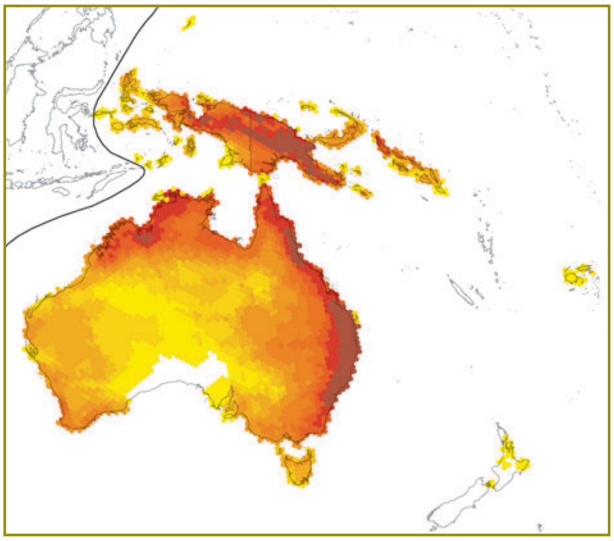


Figure 2. *The species richness of amphibians in the Australasian Realm, with darker colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes; maximum richness equals 51 species.*

Austrochaperina parkeri *(Data Deficient) is only known from two localities near Lae in Papua New Guinea. It is in the Family Microhylidae, which comprises over half the frog species of the island of New Guinea, all of which breed by direct development, and many of which are very poorly known. © Fred Kraus*

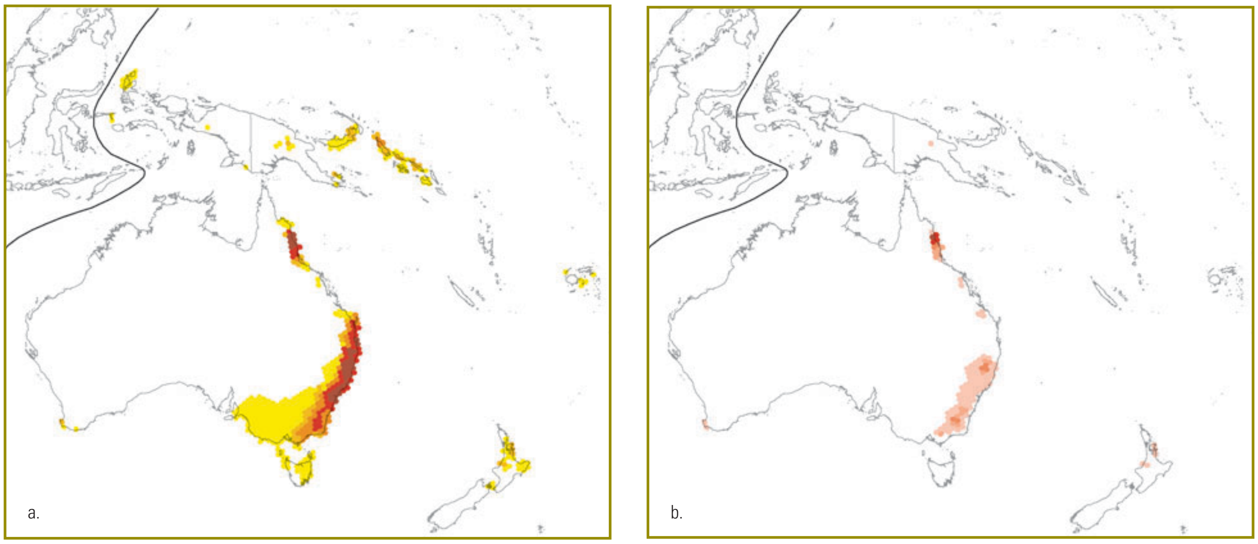


Figure 3. *a) The richness of threatened amphibians in the Australasian Realm, with darker colours corresponding to regions of higher richness. Colour scale based on five quantile classes; maximum richness equals 11 species. b) The richness of CR amphibians in the Australasian Realm. Maximum richness equals five species.*

hence where ongoing habitat loss is most severe; and, secondly, the current distribution of the amphibian chytrid fungus excludes the north coast west of north-eastern Queensland. The chytrid fungus was first detected near Brisbane on the east coast of Australia in 1978 (Speare and Berger 2005). Since then it has been found in the north and south, and it now appears to be established in coastal regions from Far North Queensland on the east coast, southwards through New South Wales and Victoria, and along the southern coast to Adelaide in South Australia. On the west coast it has been found in Perth and across most of the high rainfall zone in south-western Western Australia (Speare and Berger 2005). The spread of recorded occurrences of the disease is continuing with amphibians infected with chytrid being recorded in Tasmania for the first time in late 2004 (Obendorf 2005). It is possible that, if chytrid spreads into areas where it is not already present, more species will become threatened. However, chytrid fungus has relatively limited climatic tolerances with respect to both humidity and temperature (Woodhams *et al.* 2003). It might be less likely to have major impacts in the wet dry-tropical eucalypt woodland/grassland communities across much of northern Australia where dry seasons are too extreme and summer temperature too high for persistence, or in south-western Australia for similar reasons: extreme summer drought and associated high temperatures.

In New Zealand the map of amphibian species richness and threatened species richness are identical because all four native amphibians are threatened. In the Oceanic region, only one species is threatened, the Fijian Ground Frog *Platymantis vitiana* (EN), which is now found only on the small islands of Ovalau, Gau, Taveuni, and Viwa in Fiji (its tiny range is difficult to see in Figure 3a).

The Papuan sub-region (see Essay 6.4) has very few threatened species, particularly when considering its high species richness. The documented distribution of threatened species is incomplete due to severe lack of knowledge, but may also partly reflect a lack of certain threatening processes. For example, the chytrid fungus, which has had such a devastating impact on amphibians in Australia, has not been found in the region (though attempts to document this are limited to non-existent). There has also been relatively less habitat loss and degradation compared with Australia. However, widespread environmentally destructive logging throughout the Papuan sub-region (which is ongoing especially in parts of Papua New Guinea) may threaten numerous species in the future, particularly on smaller island archipelagos such as the Solomon Islands and the Admiralty and Bismarck Archipelagos.

The distribution of Critically Endangered species is highly congruent with that of threatened species overall (Figure 3b). New Zealand and the east coast of Australia remain focal points, with particular concentrations of Critically Endangered species in the Wet Tropics region of far northern Queensland, and in the central mountains from Fraser Island to Sydney. Tasmania is no longer highlighted, possibly because the chytrid fungus has only very recently been confirmed on the island and its impact on local amphibian populations is not yet known. In the Papuan sub-region one Critically Endangered species, *Albericus siegfriedi*, is known[6]. It has been recorded from only one location, Mount Elimbari, in Papua New Guinea (barely visible in Figure 3b).

Species Richness and Endemism within Countries

Amphibian species richness in the Australasian Realm is greatest on the two largest land masses of Australia and New Guinea (see Figure 2). Only three native amphibians occur in the Oceanic region (0.05% of the global total), compared with 187 birds (2% of the global total) (BirdLife International 2004). The only two countries in the Oceanic region that have native amphibians are Fiji (*Platymantis vitiana* and *P. vitiensis*) and Palau (*Platymantis pelewensis*). New Caledonia has one introduced species (*Litoria aurea*) as do the Northern Mariana Islands, American Samoa, the Bonin Islands, the Federated States of Micronesia, Guam and Tuvalu (*Bufo marinus* in each case).

Papua New Guinea has the most native amphibians in the Australasian Realm (245 species) and this number is predicted to almost double as species descriptions continue. Australia is the second-most diverse country (214 species), although as species descriptions continue it is likely that Indonesian New Guinea (Papua) will eventually overtake Australia's total in the region.[7] The number of species in the Solomon Islands is relatively low (19 species) and there will be a moderate increase in the known fauna with future herpetofaunal surveys. Documentation of the New Zealand native frog fauna is almost certainly complete, although recent genetic work on isolated populations of *Leiopelma hochstetteri* (Gemmel *et al.* 2003) suggests that there might be more than six distinct cryptic species. New Zealand also has three species introduced from Australia, two of which are threatened in their native ranges.

The only overview of the amphibians of the whole region is that of Tyler (1999a). There is an extensive overview literature, and guide books, on the amphibians of Australia (e.g., Barker *et al.* 1995; Glasby *et al.* 1993; Tyler 1999b; Cogger 2000), and recent assessments of amphibian declines throughout Australia include Hero and Shoo (2003), Hero and Morrison (2004), Hero *et al.* (2005) and Hero *et al.* (2006). Slatyer *et al.* (2007) made an assessment of endemism and species-richness patterns of Australian frogs. The most recent overview of the small frog fauna of New Zealand is by Gill and Whitaker (1996). Menzies (2006) provides the first review of the amphibians of the Papuan sub-region.

The percentage of species that are endemic to each country in the region varies from 100% to 5% (Figure 5). Three countries in the region – New Zealand, Fiji and Palau – have endemism of 100%, although all three of these countries have only very few species (four, two and one, respectively). Of the three countries with high species richness, Australia has the highest level of endemism at 93%, followed by Papua New Guinea with 67% and Indonesia with 59% (the lower levels of endemism in the latter two countries are due to the biogeographically arbitrary border between them, and the percentage of endemics on the island of New Guinea is over 95%). The Solomon Islands has the lowest level of endemism with only one of its nineteen native species, *Discodeles malukuna* (DD), being endemic. However, in a biogeographical context these levels of endemism are meaningless. Like the island of New Guinea, the level of endemism in the Solomon Islands Archipelago would be substantially greater if this natural and discrete biogeographic 'unit' had not been split by political boundaries.

All of the countries in the Australasian Realm that have native amphibians also have threatened species with the exception of Palau (see Figure 6). Australia contains almost three-quarters (71%) of the region's 66 threatened species and all but two of these species are endemic to the country. Predicting the impact generated by the possible spread of the pathogenic chytrid fungus throughout Australia is difficult as its spread into semi-arid and arid areas across much of southern and northern Australia might have less impact than expected, as described above. In contrast, the most diverse country, Papua New Guinea, has only 10 threatened species, of which eight are endemic. Indonesia and New Zealand, with 148 and four native species, respectively, amazingly have the same number of threatened species. As more survey work is completed in the Papuan sub-region, the number of threatened species in Indonesia, Papua New Guinea and the Solomon Islands probably will increase. This increase is likely to come from documenting newly described species with severely constrained ranges and threatened habitats, as well as from improved data that will permit a more realistic assessment of species currently in the Data Deficient category.

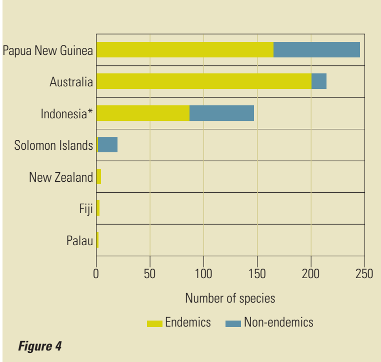


Figure 4. *The number of amphibians present in and endemic to each Australasian country. *denotes countries not entirely within the Australasian Realm, hence only the species whose ranges fall within the region are included.*

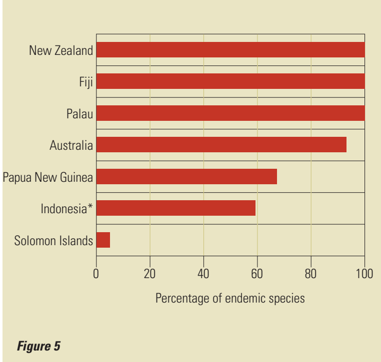


Figure 5. *Percentage of species endemic to each Australasian country. *denotes countries not entirely within the Australasian Realm, hence only the species whose ranges fall within the region are included.*

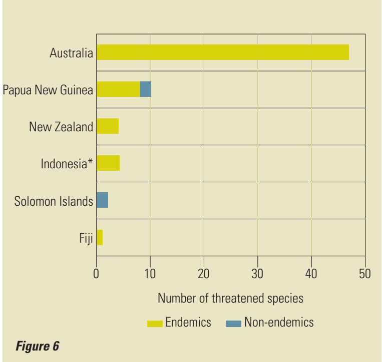


Figure 6. *The number of threatened amphibians present in and endemic to each Australasian country. Countries with no threatened species are not included in the diagram. *denotes countries not entirely within the Australasian Realm, hence only the species whose ranges fall within the region are included.*

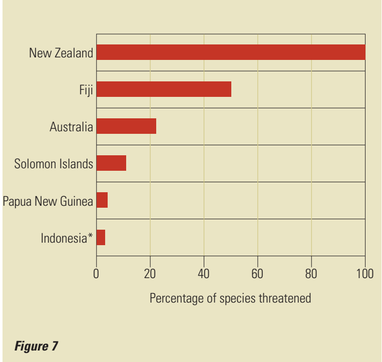


Figure 7. *Percentage of native species that are threatened. Countries with no threatened species are not included in the diagram. *denotes countries not entirely within the Australasian Realm, hence only the species whose ranges fall within the region are included.*

Left: Litoria prora *(Least Concern) is a hylid treefrog from New Guinea. It is an arboreal species and is found near small streams and forest pools in lowland and foothill rainforests. It breeds in pools and slow-flowing portions of streams. © Stephen Richards*

Right: The Sunset Frog Spicospina flammocaerulea *(Vulnerable) in the Family Myobatrachidae is known only from a small area of southwestern Australia, where it was discovered in 1994. It occurs only in a few isolated peat swamps. © Ross Knowles*

There is extreme variation in the percentage of species that are threatened in each country in the region (see Figure 7). With 100% of its native species threatened, New Zealand is top of the list, followed by Fiji with 50%, but these countries only have four and two native species, respectively. When considering countries with high species richness, Australia has by far the greatest percentage of threatened species, 22% of extant species, compared with only 4% in Papua New Guinea and 3% in Indonesia. These figures reflect the impact that chytridiomycosis, habitat loss and other threatening processes have had in Australia compared with the relatively low impact of threats in New Guinea, and perhaps also reflect the lack of data from Indonesia and Papua New Guinea. Australia, however, still has a significantly lower percentage of its species threatened than the global average of 33%.

Assessments of the conservation status of Australasian amphibians at national level have been carried out in Australia (Tyler 1997; Campbell 1999; Hero and Morrison 2004; Hero *et al.* 2006; Clayton *et al.* 2006; and see Essay 6.3), and in New Zealand (Newman 1996; Hitchmough 2002).

There are only 16 Critically Endangered species in the Australasian Realm, but 14 of these occur in Australia (where the impacts of chytridiomycosis and habitat loss have been most severe) and one each in New Zealand and Papua New Guinea.

HABITAT AND ECOLOGY

Habitat Preferences

Most amphibians in the region are found in forests (73%), and in particular in tropical forest (68%) (Table 3; Figure 8). There are also large numbers of species in grassland (19%) and shrubland (13%). However, the percentage of species in each of these habitats that are threatened is notably different: 14% of forest-dwelling species are threatened, but only 6% of grassland species and 10% of shrubland species are threatened. Similar numbers of amphibians are associated with flowing freshwater and still open freshwater; however, more than twice the total number of species associated with flowing freshwater is threatened compared with species in still open freshwater. This reflects a global trend for amphibians associated with forests and flowing freshwater to be more likely to decline rapidly (Stuart *et al.* 2004). Hero and Morrison (2004), Hero *et al.* (2005) and Hero *et al.* (2006) previously noted that montane wetland and streamside species are the most likely ones to experience enigmatic declines in Australia.

Significantly more lowland tropical forest species below 1,000m (52%) than montane tropical forest species above 1,000m (33%) occur in the region, and a higher percentage of lowland species is threatened (16%) compared with montane species (11%). This is most likely because the mountain ranges in Australia, where most threatened species in the region are found, are relatively low in elevation, and because the higher elevation mountain ranges of New Guinea are very poorly surveyed (so that a large proportion of montane species in this region is considered Data Deficient).

No amphibians occurring in savannah are considered threatened and this is largely a reflection of the wide ranges of these species. Interestingly, 25% of species in the region are found in secondary terrestrial habitats, and a significant proportion (7%) of these species is threatened.

Breeding Strategies

The most common reproductive mode amongst Australasian amphibians involves a free-swimming larval stage or 'larval development' (53%), followed closely by 'direct development' (47%) in which embryonic and larval development is completed within the egg capsule (Table 4). There are no known live-bearing species in the region, but the reproductive strategy of many species is inferred. When compared with global trends in reproductive mode, the Australasian Realm has a significantly higher proportion of direct developers (30% of species globally are direct developers), and a significantly lower proportion of larval developers (68% of species globally are larval developers). This is largely caused by nearly 200 species of the family Microhylidae occurring mainly in New Guinea, all of which are direct developers.

Reproductive mode	All Species	Threatened or Extinct species	% Threatened or Extinct
Direct development	255	24	9
Larval development	288	45	16
Live-bearing	0	0	-
Not known	1	0	0

Table 4. *Australasian amphibians categorized by reproductive mode.*

The percentage of larval-developing species that are threatened is almost double that of direct developers (Table 4). This contradicts the global trend, where 45% of direct developers and 28% of larval developers are threatened. This apparent contradiction can be explained by considering the geographical distribution of species exhibiting different breeding strategies. In Australia, where 47 of the region's 66 threatened species are found, 188 of the 217 native species are larval developers. In Papua New Guinea, where only 10 species are threatened, 160 of the 244 native species are direct developers. The situation is similar in Indonesia, where only four species are threatened, and 83 of the 148 native species are direct developers. Australia is the only country in the region in which the proportion of larval developers is higher than that of direct developers. Compared with the other two megadiverse countries in the region, Papua New Guinea and Indonesia, Australia is also the country most impacted by threats such as chytridiomycosis, introduced species, and habitat loss (Hero and Morrison 2004; Hero *et al.* 2005, 2006). Chytridiomycosis is more often implicated in declines of stream-associated, usually larval-developing, species (Lips *et al.* 2003), although some direct developers that are associated with streams have also been impacted by the disease. In New Zealand, contrary to the general pattern, the fully terrestrial *Leioipelma archeyi* (CR) has experienced a decline due to chytridiomycosis (Bell *et al.* 2004), whereas no declines have been detected in the sympatric stream-dwelling frog (*L. hochstetteri*, VU). In Fiji and Palau, all of the native species are fully terrestrial direct developers.

MAJOR THREATS

The most significant threat to species in the region is habitat loss, impacting three-quarters of threatened species (Table 5; Figure 9). This trend is global and habitat loss has been identified as a major threat for birds and mammals as well as amphibians (Baillie *et al.* 2004). Of particular interest is the second-most significant threat, invasive species[8] (primarily salmonids and *Gambusia*; Gillespie and Hero 1999), which are affecting two-thirds of all threatened species in the region, compared with only 11% of threatened species globally. This highlights the particularly severe impact that invasive species are having on native wildlife in Australia, New Zealand, and oceanic islands such as Fiji.

Pollution is a significant threat to almost half of the threatened species in the region, which is a higher proportion than the global figure of 29%. Disease is also having a major impact, and is believed to be affecting 24 threatened species in the region. The chytrid fungus has now been identified in wild populations of 48 native Australian frogs, and also

Habitat type	Number of species in each habitat	% of all species occurring in the habitat	Threatened and Extinct species	% of species occurring in habitat that are Threatened or Extinct
Forest	398	73	55	14
All tropical forest	372	68	47	13
Lowland tropical forest	281	52	44	16
Montane tropical forest	177	33	19	11
Savannah	41	7	0	0
Grassland	106	19	6	6
Shrubland	70	13	7	10
Secondary terrestrial habitats	136	25	10	7
Flowing freshwater	177	32	35	20
Marsh/swamp	95	17	14	15
Still open freshwater	171	31	15	9
Arid and semi-arid habitats	5	1	0	0

Table 3. *The habitat preferences of amphibians in the Australasian Realm.*

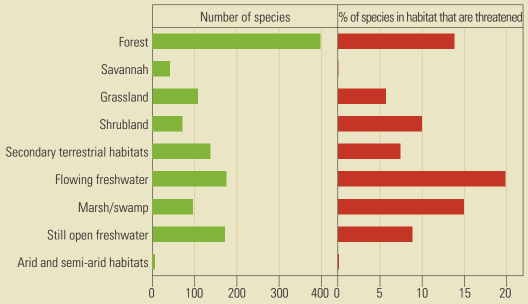


Figure 8. *The habitat preferences of amphibians in the Australasian Realm. The plot on the left-hand side shows the number of species in the region in each habitat type. On the right-hand side, the percentage of these species which are threatened is given.*

Threat type	Threatened species	% Threatened species
Habitat loss	50	76
Agriculture – Crops	4	6
Agriculture – Tree plantations	5	8
Agriculture – Livestock	24	36
Timber and other vegetation removal	17	26
Urbanization and industrial development	29	44
Invasive species	44	67
Utilization	1	2
Accidental mortality	2	3
Pollution	31	47
Natural disasters	12	18
Disease	24	36
Human disturbance	16	24
Fire	16	24

Table 5. *The major threats to globally threatened amphibians in the Australasian Realm. Only present threats to species are tallied.*

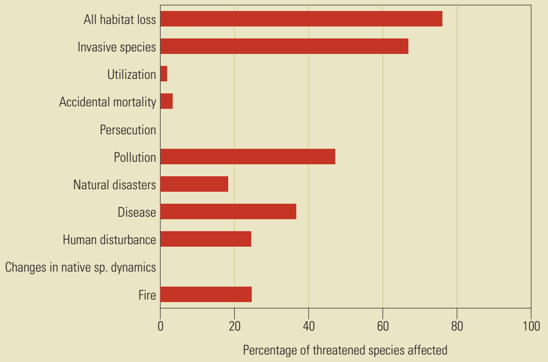


Figure 9. *The major threats impacting threatened amphibians in the Australasian Realm.*

Purpose	Subsistence	Sub-national/ National	Regional/ International	Number of species
Food - human	15 (0)	1 (0)	0	15 (0)
Food - animal	1 (0)	0	0	1 (0)
Handicrafts, curios, etc.	0	1 (0)	0	1 (0)
Pets, display animals	3 (2)	6 (3)	11 (2)	12 (3)
Research	0	2 (2*)	0	2 (2*)

Table 6. *The purposes for which amphibians are used in the Australasian Realm. The numbers in brackets are the number of species within the total that are threatened species. The two species listed as being used in "Research"* (Rheobatrachus silus *and* R. vitellinus) *are now Extinct.*

Population Trend	Number of species	% of extant species
Decreasing	53	10
Stable	286	53
Increasing	2	0.4
Unknown	200	37

Table 7. *The population trends for all extant Australasian amphibians.*

Family	Number of species in "rapid decline"	Percentage of species in family in "rapid decline"	Number of species in "enigmatic decline"	Percentage of species in family in "enigmatic decline"
Hylidae	13	8	10	6
Leiopelmatidae	1	25	1	25
Limnodynastidae	7	14	3	6
Microhylidae	2	1	0	0
Myobatrachidae	9	13	7	10
Ranidae	1	2	0	0
Rheobatrachidae	2	100	2	100

Table 8. *The number of species in "rapid decline" and "enigmatic decline" in the Australasia Realm by Family.*

in the introduced cane toad, *Bufo marinus* (Speare and Berger 2005). Captive populations of two additional species have been infected, although there is no evidence of infection within their wild populations (Speare and Berger 2005). Not all species infected have declined, and there are some species, for example *Taudactylus eungellensis* (CR), which have experienced declines in the past that might have been due to chytridiomycosis and are now showing signs of recovery. Why some species appear to be more resilient to the disease than others is still not known, although there is evidence that both innate immune defenses and environmental factors play a role (Woodhams and Alford 2005; Woodhams *et al.* 2006).

A total of 30 species (three of which are threatened and two considered Extinct) are recorded as being utilized by humans. The most common reason for harvesting Australasian amphibians is for local human consumption, and this occurs only in the Papuan sub-region. Some amphibians are harvested for the international pet trade; the most common species being treefrogs of the genus *Litoria*, which originate from both Australia and the Papuan sub-region. Much of the harvesting of amphibians in the region is not considered to constitute a major threat to the species; of the 30 species being harvested, this activity is considered to be a threat to just six species.

POPULATION STATUS AND TRENDS

Estimates of Population Trends

A summary of the inferred population trends of Australasian amphibians is presented in Table 7. For many species, particularly those in the Papuan sub-region, these trends are inferred from broad trends in the state of the habitats on which the species depend. In Australia and New Zealand, where most of the declining species are found, many of the population trends are based on field observations (for example, Campbell (1999) for Australia, and Bishop (2006) for New Zealand). Compared with global trends, the population trends in the Australasian Realm is quite different, with many more species considered to have stable, rather than decreasing, populations. More than half of the amphibians in the region are considered to have stable populations, compared with only 27% globally, and only 10% of species in the region are considered to be in decline (vs. 42% globally). This would suggest that although there have been dramatic declines, and in some cases extinctions, amongst some populations of species in Australia and New Zealand, amphibian populations overall are relatively stable. In Australia, this stability might be because the major effects of feral introductions, large-scale habitat clearance and chytridiomycosis have generally now played out. The main feral predators (cats and foxes) and habitat-changers (rabbits and domestic livestock) reached all parts of Australia some time ago. The large-scale clearance of important natural habitats was generally completed by 1950, and legislation to minimize such habitat clearance is now generally in place. The chytrid fungus had reached much of Australia by the late 1990s. As a result, there is some relative stability compared with the situation 20, 50 and 100 years ago. For a substantial proportion of species (37%), there is still insufficient information to determine a trend in population size.

"Rapidly Declining" Species

There are 35 "rapidly declining" species in the Australasian Realm, which is 7% of the global total of 470 species (a full list of all "rapidly declining" species is provided in Appendix IV and includes their occurrence within each of the realms). Twenty-three of these species are experiencing, or have experienced, "enigmatic declines", in which the causal factors are not well understood, while the other 12 have experienced declines due to reduced habitat. Australia has the highest number of "rapidly declining" species in the region, with 31 species, followed by Papua New Guinea with three species, and New Zealand with one species. All three species in Papua New Guinea are declining as a result of reduced habitat, and the reason for the decline of the one New Zealand endemic species has been identified as most likely a result of chytridiomycosis (Bell *et al.* 2004). Most of the "enigmatic declines" in the region are concentrated in eastern Australia, where chytrid is widespread.

Of the 544 species occurring in the region, 6% are considered "rapidly declining" which is slightly less than the global average of 8% of all amphibians. Considering that the region has a significantly lower percentage of threatened species than the global average (12% compared with 33%), the number of "rapidly declining" species is relatively high. This highlights the severity of the threats impacting certain species in the region, and in particular how quickly these threats can push species to the brink of extinction. Of the 66 species that are currently considered threatened in the region, 29 are also "rapidly declining". Consequently, although the region does not have a large proportion of threatened species, many species that are threatened, are also in serious decline.

The "rapidly declining" species show a distinct taxonomic pattern (Table 8). Among the larger families, the Limnodynastidae and the Myobatrachidae show the highest percentages of species in serious decline, and in the Myobatrachidae almost 10% of species are in "enigmatic decline". The largest number of species in serious decline is found in the Hylidae, but percentage wise this family appears to be less seriously affected than the Limnodynastidae and the Myobatrachidae. Some less speciose families have high percentages of species in serious decline and "enigmatic decline", most notably the Rheobatrachidae and the Leiopelmatidae, the former family now being extinct (according to the traditional family-level amphibian classification).

The Silver-eyed Barred Frog Mixophyes balbus *(Vulnerable) in the Family Limnodynastidae occurs mainly in eastern New South Wales, Australia. The species has declined and disappeared from a number of locations where it was once common. It is typically found in association with permanent streams in temperate and sub-tropical rainforest and in wet sclerophyll forest. © Frank Lemckert*

The Fiji Treefrog Platymantis vitiensis *(Near Threatened) is widespread in Fiji on the islands of Viti Levu, Vanua Levu, Ovalau and Taveuni. It is naturally a forest species, living especially along streams in giant bird's nest ferns, but occurs at much lower densities in secondary habitats. It is in the Family Ranidae and breeds by direct development, the eggs being laid in leaf axils. © Paddy Ryan*

KEY FINDINGS

- A total of 544 species occur in the Australasian Realm, of which 66 are considered threatened and three are Extinct (13%). Five species are also considered Critically Endangered (Possibly Extinct).
- Of the 544 species in the region, 99% are endemic; of 50 amphibian genera, 45 are endemic; and of the 7 families found in the region, four are endemic. Only one of the three Orders of amphibians, the anurans, occurs in the region.
- There are five families that have percentages of threatened species higher than the regional average: Leiopelmatidae (100%), Rheobatrachidae (100%), Limnodynastidae (20%), Myobatrachidae (18%), and Hylidae (14%). Two families have lower than the regional average of threatened species: Ranidae (7%) and Microhylidae (6%).
- The vast majority of threatened species in the Australasian Realm are endemic to Australia, and are concentrated along the east and south-east coast.
- Papua New Guinea has the highest number of native species in the region, followed by Australia and Indonesia. Of these three countries, Australia has the highest percentage of endemic species with 93%.
- Australia has the largest number of threatened species (47), and New Zealand has the highest percentage of threatened species (100%) in the region.
- Most amphibians in the Australasian Realm are found in forests (73%), and in particular tropical forest (68%). There are more species occurring in lowland tropical forest below 1,000m asl (52%) than in montane tropical forest (33%), and a higher percentage of lowland species are threatened (16%) compared with montane species (11%).
- Habitat loss is the most common threat, affecting 76% of species, followed by invasive species (67%), pollution (47%), and disease (36%).
- There are 35 "rapidly declining" species occurring in the region, 31 of these species are endemic to Australia. Most of these species (66%) have experienced "enigmatic" declines, probably due to chytridiomycosis, while the remainder are suffering from reduced habitat.
- Chytridiomycosis has been linked to the enigmatic declines in the Wet tropics region of north Queensland, and is probably implicated elsewhere in eastern Australia. It has also been linked to declines in New Zealand.

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Endnotes

1 $P<0.01$ (binomial test)

2 Frost *et al.*'s (2006) taxonomic rearrangement results in eight families in the Australasian Realm, of which only two are endemic: Limnodynastidae and Myobatrachidae. Frost *et al*. include the Nearctic tailed frogs (Ascaphidae) within the New Zealand frogs (Leiopelmatidae), and so under this arrangement, the latter family is not endemic to the region. However, in this section we follow the former taxonomic arrangement of families based on Frost (2004).

3 Frost *et al.* (2006) present another arrangement, separating the genus *Mixophyes* (6 species), from the Limnodynastidae and placing it within the family Myobatrachidae, and also including the Rheobatrachidae within the family Myobatrachidae.

4 Savage (1973) recognized the Australo-Papuan hylids as a separate family, the Pelodyradidae. This has more recently been treated as a subfamily, Pelodryadinae (see discussion in Frost *et al*. 2006).

5 Frost *et al.* (2006) separate the ranids found in this region into three families. Those species within the genus *Rana* remain within the family Ranidae, while the genus *Limnonectes* becomes part of a new family Dicroglossidae, and the remaining genera (*Batrachylodes, Ceratobatrachus, Discodeles, Palmatorappia* and *Platymantis*) become part of the new family Ceratobatrachidae.

6 One species recently described for Biak Island in Indonesia (*Litoria biakensis*) appears to be seriously threatened (Günther 2006b) and might be Critically Endangered. However, the species was described after the completion of data collection for this book, and is not included in this analysis.

7 The totals listed here for Indonesia only include species occurring on the islands within the Australasian Realm. For the overall country totals for Indonesia see Appendix V)

8 In this analysis, we have not considered the chytrid fungus *Batrachytrium dendrobatidis* to be an invasive, pending further information on its geographic origin.

ESSAY 6.1. GASTRIC-BROODING FROGS

The discovery in 1973 of a new species of frog, living in rainforest, near Brisbane in eastern Australia, did not at first attract much attention. The person who discovered it, David Liem, erected a new genus, *Rheobatrachus,* for it and named the species *Rheobatrachus silus* (Liem 1973). Interest in the species initially hinged upon its position in the amphibian tree of life, but in the following year a female was observed to give birth to baby frogs through the mouth (Corben *et al.* 1974). This remarkable breeding biology led to it being anointed the common name of the "Gastric-brooding Frog".

Gastric brooding represents a unique form of parental care among amphibians (Corben *et al.* 1974). Following fertilization, the female ingests the eggs. The jelly surrounding the eggs contains a compound that switches off the cells in the lining of the stomach wall that secrete hydrochloric acid to aid digestion. The compound also paralyses the muscles in the stomach wall and increases the number of small blood vessels. In effect, collectively the changes convert the female's stomach into a womb. The eggs change into cream-coloured tadpoles and finally metamorphose into young frogs after a period of six to seven weeks. The young are believed to live entirely upon their yolk for this period. Similarly, the mother does not actively feed during this time, living instead upon her body fat and glycogen from the liver. Young eventually emerge as fully formed froglets, and after four days the female's digestive tract returns to normal and she recommences feeding (Tyler and Davies 1983). Since the stomachs of all frog species are extremely similar, much of the initial research focusing on stomach acid secretion in amphibians was done using an imported pest species, the Cane Toad *Bufo marinus.*

In 1979, the Gastric-brooding Frog disappeared and, following numerous fruitless searches, is now regarded as Extinct. Because of the unique nature of its breeding habits, the species had attracted worldwide interest, and so attention was focussed upon the many potential causes for its sudden disappearance. The first was habitat degradation due to timber harvesting, as although much of the habitat was pristine rainforest, other parts were greatly disturbed. Stream siltation could have played a significant role, because it covered the large stones beneath which the frogs hid during the day. Excessive collecting was also suggested as a reason for the decline of the species, but this has since been disproved; a second species (the Mount Glorious Day Frog, *Taudactylus diurnus*) disappeared simultaneously from the same site, and is now also considered Extinct.

In 1984, a second species of *Rheobatrachus* was found approximately 800km north of the range of *Rheobatrachus silus,* in vine forest near Mackay on the Queensland coast. It differed from its sibling species in its larger size and brilliant yellow markings on the ventral surfaces. The species was named the Northern or Eungella Gastric-brooding Frog *R. vitellinus* (Mahony *et al.* 1984) and evidence of gastric brooding and oral birth was reported later that year (McDonald and Tyler 1984). Compared with *Rheobatrachus silus*, which gives birth to 18-25 young measuring 13mm, the female Northern Gastric-brooding Frog gives birth to 22 young measuring up to 16mm in length. Oddly, upon examination, the stomach of a female carrying young did not exhibit any of the physical changes observed in *R. silus.* Instead, it retained a normal muscular structure and cells secreting hydrochloric acid. It is presumed that the mechanism employed by *R. vitellinus* to avoid digesting its young was the same as that used by all vertebrate animals to avoid digesting the stomach wall, namely by coating the young with mucus.

Sadly, some 18 months after its discovery, the Eungella Gastric-brooding Frog disappeared without trace and has not been seen since. It had inhabited dense vegetation in the remote Eungella National Park and there were no signs of habitat disturbance or any event linked to the species' disappearance. The causes for the disappearance of this species, and along with it a unique mode of reproduction among amphibians, is unknown. Flannery (2006) asserts that the demise of the Southern Gastric-brooding Frog is attributable to climate change, but the rate of loss was simply too fast for this to be the case. In any event, there was no drought and no detectable environmental change. However, there is some circumstantial evidence that an environmental factor must have been involved because a small colony remained alive in a laboratory in Adelaide for three years following their disappearance from the wild.

At the Second World Congress of Herpetology held in Australia at the end of 1993, Australian researchers learned that their experience of disappearing frogs was mirrored by other species on other continents. The search for a common cause or causes has been ongoing ever since.

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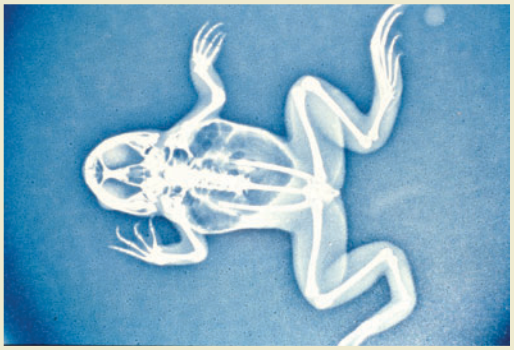
Birth of a gastric brooding frog Rheobatrachus silus. *© Michael J. Tyler*

Prematurely born tadpole aged approximately two weeks. © Michael J. Tyler



An x-ray of a female gastric-brooding frog that has given birth. The dark space in the abdomen is the stomach which held the young. © Michael J. Tyler

ESSAY 6.2. LEIOPELMATID FROGS: THE WORLD'S MOST ARCHAIC FROGS

The Leiopelmatidae represent a unique evolutionary lineage among amphibians, and are thought to be the most archaic frogs in the world. These frogs are found only in New Zealand, and all members belong to the genus *Leiopelma.* Three species are now extinct (*L. auroraensis, L markhami and L.waitomoensis*), and only four species are extant: *L. archeyi, L. hamiltoni, L. hochstetetteri* and *L. pakeka.*[1]

Members of the Leiopelmatidae exhibit a number of primitive traits that separate them from most other species, including: vestigial tail-wagging muscles, cartilaginous inscriptional ribs, the presence of amphicoelous vertebrae, and nine presachral vertebrae (most frogs have eight). *Ascaphus truei*, the tailed frog of the North-western United States, is the only other extant frog known to possess these features (Stephenson 1961). In addition, there is some evidence to suggest that *Leiopelma* evolved from an ancestor with 'normal' tadpole development and the degree of cranial remodeling that occurs in *Leiopelma* larvae at metamorphosis is intermediate between salamanders and *Ascaphus* (Bell and Wassersug 2003).

In addition to these primitive traits, *Leiopelma* differ from most other frogs because they lack external eardrums and produce only limited vocalizations. There are no mating calls and the only noises that any of the four species are known to make are chirps or yelps when harassed. It is currently thought that these frogs communicate more like salamanders than other frogs, using chemosignals to recoginize size and individuality of conspecifics (Lee and Waldman 2002; Waldman and Bishop 2004).

Although members of the genus *Leiopelma* have many similarities, each species varies in its physical characteristics, habitat preferences, distribution range, and threats faced. Hochstetter's Frog *Leiopelma hochstetteri* (VU) is the more aquatic frog (albeit semi-aquatic) of the four extant species. It is widely distributed in at least 10 fragmented and isolated populations in the northern half of the North Island. They are nocturnal and shelter by day in wet crevices or under stones or logs close to the water's edge in shaded streams. Males of this species exhibit sexual dimorphism in the form of more muscular, robust forelimbs than females. This is another distinctive trait, as the other three *Leiopelma* species are not sexually dimorphic, apart from females reaching greater body size. One of the main threats to this species is the destruction and modification of its habitat, which is still occurring either directly (e.g. afforestation, gold mining, storm water discharge) or indirectly (e.g. feral goats and pigs causing erosion leading to stream siltation). The New Zealand Department of Conservation has purchased considerable amounts of suitable land to prevent further degradation of some of their habitat, and attempts are being made to better monitor their populations.

Archey's Frog *Leiopelma archeyi* (CR) is the smallest of the indigenous species (<38mm). They are restricted to two regions on the North Island of New Zealand, occurring on the Coromandel Peninsula and the Whareorino Forest, west of Te Kuiti. In both of these areas, it occurs sympatrically with *Leiopelma hochstetteri.* They prefer to live at relatively high altitudes from 400-1000m in moist native forest; they are terrestrial and nocturnal, spending most of the day hidden under stones or logs away from streams or creeks. *Leiopelma archeyi* is a terrestrial breeder, laying a small clutch of eggs in a moist site under stones or logs. They exhibit parental care with the tailed froglets remaining on their father's back for several weeks until metamorphosis is nearly complete. Populations of this species have crashed in recent years with monitored populations decreasing by 88% over the 1996-2001 period (Figure 1). Several factors, including the severity and rapidity of the population crash, the geographic spread of the decline (from south to north), and the discovery of frogs with chytridiomycosis (caused by *Batrachochytrium dendrobatidis*), all point to disease being the major cause of the decline. A breeding facility has recently been opened at Auckland Zoo with the intention of producing a self-sustaining captive population. A top priority of the New Zealand Native Frog Recovery Group is to investigate ways of preventing further declines of this species.

Hamilton's Frog *Leiopelma hamiltoni* (EN) and the Maud Island Frog *L. pakeka* (VU) are the largest living indigenous frogs (<50mm) in New Zealand. These two species were once considered conspecific, but they have since been described as separate species based on allozyme variation (Bell *et al.* 1998). There is some debate as to whether there should be a distinction between the two, with further analysis using 12S ribosomal RNA and cytochrome *b* gene sequences finding little variation (Holyoake *et al.* 2001). However, as both these species are limited to offshore islands with no chance for genetic exchange, they need to continue to be managed as separate evolutionary significant units if not kept as separate species.

Both *L. hamiltoni* and *L. pakeka* live amongst the boulders and moss covered rocks of the remnants of coastal forest. They are terrestrial and nocturnal, spending most of the day hidden under stones or logs away from streams or creeks. They are terrestrial breeders, laying a small clutch of eggs in a moist site under suitable substrates. The only naturally occurring *L. hamilitoni* population consists of less than 300 adult frogs on Stephens Island, and after five years of intensive monitoring this population is thought to be stable. They are limited to a single rock-tumble (ca. 300 m^2) that has been fenced off to stop the predation of these frogs by Tuatara (*Sphenodon punctatus*). New habitat was created for the frogs by the construction of a second rocky tumble on the same island and, in 1992, 12 adult frogs were transferred to the new site (Brown 1994). The results of the translocation were mixed, with three frogs remaining at the new site and two homing back to the original frog site (Brown 1994; Tocher and Brown 2004). In 2004, a fence was erected to join both of these sites thereby significantly enlarging the amount of tuatara-free habitat. Also in 2004, a translocation of 40 individuals to Nukuwiata, another predator-free island in the Marlborough Sounds, took place. Initial reports are that this appears to have been a success with frogs remaining in good condition through the first year.

Leiopelma pakeka, like *L. hamiltoni*, was only found naturally on one small predator-free island, Maud Island, in the Marlborough Sounds. The population has been estimated at between 27,500 and 39,500 individuals found mainly in a 16-ha patch of native bush. One hundred of these frogs were translocated to restored forest habitat on the same island in 1984-1985 and, 20 years later, this new population appears to be thriving with new recruitment and higher adult weights than the source population (Bell *et al.* 2004b). Two inter-island translocations to predator-free islands have occurred since then in order to increase the distribution of *L. pakeka* and therefore lower their risk of extinction. The first of these involved moving 300 frogs to Motuara Island in 1997 where the population survival has been high following a 3-month settling in period and evidence of breeding success has been recorded. A second inter-island translocation to Long Island occurred in 2005 and appears to be successful as all the recaptured frogs have gained weight and some appear to be gravid.

The continued survival of these ancient species in New Zealand will largely depend upon conservation measures and research carried out by the Native Frog Recovery Group and the Department of Conservation.

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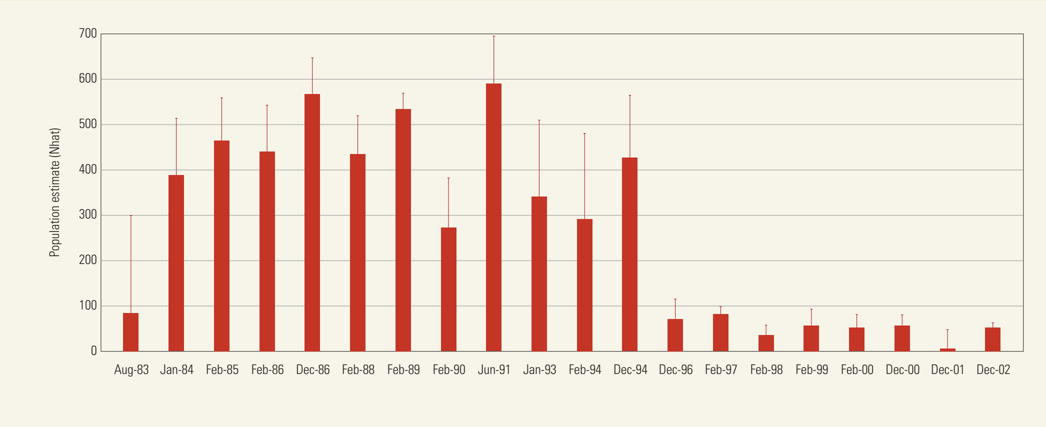

Figure 1. *Jolly-Seber population estimates of population size of* Leiopelma archeyi *(Critically Endangered) on the Tapu Ridge study plot, 1983-2002. Error bars = 1SE. (Source: Bell* et al. *2004a).*

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[1] As noted in the Introductory chapter, Frost *et al.* (2006) include the Ascaphidae (Tailed Frogs) in this family, with the result that this primitive family is expanded to contain six species, and its distribution is in New Zealand and the Pacific Northwest of North America, with the New Zealand species breeding by direct development, and the American ones by larval development. ■

ESSAY 6.3. AMPHIBIAN DECLINES IN AUSTRALIA

Concern about the status of Australian frogs first arose in the 1980s with the disappearance of the famous gastric-brooding frogs: *Rheobatrachus silus* (described in 1973, and last seen in the wild in 1981), and *R. vitellinus* (described in 1984, and last seen in the wild in 1985) (Ingram and McDonald 1993; and see Essay 6.1). Intensive searches for both of these species were conducted in the late 1980s, with no individuals located then, or since, and they are both now listed as Extinct on the IUCN Red List. This represents the loss of an entire family, as well as a unique reproductive strategy.

Around the same time that the gastric-brooding frogs disappeared, concern was raised over the status of another iconic myobatrachid – the Corroboree Frog *Pseudophryne corroboree* (CR). Declines of the Corroboree Frog were first reported in the late 1980s (Osborne 1989). Although these declines and disappearances raised concerns at the time, they were regarded as isolated events. However, increasing awareness that amphibian declines might be a global problem, and a review of the status of Australian frogs by Tyler (1991), revealed that the phenomenon of declines was more widespread. Tyler identified 23 species that were thought to have suffered recent population declines. The critical nature of the phenomenon was reinforced by Richards *et al.* (1993), whose survey of 47 sites in the Australian Wet Tropics showed that declines were occurring on a regional scale; six species had disappeared from almost all sites above 400m elevation. These species subsequently disappeared from the few higher-elevation sites at which they were present in the initial surveys (McDonald and Alford 1999).

Fortunately, Australia has well-defined procedures in place at a national level for dealing with threats to biodiversity, and these procedures were quickly mobilized. In the early 1990s, regional species recovery teams were organized, and regional and national meetings and workshops were held. Each regional recovery team was responsible for developing and implementing a recovery plan for the species under its jurisdiction. These plans went through formal review processes at the State and Federal levels. Initially, most plans called primarily for additional research, since the nature and causes of the declines were not well understood. At a national level, the federal department of the environment sponsored the production of the first version of the *Action Plan for Australian Frogs* (Tyler 1997). Knowledge of Australian frog populations and their status increased dramatically during the early to mid-1990s, largely as a result of the work carried out under the species recovery process. Of the 23 species identified as being of concern by Tyler (1991), sufficient data had been collected to show that the apparent decline of 12 species was instead just a manifestation of local fluctuations. However, an additional 16 species were identified as suffering declines, such that there were now 27 species of concern. Observations confirmed that many of them were experiencing serious declines. In late 1997, a meeting was held to review the action plan and discuss what was known about the status of frogs across the country, and to attempt to devise some standard methods for investigating and mitigating the effects of frog declines. The outcomes of this meeting were published in the book *Declines and Disappearances of Australian Frogs* (Campbell 1999).

At the time of the 1997 meeting, declines of nine species were linked to specific causes, including habitat loss and degradation, and the introduction of exotic predators. However, 18 species fell into a category since termed "enigmatic declines" by Stuart *et al.* (2004). Comparative analyses have shown that these species share a variety of characteristics; for example, McDonald and Alford (1999) found that species closely associated with stream habitats have a higher probability of declining, and many authors pointed out that declines at high elevations had occurred in protected areas.

In 1998, the pathogenic chytrid fungus, *Batrachochytrium dendrobatidis*, was described (Berger *et al.* 1998). Histological examination of dead and dying individuals collected at the time of some of the declines in Queensland confirmed that the affected frogs had been heavily infected with chytrid (Berger *et al.* 1999). It is now generally accepted that chytridiomycosis was the proximate cause of mortality in the widespread die-offs of frogs in the Australian Wet Tropics in the late 1980s and early 1990s, and was probably to blame for the earlier disappearances of the gastric-brooding frogs and day frogs (*Taudactylus* spp.) in southern Queensland. It also appears to be a factor in the decline of Corroboree Frogs in southern Australia, and may be the cause of local die-offs of many other species. Since its discovery, chytrid has been detected in 48 native frog species in the wild (Speare and Berger 2005), as well as in the introduced and now widespread Cane Toad, *Bufo marinus*. The nomadic behaviour of this introduced species means that it is one possible vector of the disease, at least on a local scale. The wide distribution of this disease and the serious threat that it constitutes to Australian amphibians, and indeed globally, was explored in detail at a conference in August 2000, attended by national and international experts (Speare *et al.* 2001).

Nyctimystes dayi *(Endangered) and* Litoria nannotis *(Endangered) are rainforest specialists from Australia's Wet Tropics; both species vanished from upland sites throughout the region, most likely due to the disease chytridiomycosis. © Jodi Rowley*

One of the outcomes of this conference was the formal nomination of chytridiomycosis, to the Australian federal Department of Environment and Heritage, as a threatening process. This nomination went through several drafts and commenting stages, and was formally adopted in June 2005. Even before its final adoption, the threatening process nomination prompted state and federal governments to increase levels of funding of research and management aimed at reducing the threat. A threat abatement plan was prepared and accepted in 2006 (AGDEH 2006).

Conservation actions targeting threatened amphibians in Australia have included habitat creation and modification, introduced species control, and captive breeding. These actions have had some success at individual sites. Several frog species that survived at low elevations in the Wet Tropics, when dramatic population declines associated with chytridiomycosis were taking place at high elevations, appear to be recolonizing some high-elevation sites without any management intervention. However, 47 species (more than 20%) of extant Australian amphibians are still listed as threatened in the Global Amphibian Assessment, and remain susceptible to chytrid (as it spreads to new areas), continued habitat modification and destruction, and introduced species. A great deal of work remains before the status of Australian frogs is fully understood and measures to preserve their remaining diversity can be implemented.

Ross A. Alford and Jodi J.L. Rowley

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ESSAY 6.4. AMPHIBIANS OF THE PAPUAN REGION

The Papuan region extends from Indonesia's Maluku Islands, in the west, to the Solomon Islands and Fiji, in the east. It is dominated by the world's largest and highest tropical island, New Guinea, and includes thousands of islands, ranging from tiny coral atolls to forest-covered ranges that rise several kilometres above the ocean. The amphibian fauna here consists entirely of frogs; salamanders and caecilians do not extend east of Wallace's Line, which extends between Bali and Lombok, and Borneo and Sulawesi.

The Papuan frog fauna has been poorly documented compared with most other regions of the globe, despite the fact that many new species are being discovered and described each year. More than 320 species are known from the region, although it has been estimated that the total will exceed 600 given the current rates of discovery (Günther 2006). Three families dominate the frog fauna: Microhylidae, Hylidae, and Ranidae. The Microhylidae is the most species-rich group of frogs on New Guinea.

They occupy a diverse range of environments, from sea level to around 4,000m asl, and can be found in semi-aquatic, terrestrial, subterranean, and arboreal (canopy) habitats. The New Guinea microhylids include some of the smallest frogs on earth (such as *Oreophryne minuta*, DD) that is adult at just 9-11.5mm; Richards and Iskandar 2000), but also include a number of very large species, including one of the few species (*Asterophrys turpicola*, LC) known to attack and bite as a means of self-defence (Richards *et al*. 1994). All New Guinean microhylids share the habit of laying their eggs out of water. Embryos develop directly into small froglets, by-passing a free-swimming tadpole stage. It appears that the father is always responsible for guarding the embryos and, in the case of the sharp-snouted frog *Sphenophryne cornuta* (LC), for carrying the freshly hatched youngsters around on their back (Bickford 2004).

The Hylidae, or treefrogs, are generally found in bushes or trees. However, in the savannah habitats of southern New Guinea, there are two species (*Litoria nasuta*, LC, and *L. nigrofrenata*, LC) that live exclusively on the ground. Their long legs and slender build allow them to jump enormous distances to escape predators. Treefrogs reach their greatest diversity in the mountains and forests of New Guinea's interior. Here, one can find bizarre species, such as *Litoria prora* (LC), with its elongated nose spike, and its habit of hanging its eggs from leaves over small forest pools. New Guinea is dominated by a mountainous spine running across its centre, including the highest peaks between the Himalaya and Andes. These precipitous mountains are drained by a myriad of torrential streams, providing a challenging environment for frogs. Many New Guinean treefrogs in the genera *Litoria* and *Nyctimystes* have taken advantage of these extreme habitats, laying large eggs, glued under stones, in steep streams. The eggs hatch into tadpoles with enormous sucker-mouths that cling to rocks, in even the fastest of torrents (e.g., Günther 2006).

The Ranidae, or 'true-frogs', a family dominating much of the temperate northern hemisphere, is poorly represented on New Guinea. However, one group of ranid frogs, the platymantines, dominates the smaller archipelagos to the west, north, and north-east of New Guinea. Like the microhylids, these frogs have a 'direct-development' reproductive strategy, and it has been suggested that this has assisted their colonization of far-flung islands in the South Pacific. Frogs of the genus *Platymantis* occur on nearly all of the smaller archipelagos north of New Guinea, and have occupied the wide range of habitats used by microhylids on mainland New Guinea. The platymantine radiation is most evident on the Solomon Islands, with *Platymantis* and several endemic genera (*Batrachylodes*, *Ceratobatrachus* and *Palmatorrapia*) dominating the fauna. Many platymantine species are endemic to single islands or small island groups, and so may be susceptible to the massive habitat destruction occurring on most archipelagos from major logging operations.

Three other frog families are poorly represented in the Papuan region: Limnodynastidae, Myobatrachidae and Bufonidae. Limnodynastidae and Myobatrachidae dominate the nearby Australian fauna, but only seven species occur here and they all occur on New Guinea. Perhaps the most interesting of these are the three species of *Lechriodus* (Limnodynastidae) – large, broad-headed frogs that construct floating foam 'nests' into which they place their small eggs during reproduction. Bufonidae, or Toads, do not occur naturally in New Guinea and are represented by two exotic species, *Bufo marinus* and *Bufo melanostictus*. *Bufo marinus,* from the Neotropics, is widespread in eastern New Guinea and in many islands of Melanesia (Lever 2001). *Bufo melanostictus* is native to western Indonesia and has recently been introduced to Papua Province (New Guinea) (Iskandar and Colijn 2000; Menzies and Tapilatu 2000). The impacts of these species (if any) on native Papuan frogs are poorly understood, and require urgent assessment.

Male Sphenophryne cornuta *(Least Concern) are responsible for carrying the freshly hatched youngsters around on their back. © Stephen Richards*

Litoria prora *(Least Concern) hangs its eggs from leaves over small forest pools. © Stephen Richards*

Albericus siegfriedi *(Critically Endangered) is known only from high elevations on Mt Elimbari in Papua New Guinea. © Stephen Richards*

Globally, the Papuan region has the highest proportion of Data Deficient frog species. Many species are known from only one or two localities, and rugged terrain and logistical and bureaucratic hurdles have hindered attempts to relocate and assess the conservation status of these frogs. Although few species appear to be at immediate risk of extinction, the severely restricted distributions of some species, coupled with increasing rates of forest destruction, have raised concerns that a number of species may be susceptible to extinction in the future. One such example is the small, shrub-dwelling microhylid *Albericus siegfriedi* (CR), which is found only at high elevations on Mt Elimbari in Papua New Guinea, where the only known population is isolated in a patch of forest that is being gradually consumed by an expanding local human population.

Further research is required to better understand the distribution and conservation status of Data Deficient frogs in this poorly documented region. Given a land-tenure system throughout the region that largely precludes the designation of protected areas by the central government, conservation of the region's unique frog fauna will depend on developing education programs for, and conservation initiatives with, local landowners. Fortunately, the Papuan region retains one of the largest blocks of tropical forest on earth, and appropriate action now will help to ensure the long-term survival of its spectacular frog fauna.

Stephen Richards

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CHAPTER 7. AMPHIBIANS OF THE INDOMALAYAN REALM

Figure 1. *Summary of Red List categories for amphibians in the Indomalayan Realm. The percentage of species in each category is also given.*

Red List Category	Number of species
🟥 Extinct (EX)	20
Extinct in the Wild (EW)	0
🟥 Critically Endangered (CR)	32
🟧 Endangered (EN)	134
🟨 Vulnerable (VU)	143
🟩 Near Threatened (NT)	104
🟩 Least Concern (LC)	311
⬜ Data Deficient (DD)	255
Total Number of Species	**999**

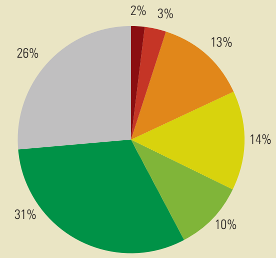


Table 1. *The Extinct amphibians of the Indomalayan Realm.*

Species	Country
Adenomus kandianus	Sri Lanka
Nannophrys guentheri	Sri Lanka
Philautus adspersus	Sri Lanka
Philautus dimbullae	Sri Lanka
Philautus eximius	Sri Lanka
Philautus extirpo	Sri Lanka
Philautus halyi	Sri Lanka
Philautus hypomelas	Sri Lanka
Philautus leucorhinus	Sri Lanka
Philautus malcolmsmithi	Sri Lanka
Philautus nanus	Sri Lanka
Philautus nasutus	Sri Lanka
Philautus oxyrhynchus	Sri Lanka
Philautus rugatus	Sri Lanka
Philautus stellatus	Sri Lanka
Philautus temporalis	Sri Lanka
Philautus travancoricus[1]	India
Philautus variabilis	Sri Lanka
Philautus zal	Sri Lanka
Philautus zimmeri	Sri Lanka

Raoul Bain, S.D. Biju, Rafe Brown, Indraneil Das, Arvin Diesmos, Sushil Dutta, David Gower, Robert Inger, Djoko Iskandar, Yoshio Kaneko, Michael Wai Neng Lau, Madhava Meegaskumbura, Annemarie Ohler, Theodore Papenfuss, Rohan Pethiyagoda, Bryan Stuart, Mark Wilkinson and Feng Xie

THE GEOGRAPHIC AND HUMAN CONTEXT

The Indomalayan Realm (sometimes termed the Oriental region) encompasses all of South and Southeast Asia, including the Indonesian and Philippine archipelagos, and incorporating the major offshore islands of Sri Lanka, Hainan, and Taiwan, as well as Japan's Ryukyu archipelago. The western and northern boundaries follow that of Olson *et al.* (2001), reaching Pakistan, the Himalaya, and southern subtropical China, although the boundary between the Palaearctic and Indomalayan Realm is somewhat unclear in south-east China. However, as here defined, the eastern boundary between Indomalaya and Australasia, which is usually taken as Wallace's line (an imaginary line named for Alfred Russell Wallace running between Borneo and Sulawesi, and between Bali and Lombok in Indonesia), is here taken to lie further to the east, such that the region includes all of Nusa Tenggara and a number of islands in Maluku (but excluding Seram, Amboin, Buru, Obi, Halmahera, Tanimbar and a few other smaller islands) (see Tyler 1999).

The geological, evolutionary, and climatic history of this region is complex and is reflected by the evolutionary history and diversity of its fauna. Peninsular India, which includes Sri Lanka, consists of a single tectonic plate (the Deccan or Indian Plate) that separated from Gondwanaland about 130 Ma and, after breaking away from Madagascar and the Seychelles around 90 Ma, rafted across the Tethys Sea eventually colliding with Eurasia at about 65-40 Ma (Beck *et al.* 2005). This massive collision resulted in the uplift of the Himalaya and the Tibetan plateau, which caused dramatic climatic changes over vast expanses across South Asia. Although the climate of almost the whole of Peninsular India is monsoonal, the region is varied both in terms of topography and vegetation, including, for example, rainforests (e.g., in the Western Ghats, south-western Sri Lanka, and Myanmar), arid areas (such as the Thar Desert in north-western India), low-lying swamps and mangroves (in the Sundarbans), and island systems (Andamans and Nicobars). Peninsular India is relatively flat, and is highest in the south-west, with the western flank of the plateau being formed by the Western Ghats.

Similarly, the coming together of the Indian plate with the Asian continental landmass has influenced much of the topography in mainland Southeast Asia, including the general north-south orientation of the mountains and main rivers. Much of this region (often referred to more generally as Indo-Burma) is characterized by distinct seasonal weather patterns (for example, in northern Vietnam and southern coastal China, the dominant weather pattern is the north or north-easterly monsoon during the northern winter and east or south-easterly monsoon in the summer). Originally, most of the region was dominated by broadleaf forests; the most diverse forests are the lowland mixed wet evergreen forests, which occur in climates with one to four dry months.

Another geological highlight of the region is the islands forming part of the Malay Archipelago, comprising the Greater Sundas – including Borneo and Sumatra (the third and sixth largest islands on earth, respectively), Java, and Sulawesi – the Lesser Sundas, the Philippines, and several islands of the Moluccas). This is one of the most active seismic regions in the world, and the site of some of the most dramatic seismic events known, including the eruption of Krakatau in 1883 and the earthquake that caused a massive tsunami in the Indian Ocean, just off the coast of Aceh, Sumatra, on December 26th, 2004. The highest point in the region is Gunung Kinabalu in northern Borneo at 4,101m. The islands of the Sunda shelf were connected to mainland Southeast Asia through most, if not all, of the Tertiary, and were also periodically connected during episodes of northern glaciation during the Quaternary, which is why the fauna and flora of these two regions have much in common. At the same time, oscillations in sea levels caused periodic severing of these ephemeral land bridges, isolating nearby continental islands, and presumably allowing for the evolution and accumulation of endemic species. The climate is tropical, and the vegetation, at least up until a few decades ago, comprised mainly lowland evergreen rainforest.

Theloderma gordoni *(Least Concern) is an Asian treefrog in the family Rhacophoridae. This species is known from monsoon forests in Thailand and Vietnam, and is believed to breed in cavities in trees. © Nikolai L. Orlov*

Human population density is very high across this region (averaging 124 people per square kilometre across Southeast Asia), including, as it does, several of the most populous countries on earth, such as India (with an estimated 1.1 billion people) and Indonesia (220 million). Population density ranges from a whopping 336 people per square kilometre in India, to 277 per square kilometre in the Philippines, 117 people per square kilometre in Indonesia, to 25 people per square kilometre in Lao P.D.R. The percentage of the population concentrated in urban areas also varies, with nearly 20% of people in Cambodia concentrated in urban areas, 30% in India, around 48% in Indonesia, and nearly two-thirds of people in the Philippines and Malaysia. With the exception of Singapore (gross national income per capita of US$24,000), all countries have a GNI per capita of less than US$5,000.

Given the high human population densities in the region, the impact of society on ecosystems has been severe. Mainland Southeast Asia was probably one of the first regions where agriculture developed (Diamond 1997), and there has been a long history of shifting or permanent small-scale agriculture. More recently, though, the exploitation of Southeast Asia's valuable timber for commercial trade, and the demand for land to grow cash-crops and trees, have led to widespread and rampant forest loss, particularly of lowland evergreen forest, dominated mainly by the giant dipterocarps. Several estimates of forest loss across the region are available; one recent study estimates that Kalimantan's protected lowland forests declined by 56% between 1985 and 2001 primarily from logging (Curran *et al.* 2004), and that less than 33% of lowland forest and peat swamp remains across all of Indonesian Borneo (Whitten *et al.* 2005). Unfortunately, even where rainforest habitat remains relatively intact, the unmitigated harvest and trade of some of the larger species of animals has been so intensive that the term "empty forest syndrome" was coined (Redford 1992); this "empty forest" phenomenon is particular apparent in China, Vietnam, Laos and Cambodia.

GLOBAL CONSERVATION STATUS

A total of 329 (33%) of the amphibian species in the Indomalayan Realm are considered to be globally threatened or Extinct (Figure 1). This is very similar to the global average. The Indomalayan Realm contains 17% of all globally threatened amphibians. When looking at the Red List Categories, Indomalaya accounts for only 7% of the world's CR species, but 17% of the EN species, and 21% of the VU species. Hence, on the basis of current knowledge, threatened Indomalayan amphibians are more likely to be in a lower category of threat, when compared with the global distribution of threatened species amongst categories. The percentage of DD species, 26% (255 species), is also similar to, though slightly higher than, the global average of 23%. This high percentage is not surprising, given that much of the region is still very poorly surveyed for amphibians.

Twenty of the world's 34 known amphibian extinctions (59%) have occurred in this region (Table 1), 19 of these in Sri Lanka and one in southern India. Eighteen of these species are frogs from the genus *Philautus*, and most of these probably had tiny ranges and died out as a result of extensive forest loss, perhaps as long ago as the late 1800s or early 1900s (Manamendra-Arachchi and Pethiyagoda 2005). In addition, one Critically Endangered species in the Indomalayan Realm is considered to be possibly extinct, *Philautus jacobsoni* from central Java, Indonesia. It is suspected that the apparent concentration of extinctions in Sri Lanka, as opposed to other parts of the region, is a result of better knowledge of this country due to recent herpetological work (e.g., Manamendra-Arachchi and Pethiyagoda 2005; and see Essay 4.1), in which the extant fauna has been extensively surveyed and compared with the historical baseline provided by museum specimens.

SPECIES RICHNESS AND ENDEMISM

Species Richness and Endemism Across Taxa

The 999 native amphibian species in the Indomalayan Realm represent 17% of the currently known global total of 5,915 species. Of these, 800 (or 80%) are endemic to the region (Table 2). All three amphibian orders, are represented in the Indomalayan Realm, but the frogs account for 92% of the species. Contrary to the situation in some other regions, endemism is much lower in the salamanders (46%) as compared with the frogs and toads (80%). This is because most of the Indomalayan salamanders occur in central China, on the poorly defined boundary (which is in fact a broad overlap zone) with the Palaearctic, thus occurring in both regions. Caecilian endemism is 100%. Although Indomalaya has the second highest number of species of any realm (though well behind the Neotropics), it has only 14 families, which is fewer than any realm except Australasia. Three of these families are endemic. Only 45 species (5% of the species in the region) are members of these endemic families, although the treefrog family Rhacophoridae occurs only marginally in the Palaearctic and Afrotropical Regions and is predominantly Indomalayan.

Under current climatic conditions, there is essentially no isolation between the Palaearctic and Indomalayan Realms, especially in China, and the boundary between these two faunas is somewhat arbitrary. The effect of this indistinct boundary is to reduce the level of endemism of both regions. Summaries of the amphibian fauna of the Indomalayan Realm are provided by Bourret (1942), Inger (1999), Iskandar and Colijn (2000), and Zhao (1999).

There are 81 genera (18% of the global total) occurring in the region, of which 37 (46%) are also endemic. Endemism at the generic level is much lower among the salamanders (with no endemic genera) than it is among the frogs and toads (46%), contrary to the situation in the Palaearctic. Generic level endemism is 100% among the caecilians. The most speciose endemic genera in the region are *Ichthyophis* (34 species), *Ansonia* (22 species), *Kalophrynus* (15 species), *Nyctibatrachus* (12 species) and *Micrixalus* (11 species). At the opposite end of the spectrum, there are 11 monotypic genera endemic to the Indomalayan Realm, all of which are frogs. The 44 non-endemic genera in Indomalaya include 37 frog genera (13 genera from the Ranidae, eight from the Megophryidae, seven from the Rhacophoridae, five from the Microhylidae, two from the Hylidae, and one each from Bombinatoridae and Bufonidae) and seven salamander genera (five from the Salamandridae, and one each from the Cryptobranchidae and the Hynobiidae). These non-endemics include the widespread genera *Bufo*, *Rana* and *Litoria*. It should be noted that future taxonomic changes are likely to have a major impact on the patterns outlined above, with a tendency for the number of genera (including monotypic genera) to increase.

As noted already, 29% (14/48) of the world's amphibian families occur in the Indomalayan Realm, and three of these are endemic: Nasikabatrachidae, Ichthyophiidae, and Uraeotyphlidae.[2] The characteristics of these families are provided in Chapter 1. Among the non-endemic families, the majority of Indomalayan species are in the Bufonidae (true toads), Megophryidae (Asian spadefoots), Microhylidae (narrow-mouthed toads), Ranidae (true frogs), Rhacophoridae (Asian treefrogs), and Salamandridae (newts and relatives). The Bufonidae occur widely in the Indomalayan Realm as far south and east as Sulawesi and the southern parts of the Philippines, with 84 species in eight genera.[3] Most species in the region are endemic, but 12 species are shared with the Palaearctic. All Indomalayan species breed by larval development, and occur in many different habitats.

There are 90 species across 10 genera in the Megophryidae in the Indomalayan Realm. This family is predominantly Indomalayan, with over 70% of its species occurring in the region, and 44% of them globally endemic (all other species occurring in the Palaearctic Region). Thirty-four species in China cross the Indomalayan-Palaearctic boundary. The family ranges from Nepal, Bangladesh, and north-eastern India, through central and southern China, and Southeast Asia as far as Java, Borneo and the Philippines.

The Microhylidae range very widely through the region, with 88 species, 77 of which are endemic. They occur in a wide variety of habitats, and all Indomalayan species breed by larval development, except for eight species of the genus *Oreophryne* in the eastern parts of Indonesia and the Philippines which are direct developers. Most of the non-endemic species are shared with the Palaearctic.

The Ranidae constitute the largest family in the Indomalayan Realm, accounting for over one-third of the total amphibian fauna of the region. One-third of the ranids are in the genus *Rana*[4]. The family is found throughout the region, occurring in most habitats, and all species breed by larval development, except in the genera *Ingerana* (5 species) and *Platymantis* (27 species).[5]

The Rhacophoridae are a predominantly Indomalayan family, with 263 species (and eight genera) occurring in the region, of which 230 are endemic. The family occurs widely through the region, east to the Philippines and Sulawesi. Many of the species are arboreal, and this family includes the flying frogs. The family is split approximately evenly between direct developers (many species in the genus *Philautus*) and larval developers (some of which use foam nests).[6]

The Salamandridae are predominantly a Palaearctic family, but 21 species occur in the Indomalayan Realm, 10 of which are endemic. Most of the Indomalayan species occur in southern China. All Indomalayan species breed by larval development.

Among the smaller non-endemic families, the Bombinatoridae (fire-bellied toads) have an unusual distribution. This family occurs mainly in the Palaearctic, but two species also occur in southern China (one extending into northern Vietnam), and another two (in the genus *Barbourula*) are highly isolated from the rest of the family in Kalimantan (southern Borneo) and in the Palawan island group (south-western Philippines). Some of these are highly aquatic species, with the genus *Bombina* breeding by larval development (the breeding remaining unknown in *Barbourula*).

The Hylidae are absent from much of the region, but eight species in the genus *Hyla* occur in the northern parts of the region (mainly in China) and four species in the genus *Litoria* occur on islands in the extreme east of the region in Indonesia.

The giant salamanders (Cryptobranchidae) are represented in the region by a single non-endemic species (the Chinese Giant Salamander *Andrias davidianus*), which until recently occurred widely in southern China. These animals are aquatic and are associated with clear streams where they breed by larval development.

The Asian salamanders (Hynobiidae) are mainly a Palaearctic family having their distribution centred on Japan and China, with six species occurring in the Indomalayan Realm. All species have larval development.

The caecilian family Caeciliidae occurs predominantly in the Neotropics and Afrotropics, but 10 species occur in India, mainly in the Western Ghats in the south of the country, though only one species is present in the north-east. All Indomalayan species are assumed to have terrestrial eggs and breed by direct development, although direct evidence is very scarce (only known for one species, *Gegeneophis ramaswamii*).

There are high percentages of threatened and extinct species in most families in the Indomalayan Realm (Table 3). The three small families Bombinatoridae, Nasikabatrachidae, and Cryptobranchidae are entirely composed of threatened species, and all but one species of Hynobiidae is threatened. The threat level among the salamanders is much higher than that of the frogs, with over half of the species at risk. The salamander faunas of the Palaearctic, Nearctic and Neotropics also face high threat levels. In the Indomalayan Realm, over-harvesting for medicine and food, coupled with habitat loss and/or restricted range, are probably the most significant threats facing these species (see later). Conversely, threat levels among caecilians appear to be very low, but this is probably an artefact of over 85% of the species in the region being Data Deficient (see Gower and Wilkinson 2005).

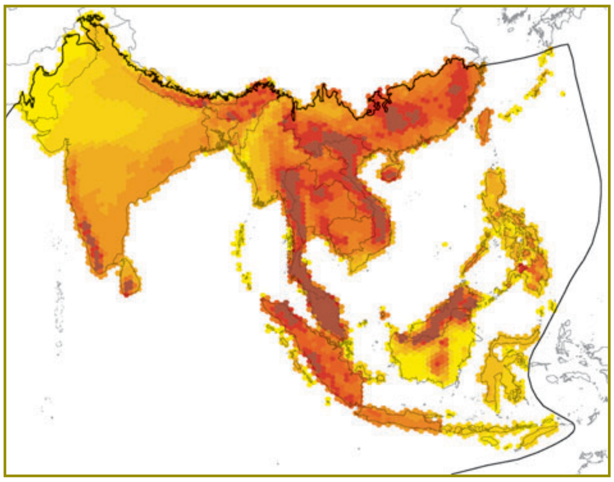


Figure 2. *The species richness of amphibians in the Indomalayan Realm, with darker colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes; maximum richness equals 84 species.*

Family	Native species (endemics to region)	Percentage of species in region that are endemic	Percentage of species in family that are endemic to region	Native genera (endemics to region)	Percentage of genera in region that are endemic	Percentage of genera in family that are endemic to region
Anura						
Bombinatoridae	4 (3)	75	30	2 (1)	50	50
Bufonidae	84 (72)	86	15	8 (7)	88	21
Hylidae	12 (4)	33	0.5	2 (0)	0	0
Megophryidae	90 (56)	62	44	10 (2)	20	20
Microhylidae	88 (77)	89	18	14 (9)	64	13
Nasikabatrachidae	1 (1)	100	100	1 (1)	100	100
Ranidae	375 (290)	77	44	24 (11)	46	28
Rhacophoridae	263 (230)	87	84	8 (1)	13	11
TOTAL ANURA	**917 (733)**	**80**	**14**	**69 (32)**	**46**	**9**
Caudata						
Cryptobranchidae	1 (0)	0	0	1 (0)	0	0
Hynobiidae	6 (3)	50	7	1 (0)	0	0
Salamandridae	21 (10)	48	14	5 (0)	0	0
TOTAL CAUDATA	**28 (13)**	**46**	**2**	**7 (0)**	**0**	**0**
Gymnophiona						
Caeciliidae	10 (10)	100	9	2 (2)	100	8
Ichthyophiidae	39 (39)	100	100	2 (2)	100	100
Uraeotyphlidae	5 (5)	100	100	1 (1)	100	100
TOTAL GYMNOPHIONA	**54 (54)**	**100**	**31**	**5 (5)**	**100**	**15**
TOTAL ALL AMPHIBIANS	**999 (800)**	**80**	**14**	**81 (37)**	**46**	**8**

Table 2. *The number of Indomalayan amphibians in each taxonomic Family present in the region.*

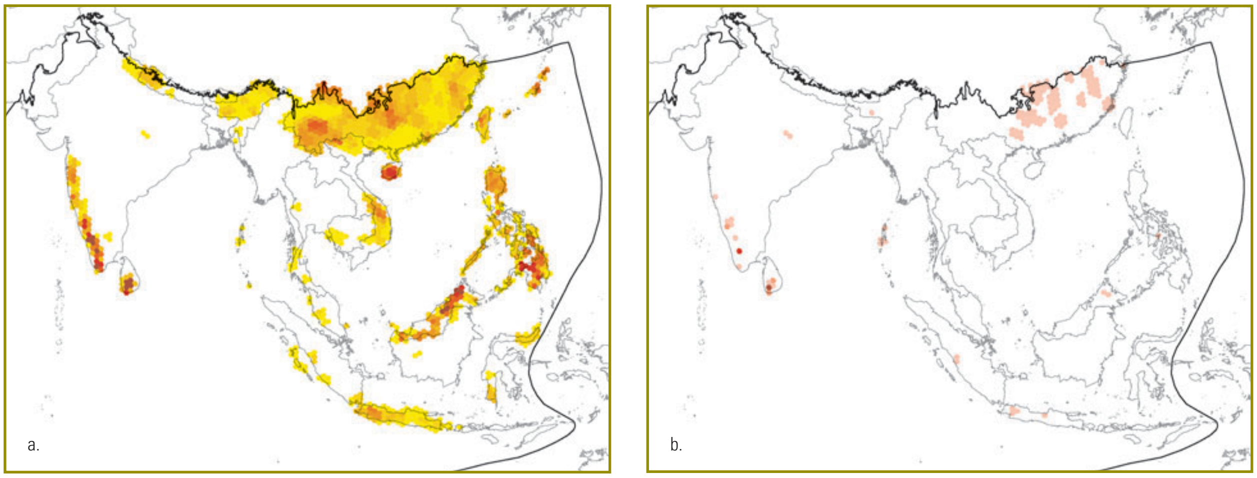
The Hole-in-the-Head Frog Huia cavitympanum *(Least Concern) is in the Family Ranidae and is endemic to central and northern Borneo, where it inhabits rainforests in hilly terrain. The tadpoles cling to rocks in strong rapids in clear streams. © Nikolai L. Orlov*

This close-up view of the head of Ichthyophis tricolor *(Least Concern) shows the tentacle which is characteristic of caecilians. This subterranean species from the Western Ghats in India lives in soil in wet semi-evergreen tropical forest, but also occurs in farmland and rubber plantations. Like other members of the Family Ichthyophiidae, it has aquatic larvae in streams. © Photo by John Measey, courtesy of The Natural History Museum, London*

Table 3. *The number of species within each IUCN Red List Category in each Family and Order in the Indomalayan Realm. Introduced species are not included.*

Family	EX	CR	EN	VU	NT	LC	DD	Total number of species	Number threatened or Extinct	% Threatened or Extinct
Anura										
Bombinatoridae	0	0	1	3	0	0	0	4	4	100
Bufonidae	1	3	17	13	11	27	12	84	34	40
Hylidae	0	0	0	0	0	9	3	12	0	0
Megophryidae	0	1	6	20	10	34	19	90	27	30
Microhylidae	0	1	8	12	11	31	25	88	21	24
Nasikabatrachidae	0	0	1	0	0	0	0	1	1	100
Ranidae	1	8	43	55	43	141	84	375	107	29
Rhacophoridae	18	17	50	33	25	57	63	263	118	45
TOTAL ANURA	**20**	**30**	**126**	**136**	**100**	**298**	**206**	**917**	**312**	**34**
Caudata										
Cryptobranchidae	0	1	0	0	0	0	0	1	1	100
Hynobiidae	0	0	3	2	0	0	1	6	5	83
Salamandridae	0	1	5	3	4	6	2	21	9	43
TOTAL CAUDATA	**0**	**2**	**8**	**5**	**4**	**6**	**3**	**28**	**15**	**54**
Gymnophiona										
Caeciliidae	0	0	0	0	0	1	9	10	0	0
Ichthyophiidae	0	0	0	2	0	5	32	39	2	5
Uraeotyphlidae	0	0	0	0	0	0	5	5	0	0
TOTAL GYMNOPHIONA	**0**	**0**	**0**	**2**	**0**	**6**	**46**	**54**	**2**	**4**
TOTAL ALL AMPHIBIANS	**20**	**32**	**134**	**143**	**104**	**310**	**255**	**999**	**329**	**33**

Figure 3. *a) The richness of threatened amphibians in the Indomalayan Realm, with darker colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes; maximum richness equals 29 species. b) The richness of CR amphibians in the Indomalayan Realm, with darker colours corresponding to regions of higher richness. Colour scale based on four quantile classes; maximum richness equals eight species.*



In general, the largest families in the region house the highest number of threatened frog species: Rhacophoridae, Ranidae, Bufonidae, Megophryidae and Microhylidae (Table 3). The Rhacophoridae has a particularly high percentage (45%) of threatened species, much of this reflecting high threat levels (54% of species) in the genus *Philautus*, in which many species have tiny ranges and can be seriously affected, even by the loss of small patches of habitat. In the Bufonidae, over 40% of the species are threatened, which is similar to confamilial levels in the Neotropics and Afrotropics (but not in the Palaearctic). Most threatened bufonid species (75%) are dependent on clear mountain streams in forests for breeding, a very threatened habitat (their larvae can be adversely affected by even modest levels of silt in the stream, which is a common affect of logging and other forms of forest clearance). The Megophryidae are dependent on the same habitats, are similarly impacted by siltation, and also face a high threat level (30%). The Indomalayan species of the family Ranidae are also facing extensive threats from both over-harvesting for human food and from habitat loss. The Microhylidae have the lowest level of threat among the larger frog families, but over 27% of the species are Data Deficient, higher than any other frog family, so this may be an underestimate. There are no threatened Hylidae in the region.

The great majority (90%) of the threatened amphibians in the Indomalayan Realm are either Endangered or Vulnerable. Furthermore, 17 of the 32 Critically Endangered species are rhacophorids, and 15 are in the genus *Philautus* (seven of these in India, seven in Sri Lanka, and one from Indonesia).

Geographic Patterns of Species Richness and Endemism

A map of overall species richness of amphibians in the Indomalayan Realm (Figure 2) shows great variation across the region. However, more than perhaps any other major biogeographic region, this map is somewhat biased by sampling intensity, and probably represents a misleading picture of amphibian species richness in this part of the world. Some of the overall patterns are probably accurate; for example, the large areas of low species richness in the drier parts of northern, central and eastern India, and in the lower Mekong Delta, and the peaks of highest species richness in the Western Ghats, south-western Sri Lanka, the Malaysian Peninsula, and northern Borneo. The overall patterns of species richness in southern China are also likely to be reasonably accurate. Through most of mainland Southeast Asia (excluding Malaysia), north-eastern India, Nepal, Bhutan, Sumatra, Kalimantan (Indonesian Borneo), Sulawesi, the Lesser Sunda Islands, and the Philippines, the patterns on Figure 2 are likely to reflect sampling intensity. Areas that are particularly poorly surveyed, include Bhutan, Myanmar, Thailand, Laos, Cambodiag, Vietnam and most of Indonesia (the stark contrast in recorded species richness between Malaysian and Indonesian Borneo emphasizes this point) (see Essay 7.1). As the results of future surveys and taxonomic work are incorporated into the Global Amphibian Assessment, our understanding of the patterns of Indomalayan amphibian species richness will change considerably.

The same caveats apply to the interpretation of the distribution of threatened species (Figure 3a) in the Indomalayan Realm. The concentrations of threatened species in the Western Ghats, Sri Lanka, southern China, northern Borneo, Java, and the Philippines probably reflect reality because these areas have been relatively heavily surveyed. However, there are likely to be important concentrations in places such as Myanmar, Thailand, Laos, Cambodia, Sumatra, Kalimantan, and Sulawesi that remain undetected due to lower sampling effort. Not surprisingly, given the small number of species involved, there are few noteworthy concentrations of Critically Endangered species in the region (Figure 3b), the most important being in Sri Lanka and southern India around the Western Ghats (see Essay 7.2; Essay 1.2). Much of the apparent concentration in China reflects the originally wide distribution of one species, the Chinese Giant Salamander.

Species Richness and Endemism within Countries

Amphibians occur naturally in 20 countries in the Indomalayan Realm (all except the Maldives). India has the largest number of species (236 extant) in the region (Figure 4), followed quite closely by China, Indonesia, and Malaysia (all have over 200 extant species). Vietnam and Thailand have over 100 extant species (Sri Lanka has 102 described species, but 19 are now considered extinct), but many countries have very low totals that almost certainly reflect inadequate survey effort (most notably Myanmar, Laos, Nepal, Cambodia, and Bhutan). India has by far the largest number of endemics (151 species), and China, Philippines, Indonesia, Sri Lanka, and Malaysia each have more than 50 endemics.

The amphibian fauna of parts of the Indomalayan Realm has been summarized in numerous national-level publications, including: India (Tiwari 1992; Dutta 1997; Das 1999, 2002; Daniel 2002; Daniels 2005); Pakistan (Khan 2006); Sri Lanka (Dutta and Manamendra-Arachchi 1996); Nepal (Schleich and Kästle 2002); China (Ye *et al.* 1993; Zhao and Adler 1993; Fei *et al.* 1999, 2005; Zhao *et al.* 2000); Japan (Maeda and Matsui 1999; Uchiyama *et al.* 2002; Goris and Maeda 2004); Peninsular Malaysia (Berry 1975); Thailand (Nabhitabhata 1989; Chan-ard 2003); Vietnam (Bain and Nguyen 2004; Bourret 1942; Inger *et al.* 1999; Ohler *et al.* 2000; Orlov *et al.* 2001, 2002; Ziegler 2002); Laos (Bourret 1942; Stuart 1999, 2005; Teynie *et al.* 2004); Cambodia (Ohler *et al.* 2002; Stuart *et al.* 2006; Stuart and Emmett in press); Thailand and Peninsular Malaysia (Chan-ard *et al.* 1999); Singapore (Lim and Lim 2002); Borneo (Inger 1966; Inger and Stuebing 1997; Malkmus *et al.* 2002); Java and Bali (Iskandar 1998; McKay 2006); and Philippines (Alcala and Brown 1998).

Although India has many more endemics than any other country in the region, Japanh, Sri Lanka and the Philippines (see Essay 7.3) have higher percentages of endemic species (all above or around 80%; Figure 5). Endemism is over 60% in India, over 50% in China, over 40% in Taiwan, and over 30% in Indonesia. The percentage endemism in a number of countries, such as Indonesia, can be expected to rise as the fauna becomes better known.

India has more threatened species (63) than any other country in the Indomalayan Realm (Figure 6). Countries with over 40 threatened species are Sri Lanka, Philippines, Malaysia and China. Indonesia has 29 threatened species; this surprisingly small number is probably a reflection of how poorly the amphibian fauna is known in this country (Essay 7.1). Vietnam has 15 threatened species, also probably a significant under-estimate (30% of the species in this country are Data Deficient). In much of mainland Southeast Asia, the numbers of threatened species are likely to be seriously under-estimated (partly because much of the amphibian fauna remains to be discovered, for example in Cambodia, Laos, Myanmar and Thailand; and see Essay 7.4).

The percentage of threatened amphibian species is highest in island nations (Figure 7), notably Sri Lanka (63%), the Philippines (49%), and Japan (46%). All other Indomalayan

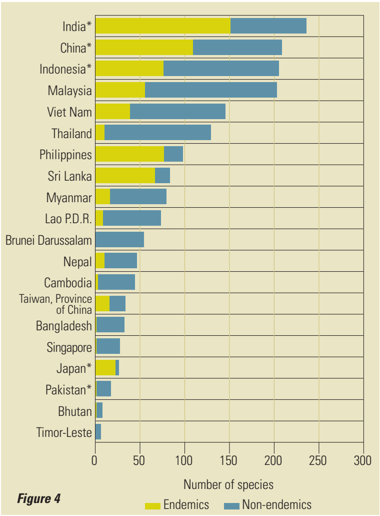


Figure 4. *The number of extant amphibians present in and endemic to each Indomalayan country. *denotes countries not entirely within the Indomalayan Realm, hence only the species whose ranges fall within the region are included. Note that 102 described species are known from Sri Lanka, but because 19 of these are extinct, only 83 are included in this figure.*

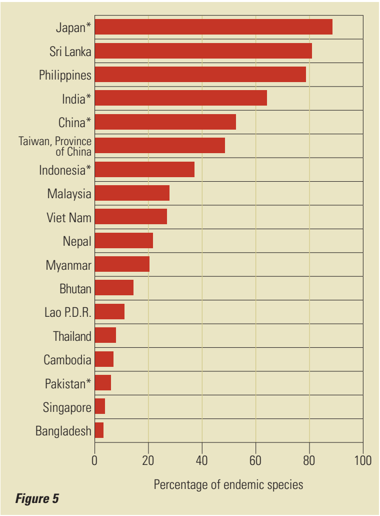


Figure 5. *Percentage of species endemic to each Indomalayan country. Countries with no endemic species are not included. *denotes countries not entirely within the Indomalayan Realm, hence only the species whose ranges fall within the region are included.*

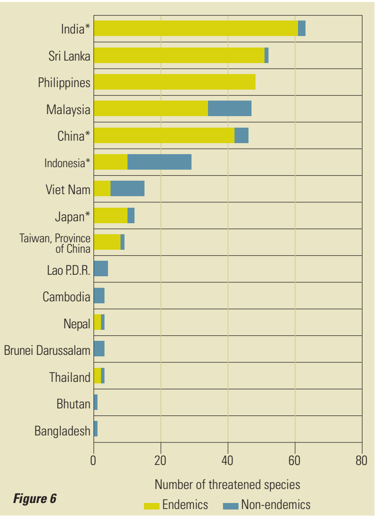


Figure 6. *The number of threatened amphibians present in and endemic to each Indomalayan country. Countries with no threatened species are not included in the diagram. *denotes countries not entirely within the Indomalayan Realm, hence only the species whose ranges fall within the region are included.*

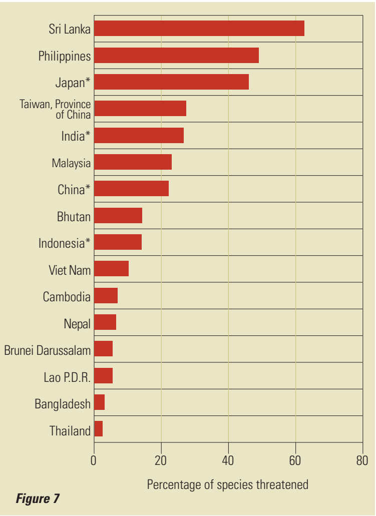


Figure 7. *Percentage of native species that are threatened. Countries with no threatened species are not included in the diagram. *denotes countries not entirely within the Indomalayan Realm, hence only the species whose ranges fall within the region are included.*

countries have levels of threat that are much lower than global average of 33%, though as mentioned above, this is likely to be under-estimated in several countries.

Assessments of the conservation status of Indomalayan amphibians have been carried out in only a few countries, for example: India (Molur and Walker 1998); Japan (Japan Agency of Environment 2000; Ota 2000); China (Zhao 1998; Xie and Wang 2004); and Philippines (Wildlife Conservation Society of the Philippines 1997). A regional overview of the threatened status of amphibians and reptiles in South Asia was published by Bamabaradeniya and Samarasekara (2001), and Pawar *et al.* (2007) carried out an assessment and prioritization of areas for amphibian conservation in north-eastern India.

There are only 32 Critically Endangered Indomalayan species, but 13 of these occur in India and 11 in Sri Lanka. Outside these two countries, there are three Critically Endangered species each in China and Indonesia, and one each in Malaysia and the Philippines.

HABITAT AND ECOLOGY

Habitat Preferences

Most Indomalayan amphibians (82%) occur in forests, including 66% in lowland tropical forest, and 47% in montane tropical forest (Table 4). As in other regions, forest species are more threatened than those occurring in other terrestrial habitats, and montane forest species are more threatened than those in lowland forest. However, the level of threat to lowland tropical forest species in the Indomalayan Realm (33%) is higher than that in the Afrotropical Region (23%), though very similar to that in the Neotropical Region (30%). Among the aquatic habitats, the level of threat is highest in flowing freshwater. So, as in other regions, forest-dwelling and stream-associated amphibians are more likely to be threatened than those occurring in any other habitats. This is the combination of habitat preferences that has been associated with rapid declines in amphibian populations worldwide (Stuart *et al.* 2004). Almost one-quarter of the fauna (23%) can survive in secondary terrestrial habitats (Table 4; Figure 8). This latter figure is higher than in either the Afrotropics or the Neotropics. Table 4 and Figure 8 show that amphibians occurring in savannahs, shrubland, and arid and semi-arid habitats are less likely to be threatened than those occurring in other habitats.

Reproductive modes

Larval development is by far the most common reproductive mode in the Indomalayan Realm (81% of species), compared with 18% for direct development (Table 5). There are no live-bearing species in the region. These figures compare with the global picture of 68% larval development, 30% direct development, and 1% live-bearing. The presumed direct-developing Indomalayan amphibians are dominated by rhacophorid treefrogs in the genus *Philautus*, and also include the ranid frog genera *Platymantis* and *Ingerana*, and the microhylid genus *Oreophryne*, as well as perhaps the caecilian genera *Gegeneophis* and *Indotyphlus*.

In the Indomalayan Realm, the percentage of globally threatened or Extinct direct-developing species is much higher than in the larval-developing species (Table 5), a pattern repeated in several other regions.

MAJOR THREATS

As is the case in all other regions, habitat loss is overwhelmingly the major threat to amphibians in the Indomalayan Realm (Table 6; Figure 9), affecting nearly 90% of the threatened species. Pollution is the next most serious threat, impacting nearly one-third of threatened species. All other threats have much lower impacts, although utilization is implicated in the rapid decline of over 20 species (see below). Many of those species being utilized are listed as Near Threatened, so they do not show in this analysis. Chytridiomycosis has not been recorded in the region.

The impacts of vegetation removal (mainly via logging) (affecting 64% of the threatened species) and expanding croplands (61%) are the most severe types of habitat loss impacting amphibians, followed by urbanization and industrial development (46%) and tree plantations (18%). Livestock constitutes a less important threat in most cases.

Habitat type	Number of species in each habitat	% of all species occurring in the habitat	Threatened or Extinct species	% of species occurring in habitat that are Threatened or Extinct
Forest	823	82	298	36
All tropical forest	800	80	291	36
Lowland tropical forest	655	66	218	33
Montane tropical forest	474	47	195	41
Savannah	17	2	0	0
Grassland	95	10	21	22
Shrubland	116	12	14	12
Secondary terrestrial habitats	229	23	50	22
Flowing freshwater	505	51	155	31
Marsh/swamp	113	11	19	17
Still open freshwater	300	30	55	18
Arid and semi-arid habitats	3	0.4	0	0

Table 4. *The habitat preferences of amphibians in the Indomalayan Realm.*

Reproductive mode	All Species	Threatened or Extinct species	% Threatened or Extinct
Direct development	181	121	67
Larval development	807	204	25
Live-bearing	0	0	-
Not known	11	4	36

Table 5. *Indomalayan amphibians categorized by reproductive mode.*

This unidentified, and possibly undescribed, species of Leptobrachium *from the Annamite Mountains in Cambodia is from the Asian spadefoot Family Megophryidae. Like most other members of the Family, it is associated with streams in hilly forested areas. © David Emmett*

A total of 143 species (26 of which are threatened) are recorded as being harvested by people in the region. The most common reasons for harvesting are for human consumption (112 species, mostly at local and national levels), pet trade (31 species, mostly at international and national levels), and medicine (27 species, mostly at local and national levels) (Table 7). Not all of the amphibian harvesting in the region is considered to constitute a major threat to these species. Of the 143 species being harvested, utilization is considered to be a threat for 87 (of which 26 are threatened species for which harvesting is believed to be contributing to a deterioration in their status). Twenty of these 26 species seriously threatened by over-harvesting occur in China, where many species of amphibians are extensively harvested for human food and medicines. Examples include 16 species of ranid frog (eight in the genus *Paa*), and six species of salamander (including the Chinese Giant Salamander). Threatened species outside China that are heavily harvested include three species of ranid frog in the Philippines and two in Indonesia.

POPULATION STATUS AND TRENDS

Estimates of Population Trends

A summary of the inferred population trends of Indomalayan amphibians is presented in Table 8, inferred from trends in the state of the habitats on which the species depend (though in some cases, population declines have been noted, especially for species that are being over-harvested). The overall population trends of Indomalayan amphibians are worse than the global trends (where 42% are decreasing and only 27% are stable). In both cases, the percentage of increasing species is very small.

"Rapidly Declining" Species

Of the 470 globally "rapidly declining" species, 58 (12%) occur within the Indomalayan Realm. Twenty of these 58 species are in decline due to over-exploitation, 37 due to reduced habitat, and one due to so-called "enigmatic declines". Not surprisingly for this region, more declines are attributed to reduced habitat and over-exploitation than to enigmatic declines. The Indomalayan Realm accounts for 53% of the world's rapid declines due to over-exploitation, but only 18% of the reduced habitat declines, and 0.4% of the enigmatic declines. Although one species in the region, *Leptophryne cruentata* (CR) from Java, has been recorded as undergoing an enigmatic decline, the causes of this decline are not known, and have not so far been linked to either chytridiomycosis or climate change (although these two threats have now been associated with many such declines that have taken place elsewhere in the

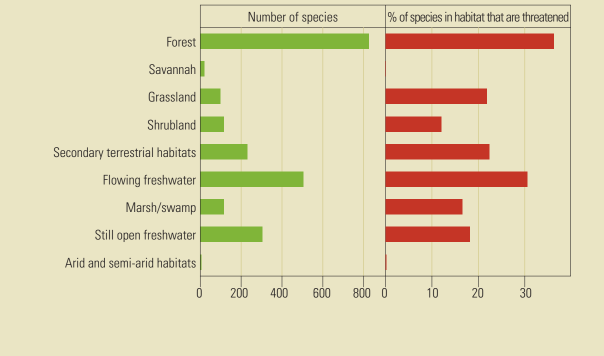


Figure 8. *The habitat preferences of Indomalayan amphibians. The plot on the left-hand side shows the number of species in the region in each habitat type. On the right-hand side, the percentage of these species which are threatened is given.*

Table 6. *The major threats to globally threatened amphibians in the Indomalayan Realm. Only present threats to species are tallied.*

Threat type	Threatened species	% Threatened Species
Habitat loss	272	88
Agriculture – Crops	188	61
Agriculture – Tree plantations	57	18
Agriculture – Livestock	15	5
Timber and other vegetation removal	198	64
Urbanization and industrial development	142	46
Invasive species	10	3
Utilization	26	8
Accidental mortality	10	3
Pollution	100	32
Natural disasters	25	8
Disease	1	0.3
Human disturbance	18	6
Fire	17	6

Figure 9. *The major threats impacting threatened amphibians in the Indomalayan Realm.*

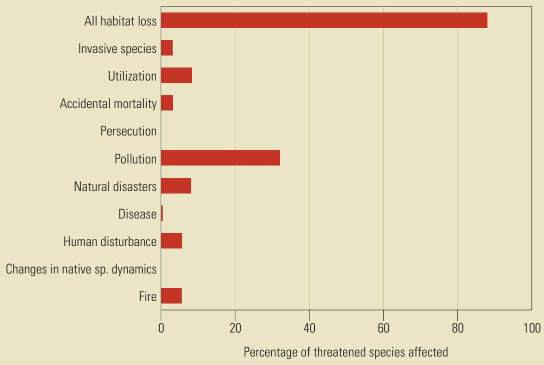


Table 7. *The purposes for which amphibians are used in the Indomalayan Realm. The numbers in brackets are the number of species within the total that are threatened species.*

Purpose	Subsistence	Sub-national/ National	Regional/ International	Number of species
Food – human	109 (22)	32 (8)	8 (1)	112 (22)
Food – animal	1 (0)	0	0	1 (0)
Medicine – human and veterinary	27 (2)	13 (2)	3 (0)	27 (2)
Pets, display animals	5 (2)	21 (6)	30 (6)	31 (7)
Research	1 (1)	6 (1)	1 (0)	7 (1)
Specimen collecting	1 (1)	0	0	1 (1)

Table 8. *The population trends for all extant Indomalayan amphibians.*

Population Trend	Number of species	% of extant species
Decreasing	509	52
Stable	161	16
Increasing	2	0.2
Unknown	307	31

Table 9. *The number of species in "rapid decline" and "over exploited decline" in the Indomalayan Realm by Family.*

Family	Number of species in "rapid decline"	Percentage of species in family in "rapid decline"	Number of species in "over-exploited decline"	Percentage of species in family in "over-exploited decline"
Bufonidae	8	10	0	0
Megophryidae	2	2	0	0
Microhylidae	6	7	2	2
Ranidae	30	8	15	4
Rhacophoridae	9	3	0	0
Cryptobranchidae	1	100	1	100
Salamandridae	2	10	2	10

Breeding and larval development in the microhylid frog Metaphrynella sundana *(Least Concern) takes place in water-filled tree holes from where the males call. It lives in lowland primary rainforest, and is widely distributed in Borneo, with a single specimen having been collected from northern Sumatra. © Björn Lardner*

The Shanjing Emperor Newt Tylototriton shanjing *(Near Threatened) from the Family Salamandridae is known only from Yunnan in southern China where it inhabits hill forests and secondary forest. It is subject to over-collection for traditional Chinese medicine, and small numbers are also exported for the international pet trade. © Henk Wallays*

world (Lips *et al.* 2006; Pounds *et al.* 2006). A full list of all "rapidly declining" species is provided in Appendix IV and includes their occurrence within each of the realms.

The "rapidly declining" species in the Indomalayan Realm show a distinct taxonomic pattern (Table 9), as over half of them, and 75% of "over-exploited" species are ranids. Among the larger families, the Bufonidae, Salamandridae, Ranidae and Microhylidae show a higher tendency to serious decline than the Megophryidae and Rhacophoridae. There are no Indomalayan species in serious decline in the Bombinatoridae, Hylidae, Nasikabatrachidae, Hynobiidae, Caeciliidae, Ichthyophiidae and Uraeotyphlidae (though these last three are very poorly known caecilian families in which most species are Data Deficient). In one small family, Cryptobranchidae, the only species in the region is in "rapid decline" and "over-exploited decline". Among the larger families, "over-exploited declines" are concentrated in the Ranidae and the Salamandridae.

Species in "rapid decline" in the Indomalayan Realm show a clear geographic pattern as well, since the major concentration of declines is in Malaysia (32 species) and Indonesia (31 species), followed by China (15), Vietnam (seven), and Thailand and the Philippines (both with five). For Malaysia and Indonesia, most of the declining species are on Borneo, where there has been very severe loss of lowland rainforest (see Essay 7.5). Of the "over-exploited declines", 14 are in China, and seven in Vietnam.

KEY FINDINGS

- A total of 999 species are recorded from the Indomalayan Realm, of which 329 (33%) are considered threatened or Extinct.
- At the species level, 800 amphibians (80%) are endemic to the Indomalayan Realm; of the 14 families found in the region, three are endemic, and of 81 amphibian genera occurring, 37 are endemic. Endemism would be higher, were it not for the unclear and somewhat arbitrary boundary with the Palaearctic Region, especially in China.
- The percentage of threatened and/or extinct species is higher than in many other parts of the world, and highest in the families Bombinatoridae (100%), Nasikabatrachidae (100%), Cryptobranchidae (100%), Hynobiidae (83%), Rhacophoridae (45%), Salamandridae (43%), and Bufonidae (40%).
- Overall, the threat levels are much higher among salamander species (54%) than frogs (34%). Caecilians are very poorly known in the region, with over 85% of the species being Data Deficient.
- Geographic concentrations of threatened species in the Indomalayan Realm occur in the Western Ghats (southern India), Sri Lanka, southern China, northern Borneo, Java and the Philippines; there are likely to be important concentrations in places such as Myanmar, Thailand, Laos, Cambodia, Sumatra, Kalimantan, and Sulawesi that remain undetected.
- India has the largest number of species (236) in the region, followed quite closely by China, Indonesia and Malaysia (all have over 200 species). Many countries have very low totals that almost certainly reflect inadequate survey efforts.
- India has by far the largest number of endemics (151 species) within the region, and China, Philippines, Indonesia, Sri Lanka, and Malaysia each have more than 50 endemics.
- India has more threatened species (63) than any other country in the Indomalayan Realm. Countries with over 40 threatened species are Sri Lanka, Philippines, China, and Malaysia.
- The percentage of threatened amphibian species is highest in island nations, notably Sri Lanka (63%), the Philippines (49%), and Japan (46%).
- Threatened species tend to show distinct habitat preferences, with forest-dwelling and stream-associated species being the most threatened (36% and 31%, respectively). This mirrors patterns seen elsewhere in the world.
- Habitat loss, primarily due to the impacts of vegetation removal (mainly logging), expanding croplands, and urbanization and industrial development is affecting nearly 90% of the threatened species in the region. Pollution impacts nearly one-third of the threatened species. Chytridiomycosis, the emerging amphibian fungal disease, has not been recorded as a significant threat in the region so far.
- Of the 470 globally "rapidly declining" species, 12% occur within the region. Most of these rapid declines (69%) are caused by severe habitat loss, and 34% are due to over-exploitation. Over-exploitation is a more serious threat in the Indomalayan Realm than in any other part of the world, except the Palaearctic.
- Twenty amphibian extinctions have been recorded from the Indomalayan Realm, 19 in Sri Lanka and one in India. One species (from Indonesia) is possibly extinct.

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The treefrog Polypedates feae *(Least Concern) from the Family Rhacophoridae is widely, but sparsely, distributed in southern China, Vietnam, Laos, Thailand and Myanmar. It is generally associated with closed-canopy evergreen rainforest, and breeds in streams, ponds and paddy fields and holes in trees. © Nikolai L. Orlov*

Endnotes

1 Note that at the time of writing, this species was rediscovered at the type locality by S.D. Biju (pers. comm.).

2 According to taxonomic changes proposed by Frost *et al.* (2006), there are 18, as opposed to 14, families in the Indomalayan Realm, three of which (Nyctibatrachidae, Micrixalidae and Ichthyophiidae) are endemic.

3 Frost *et al.* (2006) transfer many of the Indomalayan species of *Bufo* to other genera.

4 Frost *et al.* (2006) transfer many of these to other genera.

5 Under Frost *et al*'s. (2006) arrangement, the Ranidae are split into several families, resulting in the following changes in the Indomalayan Realm: a) 13 species in the genera *Nyctibatrachus* and *Lankanectes* are transferred to the family Nyctibatrachidae, which is endemic to southern India and Sri Lanka; b) 141 Indomalayan species in the genera *Chaparana*, *Euphlyctis*, *Fejervarya*, *Hoplobatrachus*, *Limnonectes*, *Minervarya*, *Nannophrys*, *Nanorana*, *Occidozyg*a, *Paa* and *Sphaerotheca* are transferred to the predominantly Indomalayan family Dicroglossidae; c) 10 species from the genus *Indirana* from southern India are transferred to the predominantly Afrotropical family Petropedetidae; d) 11 species in the genus *Micrixalus* are transferred to the family Micrixalidae which is endemic to southern India; e) 32 species in the genera *Ingerana* and *Platymantis* are transferred to the predominantly Oceanian family Ceratobatrachidae; and f) 168 species in the genera *Amolops*, *Huia*, *Meristogenys*, *Pseudoamolops*, *Pterorana*, *Rana* and *Staurois* are retained in the Ranidae.

6 Frost *et al.* (2006) changes to the Ranidae result in the Rhacophoridae becoming the largest family in the Indomalayan Realm.

7 At the time of writing, Stuart *et al.* 2006 (*Raffles Bulletin of Zoology* **54**:129) presented the description of two new species, and no fewer than 11 new country records for Cambodia alone from the hilly regions of eastern Cambodia.

8 Note that most of Japan is in the Palaearctic Region, but the Ryukyu Islands are in the Indomalayan Realm.

The ranid frog Nyctibatrachus hussaini *(Endangered) is currently only known from Kudremukh National Park in the Western Ghats of India. It has been recorded from torrential hill streams in tropical evergreen forest, and its habitat is threatened by mining activities, and by the harvesting of wood and timber. © Rohit S. Naniwadekar*

ESSAY 7.1. AN OVERVIEW OF OUR KNOWLEDGE ON INDONESIAN AMPHIBIANS

Oreophryne minuta *(Data Deficient) from the Derewo River Basin in the mountains of western Papua, Indonesia, at 2,000m asl. © Djoko Iskandar*

Straddling the tropics with more than 17,000 islands, Indonesia has the longest coastline of any country in the world, and also has among the highest mountains in the tropics. Indonesia consists of three bioregions, namely Sundaland, Wallacea, and the Papuan realm. Sundaland comprises the three large islands of Borneo, Sumatra and Java, although politically Borneo is divided among three nations. Wallacea includes the large island of Sulawesi, and the smaller islands of two extensive archipelagos: the Malukus and the Lesser Sundas (Nusa Tenggara). The Papuan realm comprises Indonesia Papua (on New Guinea), plus a number of offshore islands.

That Indonesia is ranked as the second richest country in terms of known biodiversity in the world (Mittermeier *et al.* 1997) is significant when one considers that much of the region remains unexplored or poorly surveyed. Nonetheless, the remarkable diversity and endemism of its flora and fauna is underscored in the reports of numerous undescribed species discovered in practically every new expedition undertaken in the country. According to the results of the Global Amphibian Assessment, there are nearly 350 species of amphibians documented from Indonesia (ranking Indonesia as the sixth most important country for amphibian diversity), of which nearly half (46%) are endemic. However, as an indication of just how poorly known the fauna is, one-third of amphibian species in the country are classed as Data Deficient on the IUCN Red List (significantly higher than the global average).

The amphibian fauna on Indonesia has been for the most part overlooked since the end of World War II. The islands of Sumatra and Sulawesi are particularly poorly known, and very few publications deal with these two large islands. The faunas of Kalimantan (Indonesia Borneo) and Indonesian Papua, on the other hand, are relatively better documented, but only as a direct result of the influence of herpetological surveys undertaken in neighbouring Sabah and Sarawak (Malaysia) in Borneo, and Papua New Guinea in New Guinea. Whereas the number of described amphibians on Sumatra stood at 68 in 1923, the total now stands at around 100 species mainly due to new discoveries, although this number is likely to increase exponentially given our current knowledge of undescribed forms. There is a particular paucity of information on amphibian species in montane or even or at medium elevations on Sumatra (Inger and Voris 2001; Inger and Iskandar 2005). This is also the case for Borneo. For example, at the time of the publication of the first edition of their guide to the frogs of Borneo, Inger and Stuebing (1997) recorded 15 *Philautus* species from Borneo, though not a single species was observed in the Indonesian part (Kalimantan) even though this area occupies roughly two-thirds of the land mass. More than 80% of the amphibian species of Borneo have been described from either Sabah or Sarawak.

Sulawesi has very few species in common with other islands. At present, the island is considered to be species poor, although there are indications that numerous species await formal description, especially in the genera *Limnonectes* and *Rhacophorus* (Iskandar and Tjan 1994; Evans *et al.* 2002). Iskandar and Tjan (1994) reported at least 13 undescribed amphibian species and several other new records and doubled the number of species hitherto known from the island. However, the low number of amphibian genera represented is an indication that this island may truly have an impoverished fauna. The Lesser Sunda Islands are essentially arid and consequently low in species diversity, as is the case for the Malukus. When a workshop on the Biodiversity of New Guinea was held in Biak[1], a study revealed that the ratio of publications on Indonesian Papua compared with Papua New Guinea was roughly 1 to 14, suggesting that very few works have been done in the Indonesian part. This is also evident in the number of amphibian species in Indonesian Papua, which currently has at least 100 fewer described species than Papua New Guinea, even though Indonesia represents roughly half the land mass (see also Essay 6.4).

Of the three greater regions, Sundaland is richest in terms of species, although amphibian composition differs greatly among the three main islands, particularly at the generic level. The island of Borneo, the largest and the most ecologically diverse of three, has an extremely high number of endemic species (see Essay 7.5), though bearing in mind that most Bornean species have been described from Sabah or Sarawak. By contrast, the Wallacean region is depauperate in species (especially in the Lesser Sundas), with a little over 30 species recorded.

There is much variation in body-size among Indonesia amphibians, ranging from about 10mm in *Oreophryne minuta* (DD) from Papua (Richards and Iskandar 2000) – one of the smallest amphibian species in the world – to about 300mm in *Limnonectes blythii* (NT) of Sumatra, one of the largest frog species. Reproductive strategies include parental care (Inger 1966; Inger and Voris 1988; Brown and Iskandar 2002; Günther 2006) to tadpole laying in an as yet unnamed Sulawesian species (Iskandar and Tjan 1994; and see Chapter 1). Most eggs are laid in a single gelatinous mass, but many *Limnonectes* and *Platymantis* and all the New Guinean microhylids have a derived mode of reproduction (parental care).

Unfortunately, Indonesia is a country experiencing an exceptionally high rate of forest loss due to a combination of land conversion and forest fires, and while only 10% of the country's amphibians are listed as threatened, this probably will be shown to be considerably higher with further survey work. Most forest loss has occurred in the last three decades, a result of commercial logging and major agricultural projects (including oil palm plantations) in combination with government policies. In Sumatra, for example, illegal and unsustainable logging and non-timber forest product extraction are widespread, and fueled by high demand for hardwood timber from China, North America, Europe, and Japan. Fires have become a major threat in recent years, and may often be linked to logging operations that create flammable conditions by both leaving fuelwood on the forest floor, and through exposing the understory to drying (Whitten *et al.* 2004). It may be suspected that global climate change is resulting in the drying and dessication of a number of large aquatic areas, such as the Fly River Basin and lowland areas, but further detailed study is needed.

Nyctixalus margaritifer *(Vulnerable) occurs on the island of Java, Indonesia, at elevations above 700m asl. It was rediscovered in 1997 after a long period without any records. © Djoko Iskandar*

In conclusion, our knowledge of Indonesia's amphibians is scattered and largely based on what is known from faunistic surveys in a few areas only; no single area, even on Java, has reliable data on the ecology and distribution of amphibians. Survey work is hampered by the fact that many areas in the region are too remote or inaccessible for quick study and assessment, and the facilities and resources available for study are generally lacking. However, notwithstanding, there are several regions within Indonesia that represent urgent priorities for further survey work, particularly since they are likely to be characterized by high levels of endemism, including: Mounts Leuser and Kerinci in Sumatra, the Muller and Meratus ranges in Kalimantan, the Mengkoka Mountains in Sulawesi, and most parts of Indonesian Papua. Furthermore, we have virtually no amphibian records for small- to medium-sized islands such as Karimata in the west and most of the Malukus, especially as many of them have relatively unexplored high mountains.

Djoko T. Iskandar

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ESSAY 7.2. DIVERSITY AND CONSERVATION STATUS OF THE WESTERN GHATS AMPHIBIANS

The Western Ghats are a chain of mountains in western India running parallel to the coast for over 1,600km. The mountains in the northern portion begin as low-lying hills close to the Tapti River in Gujarat, increase in height as they pass southwards through the States of Maharashtra, Goa, Karnataka and Kerala, and end abruptly in the Mahendragiri Hills of Tamil Nadu State - the southernmost tip of Peninsular India. Along their entire length, there is only one major discontinuity, the biogeographically important 'Palghat Gap' of Kerala, which is approximately 30km wide and has an elevation of less than 100m above sea level (Figure 2).

Perhaps surprisingly for such a populous country as India, about one-third of the Western Ghats is still covered by natural vegetation, including about 20,000km^2 of rapidly diminishing tropical moist forest (Collins 1990). Although these areas may constitute only around 5% of the total land area of India, they contain at least 30% of India's native species (Rodgers and Panwar 1988).

The results of the Global Amphibian Assessment indicated that 237 amphibian species are present within India[1]. This impressive diversity includes 212 species of frogs and toads in seven families and 37 genera, at least 25 species of caecilians, and a single species of salamander (*Tylototriton verrucosus*) that lives in the mountains of the north-east. The amphibian fauna of India as a whole has been discussed in a number of publications, including Inger and Dutta (1986), Inger *et al.* (1987), Daniels (1992), Dutta (1997), Pillai and Ravichandran (1999), and Das (2000)[2].

The amphibian diversity of the Western Ghats is distinctive both in its diversity and endemism (Biju 2001; Biju and Bossuyt 2003). These mountains currently hold 131 recognized amphibian species in 25 genera, with 114 of these species (87%) being entirely restricted to this biodiversity hotspot. Higher-taxonomic-level endemism clearly makes this region important in the Asiatic region (Roelants *et al.* 2004; Bossuyt *et al.* 2004), with two families (Nasikabatrachidae and Uraeotyphlidae), and eight genera (*Indirana, Indotyphlus, Melanobatrachus, Micrixalus, Minervarya, Nasikabatrachus, Nyctibatrachus, Uraeotyphlus*) being endemic[3].

According to the results of the GAA, 53 amphibian species of the Western Ghats, or 40% of the amphibian fauna, are threatened with extinction[4] (Figure 1). In addition to the high number of threatened species, it is also worrying that many of the once locally common species (e.g., *Nyctibatrachus aliciae, N. minor, Micrixalus fuscus, Rhacophorus lateralis* and several of the more widespread *Philautus* species) appear to have visibly declined in recent years (S.D. Biju pers. obs.). Several species have not been recorded since their original descriptions (e.g., *Philautus flaviventris* and *P. chalazodes*), and the possibility exists that they are extinct.

It is very likely that the leading threat to the amphibian species of the Western Ghats is the continuing conversion or modification of natural habitats. This loss of habitat is largely driven by the continuing growth of the human population in this area, and the basic needs of these people for both agricultural and urban land. Significant threats to the remaining natural forests also come from the ongoing expansion of plantations (including both non-native timber plantations and tea and coffee estates); commercial logging operations; the extensive extraction of forest products such as firewood; and, perhaps more localized, but nonetheless highly damaging, mining for metal ores and gemstones. While there are no records to date in the Western Ghats of the disease chytridiomycosis, which has been implicated in the consider-

able declines of amphibian communities in Latin America and Australia, there is a need for field surveys to confirm the current absence of this pathogen.

The primary means of protecting the amphibians of the Western Ghats is through the region's extensive system of protected areas. There are a total of nine National Parks and 45 Wildlife Sanctuaries in the mountain range (Kothari *et al.* 1989; recent updating), covering a total area of 16,935km^2 or 11% of the Ghats (Collins 1990). Many of the threatened amphibian species have at least some part of their range within these parks and reserves, but it will be important to rapidly characterize how many Critically Endangered and Endangered species are not present within these protected areas. Urgent steps are needed to also protect the remaining habitat of these species to prevent imminent extinctions.

One of the largest problems for conserving the amphibian fauna of the Western Ghats is the lack of detailed systematic and other biological information for much of the region's amphibian species. Some 41 species from the Western Ghats are categorized as Data Deficient – these are species for which insufficient details are available on the taxonomic identity, distribution, or threats to determine whether these animals are of global conservation concern. A number of the Data Deficient species from the Western Ghats are known only from the original, historical description, which can often be brief or incomplete in a contemporary context, and in many instances does not include enough specific details about the initial collection locality. Additionally, the type-series has sometimes been lost or misplaced, meaning that there is very little information available to guide contemporary workers.

However, the greatest impediment to conservation and management of this rich amphibian fauna may be hidden in the vast number of species that remain to be described. Intense fieldwork (Biju 2001) has revealed that many clearly morphologically distinct species have not yet been scientifically documented. In addition, the intra-population structure of several of the currently well-recognized species remains very poorly known. It is becoming increasingly clearer that some of the taxa that are considered to be common and widespread in the Western Ghats may actually represent cryptic 'species complexes' – groups of similar looking taxa that form distinct evolutionary lineages (Bickford *et al.* 2007). In view of the ongoing threats to the remaining natural habitat of the Western Ghats, and considering that a number of species currently hidden within these complexes will have restricted ranges, these species may, in turn, be of significant conservation concern. Molecular approaches, such as DNA barcoding (see Essay 11.11),

Red List Category	Number of species
🟥 Extinct (EX)	1
Extinct in the Wild (EW)	0
🟥 Critically Endangered (CR)	10
🟧 Endangered (EN)	27
🟨 Vulnerable (VU)	16
🟩 Near Threatened (NT)	6
🟩 Least Concern (LC)	30
⬜ Data Deficient (DD)	41
Total taxa	**131**

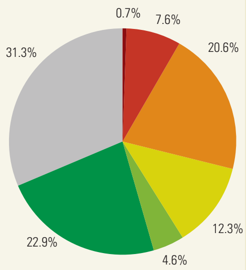

Figure 1. *Summary of the Red List status for amphibians in the Western Ghats, based on the results of the Global Amphibian Assessment.*

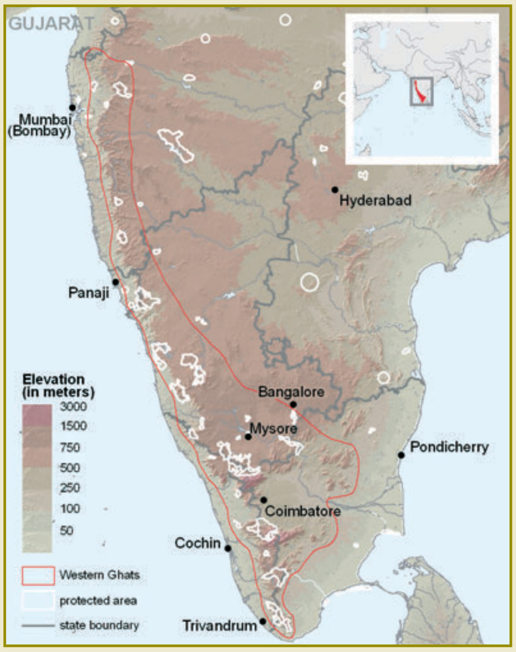

Figure 2. *Map of the Western Ghats showing a generalized boundary of the region, elevation, and protected areas in white.*

will be extremely useful to rapidly map many aspects of amphibian diversity in the Western Ghats.

Urgent work is now needed to describe, document, and protect these exceptional biota. To resolve the existing confusion, greater emphasis is needed on serious coordinated research activities for the Western Ghats amphibians. Perhaps most urgently, detailed collaborative studies by scientists working in different geographical areas of this long mountain chain are needed to finally determine the correct taxonomic identification of many of the region's amphibians. The conservation management of the exceptional amphibian fauna of the Western Ghats, and the biological diversity of this mountain range as a whole, can only benefit from such an investment.

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1 Frost (2007) currently recognizes 265 amphibian species present in India. This total includes a number of recently described species, such as the tree frog *Polypedates occidentalis* Das and Dutta (2006), not included in the 2005 results of the GAA.

2 Frost (2007) recognizes a diversity of 237 species of frogs and toads in 12 families (including the Western Ghats endemic Micrixalidae) and 50 genera, 27 species of caecilians, and a single species of salamander. Since this last version, a few additional new species of amphibian, such as the caecilian *Gegeneophis goaensis* (Bhatta *et al.* 2007), have been described from the Western Ghats.

3 Also, see Frost *et al.* (2006), Van Bocxlaer *et al.* (2006), Frost (2007) and Roelants *et al.* (2007), for emerging information on the high biological diversity of the Western Ghats.

4 In addition to the 52 threatened species (Critically Endangered, Endangered or Vulnerable), there are six Near Threatened species, and a single species regarded as Extinct.

ESSAY 7.3. PHILIPPINE AMPHIBIAN SPECIES BIODIVERSITY IS INCREASING BY LEAPS AND BOUNDS

The discovery and description of the diversity of Philippine amphibians began with early European and American professional naturalist collectors who made ancillary collections of amphibian specimens and returned these to museums in their native countries. Descriptions of these specimens were later prepared by early herpetologists such as Duméril, Bibron, Peters, Boettger, Boulenger, Günther, Mertens, Wiegmann, and Stejneger, among others. The first published descriptions of endemic Philippine species were soon followed by discoveries of strange and unique species that captured the attention and curiosity of biologists around the world.

Looking back as students of the history of herpetology in the Philippines, it is convenient now for us to think of five separate chapters in the study of Philippine herpetological diversity (Brown *et al.* 2002). These include the initial period of exploration described above, followed by the career of Edward Taylor (1913-1975). We think of Taylor as the "father" of Philippine herpetology because his work, involving multiple detailed monographs, resulted in descriptions of so many of the truly spectacular Philippine endemics and a first true appreciation of the staggering magnitude of herpetological diversity in the archipelago. The third phase was marked by the work of Robert Inger and the publication of his monograph "Systematics and zoogeography of Philippine Amphibia (Inger 1954). Inger's comprehensive review of Philippine amphibians marked a turning point in the history of herpetology in the country because of his systematic application of an explicitly stated species concept, statistical treatment of natural variation, and other advances. The fourth stage of Philippine herpetology includes the lengthy and productive collaboration of Angel Alcala and the late Walter Brown (1958-2000). This body of work included numerous comprehensive taxonomic reviews, new species descriptions, and a variety of the first ecological and developmental studies in Philippine herpetology. Finally, we consider the present day, on-going effort to review the amphibians and reptiles of the Philippines a fifth phase in the development of the study of the herpetofauna of the country. An examination of species accumulation over these years (Figure 1) provides us with an appreciation of the magnitude of taxonomic contributions from each of these five distinct periods in Philippine herpetology.

In 1993, the discovery of a new species of forest frog in the genus *Platymantis* from the mossy forests of Panay Island in central Philippines triggered a major reconsideration of species boundaries within this group. The new species (*P. panayensis*, EN) differed from an adjacent population (*P. hazelae*, EN) on nearby Negros Island by subtle differences in morphological proportions, slight differences in coloration, and by its distinct male advertisement call (Brown *et al.* 1997). The realization that closely related species may differ primarily by advertisement call unleashed a plethora of active fieldwork and taxonomic studies, resulting in a doubling of the number of species of *Platymantis* from 12 to 24 species, between 1997 and 2001 (summarized in Alcala and Brown 1999). With the appreciation that advertisement calls may provide us with insight into truly biologically meaningful suite of characters, we undertook a comprehensive assessment of the acoustic diversity of Philippine forest frogs along with a thorough re-evaluation of the species diversity in the Philippine members of the genus *Platymantis.* The other major advance in improving our understanding of species diversity in the Philippines has been the application of molecular phylogenetic approaches (Brown and Guttman 2002; Evans *et al.* 2003; Brown 2004) to new collections of genetic samples of amphibian species from a robust geographic coverage throughout the major island groups of the country. The combination of these new tools have provided new insights into species boundaries and helped uncover the presence of numerous cryptic species that had gone unnoticed for so many decades. Initial results of this ongoing work fortified our understanding of the degree to which biodiversity in Philippine Amphibia has been grossly underestimated by traditional, primarily morphology-based taxonomic practices (Figure 1). The result is a new appreciation of diversity that provides a fuller, more balanced, and biologically meaningful appreciation of the complex interactions of characteristics that have surfaced as most meaningful for the process of lineage diversification in Philippine amphibians (Figure 2).

Our current understanding of amphibian species diversity in the Philippines stands at 97 indigenous species (Brown *et al.* 2002; Diesmos *et al.* 2002). However, species descriptions of new frogs of the genus *Platymantis* currently in progress will soon increase that number to around 130 taxa. And, if work on other undescribed species of frogs of other genera that we are aware of were to be completed, the total number would eventually reach at least 165 species. If current trends in rates of species discoveries hold as biologists explore the still many biologically unexplored regions of the country, we expect a possible doubling of the richness of Philippine Amphibia within the next two decades.

The irony of the astonishing rates of species discovery, even as so many species are declining (Hanken 1999; Stuart *et al.* 2004; Köhler *et al.* 2005), coupled with the devastating loss of forested habitat in the Philippines, convinces us that no higher conservation urgency in the world exists than that of the megadiverse Philippine global biodiversity hotspot (Myers *et al.* 2000; Catibog-Sinha and Heaney 2006). With so few trained workers actively working to discover and describe new species of Philippine amphibians, we are left with doubt as to whether we can survey and characterize Philippine amphibian biodiversity within the timeframe of our own careers. Consequently, there can be no greater priority than training new students in amphibian field studies and doing everything possible to overcome logistical and bureaucratic obstacles to field work while at the same time investing in collections and related repositories. It is through the building of natural history collection resources (including digital photographic archives, sound libraries, and genetic collection resources) that will enable tomorrow's generations of biologists the opportunity to re-assess our work in light of technological advances of the future. Coupled with constant and regular conservation status assessments, we are convinced that these efforts provide the best chances of preventing impending catastrophic amphibian extinctions that loom on the horizon if we fail to take action now (Lips *et al.* 2003; Sodhi *et al.* 2004; Stuart *et al.* 2004).

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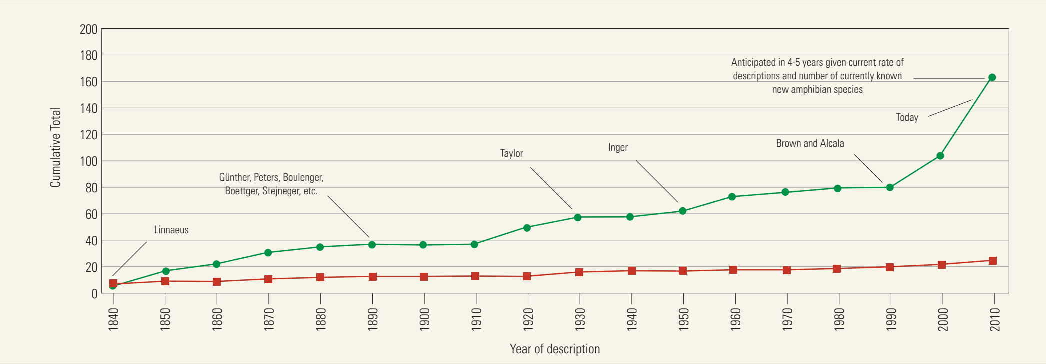

Figure 1. *Species accumulation curve for Philippine amphibians, including endemic (circles) and non-endemic (squares) species. Estimates of numbers of new species awaiting description are based on a combination of morphological, behavioural, and ecological character differences, with species' distinctiveness confirmed by bioacoustic and molecular data.*

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Figure 2. *Representatives of the species complexes defined by Brown* et al. *(1997), in part corresponding to the ecomorph classes defined by Brown (2004):* P. indeprensus *of the* Platymantis dorsalis *Species Group (ground frogs; A);* P. isarog *of the* Platymantis hazelae *Species Group (shrub frogs; B);* P. banahao *of the* Platymantis guentheri *Species Group (treefrogs; C); and an example of an enigmatic intermediate:* Platymantis insulata *(a terrestrial species, nested within the treefrog clade; D). All photos © Rafe Brown, 2006. Courtesy of HerpWatch Philippines*

ESSAY 7.4. AMPHIBIAN SPECIES DISCOVERY IN MAINLAND SOUTHEAST ASIA

The global number of recognized amphibian species has risen dramatically over the past two decades (Hanken 1999; Köhler *et al.* 2005), making amphibians one of the animal groups with the highest proportional rate of description of new species (Hanken 1999). This increase is primarily due to the discovery of truly 'novel' forms by intensified scientific collecting in previously unexplored parts of the world. Molecular genetic and bioacoustic tools in systematic studies have also aided the discovery of 'cryptic' species that were previously overlooked because they morphologically resemble other species.

Mainland Southeast Asia (defined in Figure 1) is no exception to this global trend of rapid, recent discovery of new amphibian species. Beginning in 1834 with the description of *Hoplobatrachus rugulosus* from Hong Kong, a total of 299 currently recognized species of limbed amphibians (excluding caecilians) were discovered and described from the region (Figure 1). Most strikingly, the years 2005 and 2006 (through the time of writing in early November) each yielded 16 new amphibian species, the highest number of annual descriptions from the region since the advent of Linnean classification. The descriptions of 2005-2006 came from every country in the region, suggesting that the very recent boost is not explained by scientific collecting in a localized 'hotspot'. Prior to the last few years, there have been three peaks of discovery in mainland Southeast Asia, with 10-11 currently recognized species described in each of the years 1937, 1962, and 1983 (Figure 1). Two of these peaks reflect the significant contributions of 11 new species from Vietnam by Bourret (1937) and seven new species from Guangxi Province, China, by Liu and Hu (1962), while the third peak is primarily a coincidence of species descriptions from southern China by a number of Chinese authors.

Every amphibian species described to date from mainland Southeast Asia has been distinguished from its closest relatives on the basis of morphological differences. However, a number of studies have used bioacoustic data (e.g., Kuramoto and Wang 1987; Wogan *et al.* 2003) or molecular genetic data (e.g., Li *et al.* 2001; Bain *et al.* 2003) to either discover a new species, or corroborate the morphological distinctiveness of a new species. Every molecular genetic study to date that has broadly sampled populations across the range of a widespread frog species in mainland Southeast Asia has uncovered genetic diversity that has been interpreted as unrecognized species diversity (Stuart *et al.* 2006). These findings suggest that species diversity in the region remains significantly underestimated. Molecular genetic and bioacoustic tools are likely to play increasingly important roles in the process of discovering amphibian species diversity in the region.

One of the most striking examples of recent Southeast Asian amphibian species discoveries is found in the cascade frogs of the genus *Odorrana*. Of the 30 species of *Odorrana* described from the region, 19 have been described since 2001. Many of these new *Odorrana* are morphologically very similar and have been confused with other species for over a century (Bain *et al.* 2003; Stuart *et al.* 2006). Molecular genetic tools have shown that several morphologically similar, but genetically distinct, lineages of *Odorrana* coexist in the same streams. The ecological and behavioural mechanisms that these coexisting species use to maintain their genetic distinctiveness are currently unknown.

The sociological nature of species discovery and description in the range has changed over time. Historically, scientists working on amphibians in the region tended to work and publish alone or with very few colleagues. Today, the process of discovering and describing species in the region involves collaboration among scientists from within and outside of range countries. For example, the average number of authors on species descriptions increased over time in peak years, with 1.0 in 1937, 1.73 in 1962, 2.0 in 1983, 2.38 in 2005, and 2.94 in 2006. The 2005-2006 boom in species descriptions of amphibians from mainland Southeast Asia represented papers authored by (alphabetically) American, Burmese, Cambodian, Canadian, Chinese, French, German, Indian, Japanese, Russian, Thai, and Vietnamese authors. The exchange of expertise and division of labour inherent in these growing collaborations may partly explain the increasing productivity of amphibian taxonomists working in the region.

Our current understanding of amphibian species diversity in the Philippines stands at 102 indigenous species and five or six introduced species (Brown *et al.* 2002; Diesmos *et al.* 2002; Brown 2007). However, species descriptions of new frogs of the genus *Platymantis* currently in progress will soon increase that number to around 140 taxa. Novel findings await discovery in the vast areas that are still under-surveyed. A number of geographically widespread, single species that are suspected to represent species complexes have not yet been studied with molecular genetic or bioacoustic tools. Some of these widespread species may be found to contain multiple, morphologically cryptic species, each having much smaller geographic ranges. Conversely, newly discovered species are often prematurely labeled as endemic to a limited geographic area only because scientists have just become aware of them. Although international cooperation among amphibian taxonomists is increasing, many studies have been restricted by political boundaries. As a result, some species have been described on opposite sides of borders under different names, and their known geographic distributions are limited by these sampling restrictions. These challenges indicate that much remains to be learned, and discovery efforts in the field and laboratory promise to rapidly improve our understanding of amphibian species diversity in the region.

Bryan L. Stuart and Raoul H. Bain

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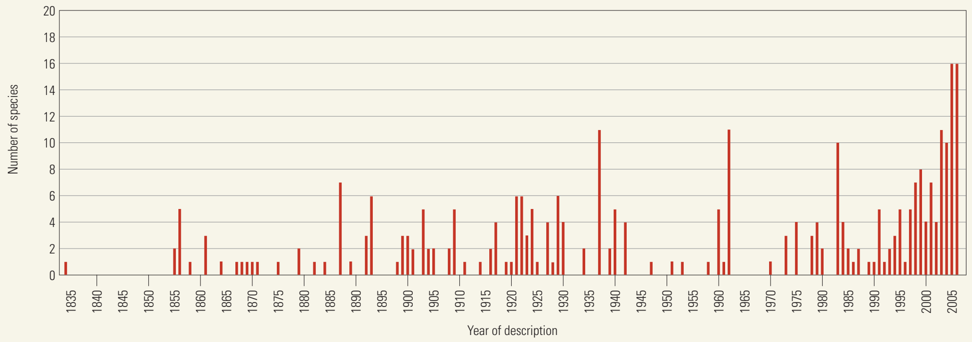

Figure 1. *Annual amphibian species descriptions (n = 299 descriptions) from mainland Southeast Asia, defined as Vietnam, Laos, Cambodia, Thailand (north of the Isthmus of Kra), Myanmar (north of the Isthmus of Kra), and southern China (Yunnan, Guangxi, Guangdong, Fujian, Hainan, Hong Kong and Taiwan). Data were obtained from Frost (2006) and subsequently published literature, except that* Hoplobatrachus rugulosus *was not treated as a junior synonym of* H. chinensis. *Other synonyms, species having the vague type locality of "China," and caecilians (owing to poorly defined species boundaries) were not included.*

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ESSAY 7.5. AMPHIBIANS OF BORNEO

Borneo, the world's third largest island, straddles the equator and until relatively recently was entirely covered in tropical forests. Given this favorable environment, it is not surprising that Borneo is one of the global hot spots for frogs. No fewer than 148 species are now known from Borneo (Inger and Stuebing 2005) and new species continue to be discovered. Most explorations of this rich fauna have concentrated on the Malaysian portions of the island, Sarawak and Sabah. Relatively little work has been carried out in Kalimantan, which occupies roughly two-thirds of the land mass.

This rich fauna is diverse taxonomically and consists of species in six families, most of which are also very rich in species in the adjacent land masses of Sumatra and the Malay Peninsula. These frogs vary in size from the tiny *Microhyla perparva* (NT) at 15mm to the giant *Bufo juxtasper* (LC) at 215mm in body length. The fauna is also ecologically diverse, demonstrating almost all the modes of life that frogs are capable of, from species that burrow (e.g., *Calluella smithi* DD), to those that live mostly high in trees (e.g., *Rhacophorus pardalis* LC).

The breeding habits of the Bornean species also cover almost the entire range of variation known for frogs (Inger and Tan 1996). Most species deposit their eggs in the water of ponds or streams, but a few lay their eggs in water-containing tree holes (e.g., *Metaphrynella sundana* LC). Some even lay their eggs under leaf litter on the forest floor (e.g., *Limnonectes palavanensis* LC), where they are guarded by the male who later transports the small tadpoles on his back to a small rain pool on the forest floor. Tadpoles vary also in shape and size (Inger 2005). Those that develop in ponds, such as the tadpoles of *Polypedates otilophus* (LC), have fat, almost spherical bodies and are large (up to about 65mm), while those that develop in streams tend to have more slender bodies. The tadpoles of the Slender Litter Frogs (genus *Leptolalax*) have very lithe bodies and wriggle into the crevices between the rocks lining the bottoms of the swift streams in which they live. Some tadpoles, for example, those of the Torrent Frogs (genus *Meristogenys*), live in rapids and have a large sucker on the underside that enables them to cling to rocks in the strongest currents. There are also a few kinds of small tadpoles, like those of the Sticky Frogs (genus *Kalophrynus*) that do not feed, but subsist through their short developmental periods on the store of yolk in the eggs. These tadpoles are usually found in very small, shallow pools of rain water, sometimes those that form in rotting logs. There is also a group of species, the Bush Frogs (genus *Philautus*) that do not have free-swimming tadpoles. These frogs have very large (relative to their body size) eggs, rich in yolk, which are usually laid under the moist leaf litter of the forest floor. The embryo develops within the gelatinous envelope of the egg and hatches out as a tiny froglet.

A Bornean endemic, Ansonia spinulifer *(Near Threatened), is a characteristic species reported from lowland localities throughout Borneo from 150-750 m asl. © Djoko Iskandar*

From many points of view this is a rich, very diverse frog fauna. But, because it is a *tropical forest* fauna, it is at risk because of forest conversion and clearing, primarily due to logging, agriculture and mining. The entire forest fauna depends on the very high humidities and moderate temperatures created by the closed canopy of the forest. Nearly one-third of the Bornean frog species (29%) – all but one of them known only from Borneo – are listed as threatened on the IUCN Red List, and all because of serious habitat modification. Although economic development poses a hazard to all of these rainforest frogs, it is clear that certain ecological or behavioral characteristics put some species at particular risk. The frog fauna of Borneo is roughly equally divided between those species that breed in streams (61 of 148 species) and those that breed in small bodies of standing water (64 species). However, when one considers only the threatened species, then those that breed in streams (19 of 42 species) outnumber those that that breed in standing water (10 species). The majority (14 species) of these threatened stream-breeding amphibians have tadpoles specialized for living in strong, clear currents.

One of the immediate consequences of selective logging, which harvests only the largest trees, is stream siltation, which results in the accumulation of a fine layer of silt covering the stream bottom. Forest clearing results in an even deeper layer of silt. This silt clogs the bottom crevices in which some kinds of tadpoles live (e.g., tadpoles of the genus *Leptolalax*) and prevents the growth of rock-clinging algae on which other kinds of tadpoles feed (e.g., tadpoles of the Torrent Frogs, *Meristogenys*). The result is a sharp, rapid decline in the populations of these two groups of species that breed in streams having clear water and gravel or rock bottoms.

Opening of the forest exposes the leaf litter in which many frog species live to much higher temperatures and lower humidity. The Bush Frogs (*Philautus*) place their fertilized eggs under dead leaves, which in undisturbed forests, remain continually moist. As soon as the forest is opened, more sunlight reaches the floor raising the temperature and drying out the floor litter. Ten of the 16 Bornean species of *Philautus* are considered to be threatened. While there has been no direct study of the impact of high temperature and low humidity on litter-dwelling frogs, the failure to find these species in open areas, such as surrounding agricultural fields, suggests a direct relation between forest clearance and disappearance of these species.

Yet some species manage to survive in secondary forests, those forests from which some trees have been removed. Large areas cleared of forest in Borneo have been converted to non-native tree plantations, mostly oil palm, but also *Acacia mangium*. These tree plantations have some of the physical characteristics of natural forest, such as a closed canopy, reduction in sunlight reaching the floor, and high humidity. If these plantations are adjacent to forest, even secondary forest, it is possible that some rain forest frogs may move into and survive in these environments. In fact, an as yet incomplete survey of the frogs living in *Acacia* plantings in Sarawak has discovered species of frogs characteristic of rain forests in these exotic environments. At least one threatened floor-dwelling species, *Kalophrynus intermedius* (VU), has been recorded within an *Acacia* planting. These particular plantations are adjacent to secondary forests, and this secondary forest is probably the source of the *Acacia*-dwelling frogs. It may also be significant that pesticides have not been broadcast in these plantings, and more investigation of the fauna of tree plantations is needed to determine what portion of the fauna can adjust to living in that kind of exotic environment, and for how long populations can persist. Until such study is completed, we may not know how grim the future is for this interesting, unique amphibian fauna.

Robert F. Inger

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A calling male tree hole frog Metaphrynella sundana *(Least Concern), with the vocal sac inflated. Some tree holes may be as much as 10 metres or more above the ground (©) Björn Lardner*

Limnonectes rhacoda *(Near Threatened) is a lowland rainforest species currently known only from Indonesian Borneo. © Djoko Iskandar*

CHAPTER 8. AMPHIBIANS OF THE NEARCTIC REALM

Don Church, David M. Green, Geoffrey Hammerson, Joseph Mitchell, Gabriela Parra Olea and Georgina Santos Barrera

THE GEOGRAPHIC AND HUMAN CONTEXT

The Nearctic Realm includes most of mainland North America, south to central Mexico (excluding the Caribbean coast of Mexico, and extreme southern Florida in the United States). North America currently has a land connection to South America that was formed relatively recently, beginning in the late Pliocene, some 3.5 Ma. Even earlier in the Permian to early Jurassic Periods, some 285-190 Ma, North America had land connections with Eurasia and Africa. Biogeographic relationships between these regions are seen today, for example, in the presence of giant salamanders in the Appalachians and in China and Japan. The Appalachian Mountains in the eastern United States began to uplift some 680 Ma, when the European and African plates pressed against the east side of the North American plate, long before the time when the first amphibians crawled or hopped. These mountains had eroded almost entirely by the Mesozoic Era, but further uplift during the Cenozoic Era and subsequent erosion by newly formed rivers and streams shaped the Appalachians as we know them today. The moist temperate forests that now cover these mountains grow on severely eroded remnants of a formerly towering cordillera that was putatively higher than the Himalaya.

The western part of the region is much more mountainous and includes the Rocky Mountains, the Cascade Range, the Alaskan Range, and many others. The topographical and geological histories of this region are complex. Three major mountain-building episodes restructured the topography of the west during the period of about 170 to 40 Ma (Jurassic to Cenozoic Periods). Orogenous uplift continues today in the Cascades and other westernmost ranges as seen in modern eruptions of mountain peaks like Mount Saint Helens. The Rockies and the Sierra Madre Mountains in Mexico date from uplifts that occurred during the Laramide orogeny some 70-40 Ma in the Palaeocene and Eocene Epochs. The highest point in the Nearctic Realm is Mount McKinley in Alaska at 6,194m.

During the more recent geological past, as in the Pleistocene, sea levels rose and fell during several glacial-interglacial episodes. The eastern coastline of North America during the last major glacial event (that ended about 10,000 years ago) was as far as 100km east of its current location and -130m to -180m below current sea level. The Coastal Plain terraces are the result of previous sea level rise and fall events. Glacial and interglacial episodes in the Pleistocene had dramatic effects on the flora and fauna in most of North America with major latitudinal and elevational shifts in ranges of entire communities and ecosystems (Flint 1971). Many of the current distributions of amphibians in the Nearctic are the result of these historical events. Many amphibians that now range northward to New York or nearly so, for example, expanded their ranges up the Coastal Plain following glacial retreat.

Boreal coniferous forests dominate the northern part of the region through Alaska and Canada, although high-elevation mountains such as in the southern Appalachians and the Rocky Mountains also support such forests. The eastern part of the region was originally covered with mixed and broad-leaved forests after the Pleistocene glaciations, giving way to vast grasslands in the central part of the continent east of the Rockies. The south-eastern portion of the Nearctic Realm was dominated by pine forests after the last glaciation some 10,000 years ago. In keeping with the topography, habitats are much more complex in the west, ranging from hot deserts, to sagebrush, Mediterranean-type chaparral, montane coniferous forests, alpine tundra, and extremely wet temperate rainforests in the Pacific Northwest. The Mexican portion of the Nearctic Realm supports desert and desert grassland between the Sierra Madre Oriental and the Sierra Madre Occidental. High mountains in these regions support xeric oak and pine vegetation. Descriptions of biotic communities, vegetation, and ecoregions in the Nearctic Realm are in Scott (1995), Brown *et al.* (1998), Ricketts *et al.* (1999), and Barbour and Billings (2000), among others.

Compared with other parts of the world, the Nearctic Realm has a low human population density (approximately 15 people per square km in 2005), only 23% of which lives in rural areas, and a low population growth rate (1.2% per annum), which is gradually decreasing. The human population is distributed very unevenly, with high concentrations in southern Canada, on the Coastal Plain and Piedmont in the eastern and north-eastern United States, and in California and Florida. Gross income per capita in the United States and Canada was over US$38,000 in 2004, but the southern part of the region in northern Mexico is poorer, with a gross income per capita of less than US$10,000 in 2004. The high wealth of much of the region helps to explain why damage to natural ecosystems has been extensive in relation to the low human population density; due to large-scale agriculture, urbanization, roads, wetland loss. Economic growth rates in the region have been relatively high (3.5% in 2005), especially for a wealthy region.

The human impact on Nearctic ecosystems varies greatly through the region. There have been high levels of anthropogenic disturbance over the last 300 years, with very extensive forest loss in the eastern and southern United States and conversion of the formerly extensive grasslands to commercial agriculture in the centre of the country. Over the last century, there has been some forest regeneration in parts of the east, although this regrowth has recently been targeted for much timber harvesting. Damage to ecosystems has been as severe in the drier west due to timbering and cattle grazing. The coniferous stands in the northern boreal zone were relatively untouched until recently. Urbanization and suburbanization are expanding rapidly in all cities and towns and contributes substantially to habitat loss. Pollution of rivers, streams and lakes is a problem in many areas of the Nearctic, and approximately 40% of these in the United States are classified by the United States Environmental Protection agency as polluted. Freshwater wetland loss has been high (Fretwell *et al.* 1996) because of land conversion to urbanization and agriculture. Overviews of threats to and losses of animals, habitats, and ecosytems in North America are in LaRoe *et al.* (1995) and Noss *et al.* (1995).

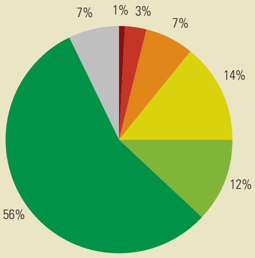
GLOBAL CONSERVATION STATUS

A total of 83 species (24%) of the 337 amphibian species in the Nearctic Realm is considered to be globally threatened or Extinct (Figure 1). This is significantly less than the global average of 33%[1], but very similar to the situation in the Palaearctic. The Nearctic Realm contains 4% of all globally threatened amphibians. It accounts for only 2% of CR species and 3% of the EN species, but 7% of the VU species. Hence, threatened Nearctic amphibians are more likely to be in a lower category of threat, when compared with the global distribution of threatened species amongst categories. The percentage of DD species, 7% (25 species), is also less than the global average of 23%. This result is not surprising for such a well-surveyed region.

Two of the world's 34 known amphibian extinctions have occurred in this region, namely the Vegas Valley Leopard Frog *Rana fisheri* and the poorly known Catahoula Salamander *Plethodon ainsworthi* in Mississippi. In addition, the only amphibian in the world currently listed as Extinct in the Wild with only captive populations in existence, the Wyoming Toad *Bufo baxteri*, is also found here. Three Critically Endangered species in the Nearctic Realm are also considered possibly extinct: Tlaloc's Leopard Frog *Rana tlaloci* from the Mexican Plateau, the Bigfoot Splayfoot Salamander *Chiropterotriton magnipes*[2] from San Luis Potosi and Queretaro, Mexico, and the Cave Splayfoot Salamander *Chiropterotriton mosaueri* from northern Hidalgo, Mexico (the first two of these also occur in the Neotropical Region). These taxa represent 2.3% of the 130 possibly extinct species in the world. There is little in the way of overall discernible pattern in Nearctic amphibian extinctions thus far.

Figure 1. *Summary of Red List categories for amphibians in the Nearctic Realm. The percentage of species in each category is also given.*

Red List Category	Number of species
🟥 Extinct (EX)	2
🟥 Extinct in the Wild (EW)	1
🟥 Critically Endangered (CR)	10
🟧 Endangered (EN)	24
🟨 Vulnerable (VU)	46
🟩 Near Threatened (NT)	40
🟩 Least Concern (LC)	189
⬜ Data Deficient (DD)	25
Total Number of Species	**337**



SPECIES RICHNESS AND ENDEMISM

Species Richness and Endemism Across Taxa

The 337 native amphibian species in the Nearctic Realm represent 6% of the currently known global total of 5,915 species. Of these 337 species, 230 (or 68%) are endemic to the Nearctic (Table 1). Both salamanders and frogs occur in the region, but no caecilians. Unlike the situations in all other major biogeographic realms, there are more species of salamanders (Caudata) than frogs and toads (Anura), the former accounting for 58% of the species in the Nearctic. Endemism is also much higher in the salamanders (89%), as compared with frogs and toads (39%). This presumably reflects a more fine-grained pattern of isolation and speciation, and accordingly generally much smaller range sizes, among salamanders in the Appalachian Mountains in the east and Sierra Nevada Mountains in the west. Of the 17 families that are native to the region, only three of them are endemic (Table 1). Only 10 species (3%) are members of these endemic families, but this low percentage is a reflection of the fact that several families occur only marginally in other regions.

Under current climatic conditions, there is less isolation between the Nearctic and Neotropical Realms than there is between the Afrotropical and Palaearctic Realms, and there are points of contact between the two faunas along the Caribbean coast of Mexico and in Florida (although the transvolcanic belt in central Mexico does form a barrier to faunal dispersal). The result of this indistinct boundary is to reduce the level of endemism of both regions. The families Scaphiopodidae, Ambystomatidae, Amphiumidae, and Sirenidae are nearly endemic to the Nearctic, and Leptodactylidae and Rhinophrynidae are almost endemic to the Neotropics. Proteidae is also overwhelmingly Nearctic with just one species in the Palearctic. Duellman and Sweet (1999), Green (1997) and Lannoo (2005) provide summaries of the amphibian fauna of the Nearctic.

Of the 51 genera (11% of the global total) that occur in the region, 22 (33%) are also endemic. Endemism at the generic level is much higher among the salamanders (67%) than it is among frogs and toads (4.2%), a pattern mirrored in the Palaearctic. The most speciose genera in the region are *Plethodon* (48 species), *Rana* (38 species), *Bufo* (28 species), *Eurycea* (24 species), and *Ambystoma* (21 species). At the opposite end of the spectrum, there are nine monotypic genera endemic to the Nearctic Realm, eight of which are salamanders and seven of which are in the family Plethodontidae. The 32 non-endemic genera in the Nearctic include 23 frog genera (13 genera in Hylidae, three in Leptodactylidae, two each in Microhylidae and Scaphiopodidae, and one each in Bufonidae, Ranidae and Rhinophrynidae) and nine salamander genera (four in Plethodontidae, two in Sirenidae, and one each in Ambystomatidae, Amphiumidae, and Salamandridae). These non-endemics include the widespread genera *Bufo* and *Rana*.

The Lesser Siren Siren intermedia *(Least Concern) is one of the four species of siren in the family Sirenidae, a group of highly aquatic salamanders with small front legs and no back legs. It ranges from the south-eastern United States to north-eastern Mexico, and lives in shallow water with abundant vegetation (burrowing into the bottom mud if the water dries up). © Michael Graziano*

Table 1. *The number of Nearctic amphibians in each taxonomic Family present in the region.*

Family	Native species (endemics to region)	Percentage of species in region that are endemic	Percentage of species in family that are endemic to region	Native genera (endemics to region)	Percentage of genera in region that are endemic	Percentage of genera in family that are endemic to region
Anura						
Ascaphidae	2 (2)	100	100	1 (1)	100	100
Bufonidae	28 (12)	43	3	1 (0)	0	0
Hylidae	39 (14)	36	2	13 (0)	0	0
Leptodactylidae	23 (3)	13	0.2	3 (0)	0	0
Microhylidae	4 (0)	0	0	2 (0)	0	0
Ranidae	38 (21)	55	3	1 (0)	0	0
Rhinophrynidae	1 (0)	0	0	1 (0)	0	0
Scaphiopodidae	7 (4)	57	57	2 (0)	0	0
TOTAL ANURA	**142 (56)**	**39**	**1**	**24 (1)**	**4**	**0.3**
Caudata						
Ambystomatidae	21 (16)	76	53	1 (0)	0	0
Amphiumidae	3 (2)	67	67	1 (0)	0	0
Cryptobranchidae	1 (1)	100	33	1 (1)	100	50
Dicamptodontidae	4 (4)	100	100	1 (1)	100	100
Plethodontidae	147 (136)	93	37	17 (13)	76	45
Proteidae	5 (5)	100	83	1 (1)	100	50
Rhyacotritonidae	4 (4)	100	100	1 (1)	100	100
Salamandridae	6 (4)	67	6	2 (1)	50	6
Sirenidae	4 (2)	50	50	2 (0)	0	0
TOTAL CAUDATA	**195 (174)**	**89**	**33**	**27 (18)**	**67**	**29**
TOTAL ALL AMPHIBIANS	**337 (230)**	**68**	**4**	**51 (19)**	**37**	**4**

The Marbled Salamander Ambystoma opacum *(Least Concern) occurs in the eastern United States in various wooded habitats, in the vicinity of swamps and vernal pools. For most of the year the adults are subterranean in rodent tunnels, but in the autumn they congregate, sometimes in large numbers as shown here, to lay eggs in forest depressions such as vernal pool basins. © Don Church*

As noted already, 17 of the world's 48 amphibian families (35%) occur in the Nearctic, with three endemic: Ascaphidae, Dicamptodontidae and Rhyacotritonidae[3]. The characteristics of these families are provided in Chapter 1.

Among the non-endemic families, the majority of Nearctic species are in the Bufonidae, Hylidae, Leptodactylidae, Ranidae, Ambystomatidae and Plethodontidae. Of the Nearctic Bufonidae, all 28 species are in the widespread genus *Bufo*[4]. This family occurs through most of the region, and 16 species (57%) are shared with the Neotropics. All Nearctic species have free-living aquatic larvae.

There are 39 species of Hylidae in the Nearctic currently placed in 13 genera (Faivovich *et al.* 2005). This family is also very widespread within the region; 25 species (64%) range into the Neotropics. Within this region, these species include treefrogs, chorus frogs and cricket frogs, and are associated with many different habitats. All Nearctic species have free-living aquatic larvae.

Although the family Leptodactylidae is almost endemic to the Neotropics, 23 species occur in the Nearctic in Mexico, and some range into the southern United States. These include representatives of the genera *Eleutherodactylus* and *Craugastor*, which breed by direct development on land, and *Leptodactylus,* which have free-living aquatic larvae.[5]

All of the Nearctic Ranidae are in the genus *Rana*[6]. The family is very widespread in the region, occurring in most aquatic and wetland habitats, and all members in the region have free-living aquatic larvae.

The mole salamanders (Ambystomatidae) are mainly a Nearctic family, with 21 species (70% of the global total) occurring in the region, 16 of which are endemic. The species are mainly subterranean as adults and juveniles, with aquatic larvae that develop mainly in temporary pools and occasionally in streams.

The Plethodontidae (lungless salamanders) is by far the largest family in the Nearctic, with 147 species (40% of the global total), of which 136 are endemic. The family includes both direct-developing species, which breed terrestrially with no association with water (for example, *Plethodon*, *Aneides*, and *Batrachoseps*), and aquatic larval developing species, typically associated with streams (for example, *Desmognathus* and *Eurycea*). Although the family is widespread through much of the region (but avoiding highest latitudes), it reaches extraordinary diversity in the southern Appalachians (see Essay 8.1). Most species in this family are strongly tied to forest habitats (though some, especially in the genus *Eurycea*, live in caves).

As home to four small salamander families that occur mainly in the eastern United States, the Nearctic contributes uniquely to global amphibian diversity. Both the Amphiumidae (amphiumas) and Sirenidae (sirens) occur largely on the Coastal Plain of the eastern and southern United States (ranging only marginally into the Neotropics). The Cryptobranchidae (giant salamanders) has one species in the Nearctic (the Hellbender *Cryptobranchus alleganiensis*; NT); two others are in East Asia. The Proteidae (mudpuppies and waterdogs) has five species in the Nearctic (all in the eastern United States), with one species in Europe. The members of all four families are mainly large salamanders that are completely aquatic as both larvae and adults.

The Wood Frog Rana sylvatica *(Least Concern) ranges farther north than any other North American amphibian. It is abundant and widespread, and occurs in various kinds of forest and woodland habitats, and also willow thickets and grass/willow/aspen associations. The eggs are laid, and larvae develop, usually in small fish-free ponds in wooded or, sometimes, open areas. © Don Church*

Table 2. *The number of species within each IUCN Red List Category in each Family and Order in the Nearctic Realm. Introduced species are not included.*

Family	EX	EW	CR	EN	VU	NT	LC	DD	Total number of species	Number Threatened or Extinct	% Threatened or Extinct
Anura											
Ascaphidae	0	0	0	0	0	0	2	0	2	0	0
Bufonidae	0	1	0	4	1	2	20	0	28	6	21
Hylidae	0	0	0	2	1	2	34	0	39	3	8
Leptodactylidae	0	0	1	2	5	1	9	5	23	8	35
Microhylidae	0	0	0	0	0	0	4	0	4	0	0
Ranidae	1	0	4	1	5	5	20	2	38	11	29
Rhinophrynidae	0	0	0	0	0	0	1	0	1	0	0
Scaphiopodidae	0	0	0	0	0	1	6	0	7	0	0
TOTAL ANURA	**1**	**1**	**5**	**9**	**12**	**11**	**96**	**7**	**142**	**28**	**20**
Caudata											
Ambystomatidae	0	0	3	1	2	1	13	1	21	6	29
Amphiumidae	0	0	0	0	0	1	2	0	3	0	0
Cryptobranchidae	0	0	0	0	0	1	0	0	1	0	0
Dicamptodontidae	0	0	0	0	0	1	3	0	4	0	0
Plethodontidae	1	0	2	12	31	21	63	17	147	46	31
Proteidae	0	0	0	1	0	1	3	0	5	1	20
Rhyacotritonidae	0	0	0	0	1	2	1	0	4	1	25
Salamandridae	0	0	0	1	0	1	4	0	6	1	17
Sirenidae	0	0	0	0	0	0	4	0	4	0	0
TOTAL CAUDATA	**1**	**0**	**5**	**15**	**34**	**29**	**93**	**18**	**195**	**55**	**28**
TOTAL ALL AMPHIBIANS	**2**	**1**	**10**	**24**	**46**	**40**	**189**	**25**	**337**	**83**	**24**

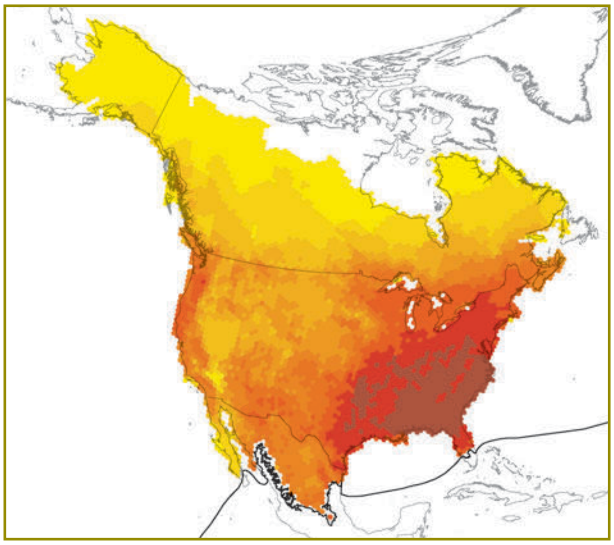


Figure 2. *The species richness of amphibians in the Nearctic Realm, with darker colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes; maximum richness equals 52 species.*

The Rhyacotritonidae (torrent salamanders) and Dicamptodontidae (Pacific giant salamanders) are wholly restricted to the Pacific north-west. Members of both families are inhabitants of coldwater mountain streams.

The small frog family Scaphiopodidae (American spadefoots), with just seven species, occurs mainly in the Nearctic, but three of the species also range into the Neotropics. The remaining families include the Microhylidae (globally widespread, with just four species in the region, none of which are endemic), the primitive Rhinophrynidae (which marginally ranges into the region), and the Salamandridae (mainly a Palaearctic family, with six species in the region).

The threatened and extinct species in the Nearctic are overwhelmingly in the Plethodontidae (46, 84% of the total in the region; Table 2). This is a reflection of the many species with small ranges that occur in mountainous regions (especially in the Appalachians and in Mexico), where they are threatened in many places by forest loss. Nearly one-third (31%) of the lungless salamanders in the region are globally threatened or extinct. There is also a high percentage of threatened species (29%) among the mole salamanders (Ambystomatidae), which are also threatened mainly by habitat loss.

Most threatened frog species occur in the larger families, namely Bufonidae, Leptodactylidae, and Ranidae (Table 2). The threatened toads (Bufonidae) occur mainly in the western United States, where they have been impacted by habitat degradation, and in some cases by introduced bullfrogs (*Rana catesbeiana*) and the disease chytridiomycosis. The eight threatened species of Leptodactylidae are all Mexican endemics threatened by habitat loss (and perhaps, in a few cases, by chytridiomycosis). The threatened Nearctic species in the Ranidae range widely in Mexico and the western and southern United States. As with the other families, they are impacted by habitat loss and chytridiomycosis, but invasive species and water pollution have also been detrimental. It is noteworthy that the percentage of threatened treefrogs (Hylidae) in the region is much lower than for the other large families.

The great majority (88%) of the threatened amphibians in the Nearctic are in the Endangered and Vulnerable categories. The generally low number of Critically Endangered species masks some important family-level differences, with 14% of the Nearctic Ambystomatidae, and 11% of the Nearctic Ranidae falling into this category.

Geographic Patterns of Species Richness and Endemism

Overall species richness of amphibians in the Nearctic Realm (Figure 2) is highest in the southeastern United States, especially on the Coastal Plain and in the Appalachian Mountains. Species richness is low in the drier parts of northern Mexico, through much of the central and western United States (although there are more species in moist areas along the northwest Pacific coast), and in Canada. The Nearctic Realm is well studied, and Figure 2 probably reflects genuine patterns of amphibian species richness.

Concentrations of threatened species (Figure 3a) in the Nearctic are less marked than in many tropical regions. Nevertheless, there are some notable concentrations in the southern Appalachians (centred on the Great Smoky Mountains), the mountains of northern Mexico, along the Edwards Plateau in Texas, and in the mountains of California. These geographic concentrations generally reflect the topographically diverse montane parts of the region where amphibians have naturally small ranges and where habitat destruction is ongoing. The Texan concentration largely reflects subterranean salamanders in the genus *Eurycea* and blind species in the genus *Typhlomolge*. Not surprisingly, given the small number of species involved, there are no noteworthy concentrations of Critically Endangered species in the region, with the exception perhaps of the California floristic region (see Essay 8.2) (Figure 3b).

Species Richness and Endemism within Countries

Although Mexico as a whole has more amphibian species than the United States, within the Nearctic Realm the United States has more than double the number of species (261 species vs. 116) (Figure 4). Species richness in Canada is low, with just 45 species.

The amphibian fauna in Mexico is less well known than that of either the United States or Canada, although the Nearctic parts of Mexico are probably better surveyed than the more diverse Neotropical areas to the south. The Mexican amphibian fauna is not well summarized in review literature other than in Flores-Villela (1993) and Flores-Villela *et al.* (1995). However, there are some recent regional publications from northern Mexico (Lemos-Espinal *et al.* 2004; Vazquez-Díaz and Quintero-Díaz 2005). The

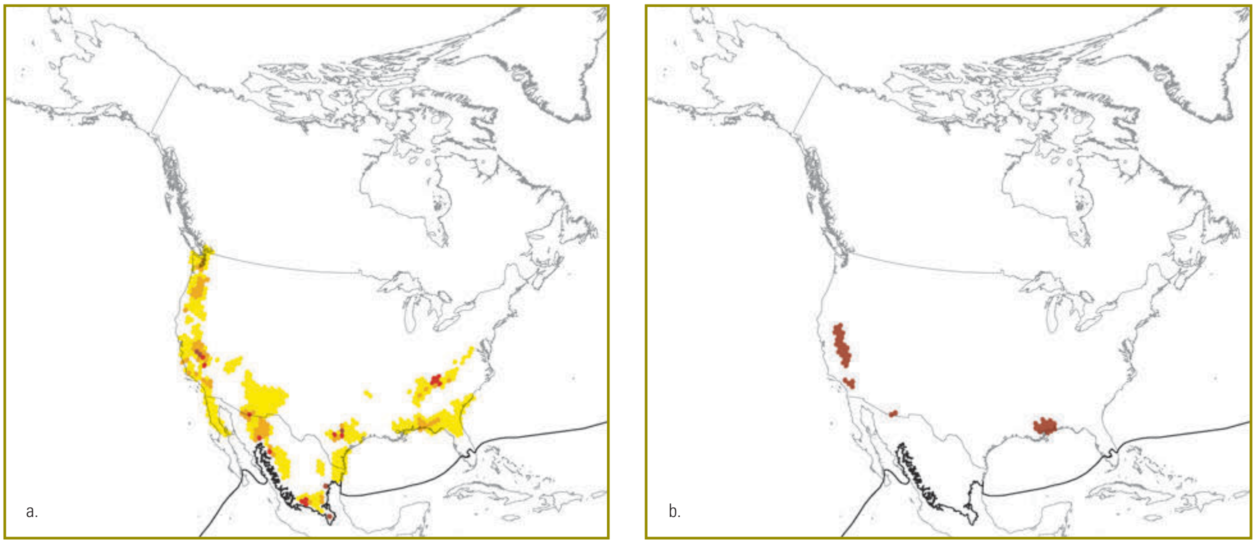


Figure 3. *a) The richness of threatened amphibians in the Nearctic Realm, with darker colours corresponding to regions of higher richness. Maximum richness equals four species. b) The richness of CR amphibians in the Nearctic Realm. Maximum richness equals one species.*

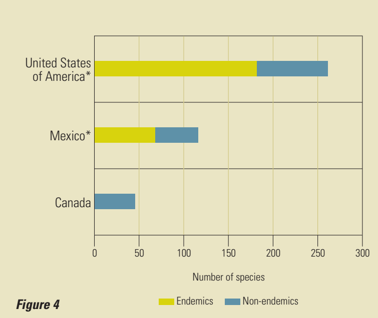


Figure 4

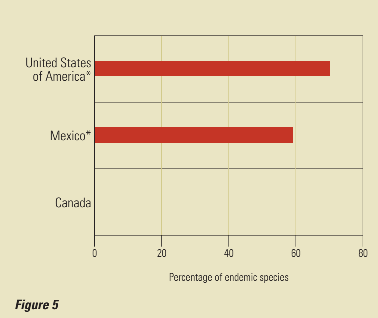


Figure 5

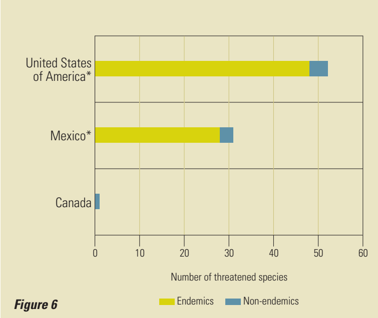


Figure 6

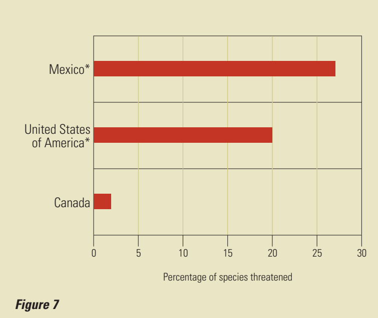


Figure 7

Figure 4. *The number of amphibians present in and endemic to each Nearctic country. *denotes countries not entirely within the Nearctic Realm, hence only the species whose ranges fall within the region are included.*

Figure 5. *Percentage of species endemic to each Nearctic country. *denotes countries not entirely within the Nearctic Realm, hence only the species whose ranges fall within the region are included.*

Figure 6. *The number of threatened amphibians present in and endemic to each Nearctic country. *denotes countries not entirely within the Nearctic Realm, hence only the species whose ranges fall within the region are included.*

Figure 7. *Percentage of native species that are threatened. *denotes countries not entirely within the Nearctic Realm, hence only the species whose ranges fall within the region are included.*

amphibians of the United States and Canada are amongst the best known in the world, with a very extensive review literature and many books, including Green (1997), Harding (1997), Conant and Collins (1998), Petranka (1998), Stebbins (2003), and Lannoo (1998, 2005). Summaries of the amphibian fauna of the Nearctic are provided by Duellman and Sweet (1999) and Lannoo (2005). There are numerous State and Province level summaries of the amphibian fauna, such as Stebbins (1972), Mount (1975), Martof *et al.* (1980), Nussbaum *et al.* (1983), Green and Pauley (1987), Dundee and Rossman (1989), Klemens (1993), Leonard *et al.* (1993), Russell and Bauer (1993), Degenhardt *et al.* (1996), Weller and Green (1997), Bartlett and Bartlett (1999), Hammerson (1999), Hunter *et al.* (1999), Dixon (2000), Johnson (2000), Hulse *et al.* (2001), Minton (2001), MacCulloch (2002), Dodd (2004), Trauth *et al.* (2004), Werner *et al.* (2004), Corkran and Thoms (2006) and Matsuda *et al.* (2006).

The United States has far more endemic Nearctic species (182) than the other two countries in the Nearctic (Figure 4). Mexico has 68 endemic Nearctic species, but there are no endemic amphibians in Canada. In the United States, 70% of the Nearctic species are endemic, compared with 59% in Mexico (Figure 5).

Only one globally threatened amphibian species occurs in Canada, compared with 31 in Mexico and 52 in the United States (Figure 6). The percentage of threatened amphibian species is highest in Mexico (27%) compared with the United States (20%) (Figure 7). In both cases, this level of threat is lower than the global average of 33%.

Assessments of the conservation status of Nearctic amphibians at the national level have been carried out by NatureServe (e.g., Stein *et al.* 2000), since updated as part of the Global Amphibian Assessment (Young *et al.* 2004). There are also official governmental threatened species listing processes in Canada (http://www.cosewic.gc.ca/index.htm) and in the United States (http://www.fws.gov/Endangered/esa.html). An official Mexican red list of amphibians is in preparation (the draft is on http://www.semarnat.gob.mx/leyesynormas/Normas%20Oficiales%20Mexicanas%20vigentes/NOM-ECOL-059-2001.pdf).

The proportion of Critically Endangered Nearctic species is highest in Mexico (6%), being 1% in the United States, and zero in Canada. This reflects the generally poor conservation situation for amphibians in Mexico (see Neotropical section). However, the only Extinct and Extinct in the Wild species in the region are in the United States, although, as mentioned above, two of the Critically Endangered species in Mexico are possibly extinct.

HABITAT AND ECOLOGY

Habitat Preferences

Most Nearctic amphibians (79%) occur in forests; only 17% of which can survive in secondary terrestrial habitats (Table 3; Figure 8). As in other regions, forest-dwelling and stream-associated amphibians are more likely to be threatened than are those occurring in any other habitats, with nearly 20% of species being globally threatened. This combination of habitat preferences is associated with rapid declines in amphibian populations worldwide (Stuart *et al.* 2004). Amphibians occurring in savannahs, marshes and swamps, arid and semi-arid habitats, and secondary terrestrial habitats are less likely to be threatened than those occurring in these other habitats (Table 3; Figure 8).

Reproductive Modes

Larval development is the most common reproductive mode in the Nearctic (65% of species), compared with 35% for direct development and no live-bearing species (Table 4; this compares with the global picture of 68% larval development, 30% direct development, and 1% live-bearing). The Nearctic amphibians clearly have a larger proportion of direct-developing species than the global average. Most of the direct-developing Nearctic amphibians are plethodontid salamanders, especially in the genera *Plethodon* (48 species), *Batrachoseps* (19), *Chiropterotriton* (10), and *Pseudoeurycea* and *Aneides* (both 6). The other concentration of direct-developing frogs in the region is among the leptodactylid frogs in the genus *Eleutherodactylus* (12 species) and *Craugastor* (9).

In the Nearctic, the percentage of globally threatened or Extinct direct-developing amphibians is much higher than for larval-developing species (33% as apposed to 20%). As in other regions, this is probably because direct-developing species have smaller ranges on average, and are therefore more seriously affected by habitat loss.

MAJOR THREATS

As in other parts of the world, habitat loss is overwhelmingly the major threat to amphibians in the Nearctic Realm (Table 5; Figure 9), affecting nearly 80% of the threatened species.

Habitat type	Number of species in each habitat	% of all species occurring in the habitat	Threatened and Extinct species	% of species occurring in habitat that are Threatened or Extinct
Forest	266	79	51	19
Savannah	10	3	0	0
Grassland	70	21	10	14
Shrubland	77	23	8	10
Secondary terrestrial habitats	56	17	5	9
Flowing freshwater	169	50	32	19
Marsh/swamp	87	26	8	9
Still open freshwater	141	42	16	11
Arid and semi-arid habitats	21	6	2	10

Table 3. *The habitat preferences of amphibians in the Nearctic Realm.*

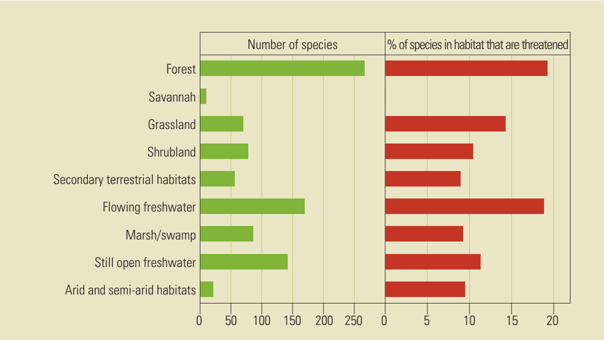


Figure 8. *The habitat preferences of Nearctic amphibians. The plot on the left-hand side shows the number of species in the region in each habitat type. On the right-hand side, the percentage of these species which are threatened is given.*

The Columbia Torrent Salamander Rhyacotriton kezeri *(Near Threatened) is restricted to a small area in the Coastal Ranges of Oregon and Washington in the United States. It is one of only four torrent salamander species in the Family Rhyacotritonidae, which is endemic to the Pacific Northwest. All the species are strictly associated with streams in forest. © Henk Wallays*

Reproductive mode	All species	Threatened or Extinct species	% Threatened or Extinct
Direct development	118	39	35
Larval development	219	44	65
Live-bearing	0	0	-
Not known	0	0	-

Table 4. *Nearctic amphibians categorized by reproductive mode.*

Threat type	Threatened species	% Threatened species
All habitat loss	63	79
Agriculture – Crops	23	29
Agriculture – Tree plantations	12	15
Agriculture – Livestock	11	14
Timber and other vegetation removal	39	49
Urbanization and industrial development	31	39
Invasive species	17	21
Utilization	6	8
Accidental mortality	6	8
Persecution	1	1
Pollution	27	34
Natural disasters	9	11
Disease	14	18
Human disturbance	12	15
Changes in native species dynamics (excluding disease)	1	1
Fire	13	16

Table 5. *The major threats to globally threatened amphibians in the Nearctic Realm. Only present threats to species are tallied.*

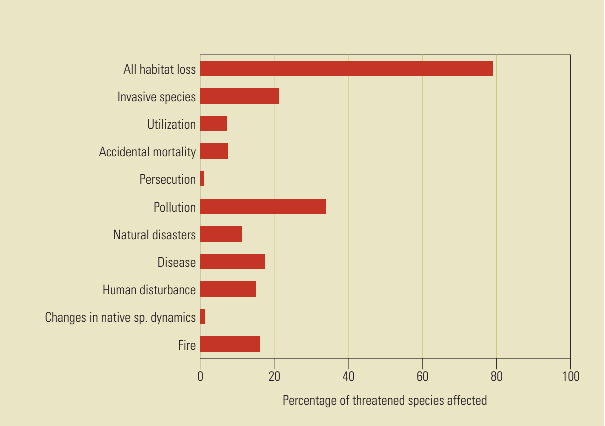


Figure 9. *The major threats impacting threatened amphibians in the Nearctic Realm.*

Couch's Spadefoot Scaphiopus couchii *(Least Concern) occurs in northern Mexico and the south-western United States in arid and semi-arid shrublands, short grass plains, mesquite savannah, creosote bush desert and cultivated areas. It burrows underground or occupies rodent burrows when inactive, but emerges to breed explosively when temporary pools are formed by the rain. © Twan Leenders*

Pollution is the next most serious threat, affecting one-third of the threatened species. Invasive and introduced species, disease, human disturbance, and fire also have significant impacts on certain species. Most other threats are of relatively minor importance. Although chytridiomycosis has been recorded widely in the region (e.g., Fellers *et al.* 2001; Bradley *et al.* 2002), and is associated with some serious declines, its overall impacts still seem to be less than in the Neotropics. However, there have been some reports of crashes in amphibian populations in North America (e.g., Kagarise Sherman and Morton 1993; Drost and Fellers 1996) that could well be attributable to chytridiomycosis. Ongoing research may show that this fungal disease is a greater threat than current documentation indicates.

Of the types of habitat loss impacting amphibians in the Nearctic, the impacts of vegetation removal, mainly via logging (which affects nearly half of the threatened species), and urbanization and industrial development (nearly 40%) are the most severe, followed by expanding croplands (nearly 30%) (Table 5). Tree plantations and livestock are less important threats in most cases.

A total of 31 species (only nine of which are threatened) are recorded as being used for some or other purpose in the region (Table 6). The most common reasons for harvesting Nearctic amphibians are for the pet trade and human consumption. Much of the harvesting of amphibians in the region is not considered to constitute a major threat to the species. Of the 31 species being harvested, utilization is considered to be a threat for just 14 (of which only six are threatened species for which harvesting is believed to be contributing to deterioration in their status, most prominently the Critically Endangered Axolotl *Ambystoma mexicanum*).

POPULATION STATUS AND TRENDS

Estimates of Population Trends

Roughly half of Nearctic amphibian species are believed to have stable populations whereas nearly one-third are thought to be decreasing (Table 7). The population trend is unknown for a substantial percentage of species. For the majority of species, these trends are inferred from trends in the state of the habitats on which the species depend (although in a few cases population declines and increases have been noted). Species with decreasing populations are typically forest-dependent species that can tolerate little disturbance to their habitats. Overall trends for Nearctic amphibians reflect a healthier situation than is the case globally where 43% are decreasing and only 27% are stable. In both cases, however, the percentage of increasing species is very small.

"Rapidly Declining" Species

Of the 470 globally "rapidly declining" species, only 24 (5%) occur within the Nearctic Realm (a full list of all "rapidly declining" species is provided in Appendix IV and includes their occurrence within each of the realms). One of these 24 species, *Rana megapoda*, is in decline due to over-exploitation, 14 due to reduced habitat, and nine due to so-called "enigmatic declines" (now generally attributed to the synergistic effects of chytridiomycosis and climate change (Lips *et al.* 2006; Pounds *et al.* 2006)).

The "rapidly declining" species show a distinct taxonomic pattern (Table 8). Among the larger families, the Ranidae and Bufonidae show by far the highest percentages of species in serious decline and in "enigmatic decline". There are no Nearctic species in serious decline in the Hylidae, and the percentages are also low in the Leptodactylidae and the Plethodontidae. Some small families have high percentages of species in serious decline, most notably the Proteidae, Salamandridae and Scaphiopodidae. The relatively small number of "rapid declines" in the Nearctic are widely scattered across the region without any clear geographic pattern.

KEY FINDINGS

- A total of 337 species are recorded from the Nearctic Realm, of which 80 (24%) are considered threatened.
- The Nearctic is the only region of the world in which salamanders outnumber frogs (195 as opposed to 142 species).
- At the species level, 230 amphibians (68% of those present) are endemic to the Nearctic; of the 17 families found in the region, three are endemic, and of 51 amphibian genera occurring, 19 are endemic. Endemism is lower in the Nearctic than in some other regions, especially due to the unclear and somewhat arbitrary boundary with the Neotropics in several places.
- The percentage of threatened or Extinct species is lower than in many other parts of the world, but highest in the families Leptodactylidae (35%), Plethodontidae (31%), Ranidae (29%), Ambystomatidae (29%), Rhyacotritonidae (25%), Bufonidae (21%), and Salamandridae (17%).
- Geographic concentrations of threatened species in the Nearctic are less marked than in many tropical regions, but there are some notable concentrations in the southern Appalachians (centred on the Great Smoky Mountains), the mountains of northern Mexico, the Edwards Plateau in Texas, and the mountains of California.
- The United States has the largest number of species in the Nearctic Realm (261 species), and also has more endemics (182). Mexico has 68 species endemic to the Nearctic, whereas Canada has none.
- The United States has the largest number of threatened species (52), followed by Mexico (31). However, the percentage of threatened species is higher in Mexico (27% versus 20%).
- Threatened species tend to show distinct habitat preferences, with forest-dwelling and stream-associated species being the most threatened (19% and 19%, respectively). This pattern is mirrored elsewhere in the world.
- Habitat loss, primarily due to vegetation removal (mainly logging), urbanization/industrial development, and expanding croplands is affecting almost 80% of the threatened species in the region. Pollution impacts over one-third, and invasive species over 20%, of the threatened species. Disease (usually chytridiomycosis) is negatively affecting 18% of globally threatened species in the region, but is implicated in 38% of the rapid declines.
- Only 5% of the 470 globally "rapidly declining" species occur within the region. Most of these rapid declines (58%) are caused by severe habitat loss, but chytridiomycosis is a growing concern.
- Two amphibian extinctions have been recorded from the Nearctic, and one species is Extinct in the Wild, all of these being from the United States. A further two species are possibly extinct (both from Mexico).

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The Two-toed Amphiuma Amphiuma means *(Least Concern) is one of three species in the Amphiumidae, a Family of three eel-like salamanders from the south-eastern United States with vestigial limbs. It can be found in a variety of still-water habitats, and may leave water, especially on rainy nights. © Suzanne L. Collins, CNAH*

Table 6. *The purposes for which amphibians are used in the Nearctic Realm. The numbers in brackets are the number of species within the total that are threatened species.*

Purpose	Subsistence	Sub-national/ National	Regional/ International	Number of species
Food – human	11 (5)	5 (1)	3 (0)	13 (5)
Medicine – human and veterinary	2 (1)	0	0	2 (1)
Wearing apparel, accessories	1 (0)	0	0	1 (0)
Handicrafts, curios, etc.	1 (0)	1 (0)	1 (0)	1 (0)
Pets, display animals	3 (1)	7 (2)	11 (2)	14 (2)
Research	0	2 (1)	3 (1)	4 (1)
Specimen collecting	1 (1)	8 (4)	1 (1)	8 (4)

Table 7. *The population trends for all extant Nearctic amphibians.*

Population Trend	Number of species	% of species
Decreasing	103	31
Stable	162	48
Increasing	2	0.6
Unknown	68	20

Table 8. *The number of species in "rapid decline" and "enigmatic decline" in the Nearctic Realm by Family.*

Family	Number of species in "rapid decline"	Percentage of species in family in "rapid decline"	Number of species in "enigmatic decline"	Percentage of species in family in "enigmatic decline"
Bufonidae	5	18	3	11
Leptodactylidae	1	4	1	4
Ranidae	8	21	4	11
Scaphiopodidae	1	14	0	0
Ambystomatidae	1	5	0	0
Plethodontidae	6	4	3	2
Proteidae	1	20	0	0
Salamandridae	1	17	0	0

The Coastal Tailed Frog Ascaphus truei *(Least Concern) ranges from southern British Columbia and northern California, and is one of only two species in the Family Ascaphidae. Both species are associated with clear, cold, swift-moving mountain streams in forests and lay eggs in long strings under stones in water. © Suzanne L. Collins, CNAH*

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Endnotes

1 P<0.01 (binomial test).

2 At the time of writing, *Chiropterotriton magnipes* was discovered in two new localities, away from the type locality (G. Parra Olea pers. comm.).

3 By merging the Dicamptodontidae into the Ambystomatidae, Frost *et al.* (2006) reduce the number of families in the region to 16, and the number of endemic families to two. Frost *et al.* (2006) also merged Ascaphidae into Leiopelmatidae. However, in this section we follow the former taxonomic arrangement of families based on Frost (2004).

4 Frost *et al.* (2006) transfer these species to other genera.

5 Frost *et al.* (2006) transfer *Eleutherodactylus* and *Craugastor* to the family Brachycephalidae.

6 Frost *et al.* (2006) transfer most of these to the genus *Lithobates*

ESSAY 8.1. APPALACHIAN AMPHIBIANS

Although widely distributed throughout much of the United States, southern Canada south to northern Mexico in the Sierra Madre Occidental, the Tiger Salamander Ambystoma tigrinum *(Least Concern) is absent from most of the Appalachian Mountains and occurs only in the Shenandoah Valley at the base of the Blue Ridge Mountains in west-central Virginia. © Don Church*

The Appalachian Mountains lie in a 2,414km north-east to south-west stretch of eastern North America from Newfoundland and Labrador in Canada to north-central Alabama in the United States (with their foothills in north-eastern Mississippi). The topographic system is divided into a series of ranges, with the highest of the group being Mt. Mitchell in North Carolina (2,040m). This summit is also the highest point on the continent east of the Mississippi River. Because North America and Africa were once connected, the Appalachians were once part of the same mountain chain as the Atlas Mountains in Morocco. Many floristic and some animal species (e.g., giant salamanders) are also related to those in the mountains of western China based on ancient continental connections.

The Appalachian region supports a startling diversity of amphibians, all the more so since more than one-third of the species (37 of the 98 present) are endemic. Salamander genetic diversity in the Appalachians is the highest in the world, although Central America supports a higher species richness (see Essay 9.3). In total, 72 salamander species inhabit the region, with 60 representatives of the family Plethodontidae (the lungless salamanders). All of the region's endemic amphibians are plethodontids. Although the area's salamander fauna has been intensively studied for over 150 years, new species are still being discovered. Several species with restricted distributions remained hidden to herpetologists among mountains and caves until the middle of the 20th century. Dunn (1926) recognized 22 species in his seminal revision of the Plethodontidae. By 1967, the plethodontid count was at 26 species (Brame 1967). However, the advent of molecular genetic techniques in the mid-1960s sparked another scientific inquisition into the region's salamander fauna. The number of described plethodontid species more than doubled by the beginning of the 21st century. For example, Conant and Collins (1998) recognized 56 Appalachian species in their field guide. Genetic analyses continue to discover cryptic species that are difficult to resolve with only morphological differences.

Colour, pattern, and morphological variation abound geographically and among species in the Appalachians. Green Salamanders, *Aneides aeneus* (NT), have, for example, a bright green moss-like pattern, splayed limbs, and large feet used for climbing and living in rock crevices. Seepage and streamside salamanders include the bright yellow, sleek Two-lined Salamanders, members of the genus *Eurycea*, the robust, brilliant Red Salamander, *Pseudotriton ruber* (LC), and the large Spring Salamander, *Gyrinophilus porphyriticus* (LC), a predator of all of the rest. The many streamside salamanders in the genus *Desmognathus* have dull brown to black colours and varying dull reticulate and spot patterns, but are amazingly abundant in mountain streams. Some species are fully aquatic, like the Shovel-nosed Salamander, *Desmognathus marmoratus* (LC), whereas others spend as much time on land as in the water, like the Allegheny Mountain Dusky Salamander, *Desmognathus ochrophaeus* (LC). The many species in the completely terrestrial salamander group, genus *Plethodon*, lay eggs in moist microhabitats in forests where all embryonic development occurs within the egg capsule. Hatchlings are adult forms and fully terrestrial. The Red-backed Salamander, *Plethodon cinereus* (LC), may be the most abundant vertebrate in the Appalachians. Their biomass per square meter can be higher than all the mammals and equal to that of all the birds in the area (Burton and Likens 1975).

The lungless salamanders within the Appalachian region have been very valuable to our understanding of speciation and other evolutionary processes (Frost 2000). The diversity of the Appalachian amphibian fauna is enhanced by a few species from other families that have small relict populations. For example, the Tiger Salamander *Ambystoma tigrinum* (LC) is found patchily along the Coastal Plain, but is also known to occur in only a single location within the Appalachian region. This disjunct population is dependent upon a unique complex of ancient sinkhole ponds in the Shenandoah Valley at the base of the Big Levels massif of the Blue Ridge Mountain chain in west-central Virginia (Buhlmann and Hoffman 1990; Mitchell and Buhlmann 1999). Although the next nearest Tiger Salamander population occurs on Virginia's Coastal Plain, mitochondrial DNA evidence reveals that this relict mountain population is most closely related to a population in west-central South Carolina, but became isolated 100,000-300,000 years ago (Church *et al.* 2002). Genetic and fossil data strongly suggest that the Tiger Salamander once had a more continuous distribution throughout the Appalachian region but became isolated in the Big Levels area before or during the last Pleistocene glaciation event. Interestingly, these Shenandoah Valley sinkhole ponds also support disjunct populations of plant, dragonfly, and damselfly species (Fleming and Van Alstine 1999; Roble 1999) suggesting that this region of Appalachia may have provided Pleistocene refugia for entire communities. Future studies of these relict populations will reveal how species ranges have contracted and expanded and, hence, what the consequences may be from future climate change.

Several of the endemic Appalachian plethodontid salamander species have extremely restricted distributions. These species are susceptible to habitat loss and climate change and are, therefore, important flagship species for the region. The Shenandoah Salamander, *Plethodon shenandoah* (VU), for example, is restricted to talus slopes between 914 and 1,143m asl on the north and north-west slopes of Hawksbill Mountain, Stony Man Mountain, and The Pinnacles in the Blue Ridge of north-central Virginia (Petranka 1998; Mitchell and Reay 1999). The conservation status of this species is apparently secure for the immediate future given that its entire range lies within Shenandoah National Park. The Peaks of Otter Salamander, *P. hubrichti* (VU), is another small, entirely terrestrial species restricted to a 19-km high elevation length of the Blue Ridge Mountains in west-central Virginia. Although abundant within parts of its range, this salamander is susceptible to timbering and habitat fragmentation due to its very low dispersal rate and restricted distribution (Kramer *et al.* 1993). The Junaluska Salamander, *Eurycea junaluska* (VU), is another rare Appalachian salamander found patchily and in low abundance in the Cheoah River drainage of North Carolina and along Fighting Creek and Tellico River in Tennessee. This very rare species has a biphasic life history, with stream-dwelling larvae and adults that enter forests. Thus, the Junaluska Salamander is vulnerable to degradation of both stream and forest habitats.

Although not endemic to Appalachia, the Hellbender, *Cryptobranchus alleganiensis* (NT), is another important flagship amphibian for the region. This species is the sole representative of its genus, and one of only three surviving species within the family of giant salamanders, Cryptobranchidae. Hellbenders are bizarre animals with fleshy folds of skin undulating along their sides and are capable of reaching 74 cm in total length. Living their entire lives in large, fast-flowing streams, they have laterally compressed tails and are capable of swimming quickly underwater. Their large, dorsally flattened heads support only diminutive eyes, but have huge mouths capable of engulfing crayfish and small fish, the mainstays of their diet. A mature male constructs a nesting cavity under a large flat rock during the breeding season and aggressively guides gravid females to enter, whereupon he detains her until she oviposits her clutch of up to 750 eggs. The male then fertilizes the eggs, evicts the mother, and subsequently guards the nest from intruders for a period of the incubation (Bishop 1943; Dodd 2004). Hellbenders were traditionally eaten by Native Americans, who probably skinned them first as their slimy skin secretions are toxic to many predators (McCoy 1982). The majority of the Hellbender's range occurs within the Appalachian region, where it was undoubtedly abundant in streams prior to European colonization (Petranka 1998). Populations have since declined drastically across much of their range and have gone locally extinct due to their susceptibility to stream impoundment, siltation from timber harvest operations and development, and pollution from industry (Bury *et al.* 1980; Mitchell *et al.* 1999). Although many river systems within the Hellbender's range are protected, this species, like many amphibians, is highly susceptible to anthropogenic activities outside the primary habitat.

Despite the high species richness and abundance of the salamanders in the Appalachian Mountains of North America, many of them are threatened. Population extinction and range contraction is occurring for several of these unique vertebrates. None appears to be in imminent danger of complete extinction, but urban sprawl, pollution, climate change, and some types of agriculture and timber harvesting are causing declines in many areas. Fortunately, large parts of the Appalachian Mountain chain, especially in the southern Appalachians, are in U.S. National Park and National Forest Service ownership. Conservation and management of these spectacular amphibians is ongoing at many levels, such as with the Habitat Management Guidelines produced by Partners in Amphibian and Reptile Conservation (Bailey *et al.* 2006; Mitchell *et al.* 2006).

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The Blue Ridge Red Salamander Pseudotriton ruber *(Least Concern) ranges from the Hudson River in New York southwestward to Indiana and southward to Louisiana and the Gulf Coast; adults are both aquatic and terrestrial. © Don Church*

ESSAY 8.2. AMPHIBIAN DECLINES IN CALIFORNIA

California, along with Central America and Australia, has been a focal area for the study of amphibian population declines, because of the severe declines of many of its species. The region is recognized as one of the world's biodiversity hotspots (the "California Floristic Province") and contains a heterogeneous landscape that sustains a wide variety of ecosystems, such as Sonoran deserts, marshes and wetlands, oak woodlands, high-elevation alpine systems, temperate rain forests, and many others. The amphibian fauna is diverse and, at the time of writing, includes 64 recognized native species (Figure 1a), including 40 species of salamanders from five families and nine genera, and 24 species of frogs and toads from five families and six genera (plus two introduced species; AmphibiaWeb 2006). Amphibians in California can be found in nearly all habitat types ranging from near Mount Whitney (at 3,657 m, the highest peak in the contiguous United States) to Death Valley (85 m below sea level). Despite the fact that California contains some of the largest contiguous protected habitats in the continental United States, nearly one-quarter of amphibians in California are threatened (Figure 1b).

Many potential causes for the widespread declines of amphibians have been proposed. In general these can be grouped into two major categories: 1) factors general to the overall biodiversity crisis, including habitat destruction, alteration and fragmentation, introduced species and over-exploitation, and 2) factors associated with amphibians that might account for declines in relatively undisturbed habitats. The first category includes relatively well understood direct ecological phenomena, whereas the second includes complex and elusive mechanisms, such as climate change, increased ultraviolet (UV-B) radiation, chemical contaminants, infectious diseases, and the causes of deformities (or malformations). The underlying mechanisms behind these factors are complex and may be working synergistically with more evident factors, such as habitat destruction and introduced species, to exacerbate declines. Many biologists believe that there are some dominant causes, such as new infectious diseases, whereas others are not convinced that there is a single overarching cause for global declines, but that many factors are threatening amphibian populations to a greater or lesser extent.

In California, amphibian declines are associated with many of the various hypotheses. Habitat destruction, alteration, and fragmentation have affected a large number of species including the Foothill Yellow-legged Frog *R. boylii* (NT), the Arroyo Toad *Bufo californicus* (EN), and the California Tiger Salamander *Ambystoma californiense* (VU), to name a few (Lannoo 2005). Some amphibians suffered declines long ago. In the 19th century, the California Gold Rush brought waves of new settlers who quickly over-exploited some frog species for food. They also altered the environment in ways that have had much more substantial effects on amphibians. Cities were built, rivers dammed and diverted, forests were cleared, and the waterways of Great Central Valley were completely altered for agriculture and to provide water for cities and industrial growth. The effect on California's ecosystems has been profound. As elsewhere, habitat conservation has become a central theme in efforts to preserve the region's biodiversity. However, recent amphibian declines in California have occurred in remote habitats well protected from development.

Beginning in the 1980s, scientists began to document alarming amphibian disappearances in protected habitats in California, Central America, and Australia. Some of the best documented examples of declines can be found in the Sierra Nevada, which not only contains large sections of roadless, undisturbed habitat, but also has a rich history of biological surveys going back to the turn of the 20th century (Grinnell and Storer 1924). These data are useful for comparisons with present day distributions of amphibians. For example, historical surveys noted abundant amphibians throughout the Sierra Nevada, and at higher elevations (>1500 m) the Mountain Yellow-legged Frog *Rana muscosa* (CR) (Figure 2) was termed the most abundant of all vertebrates! But, in the last three decades, nearly the entire amphibian fauna of the Sierra Nevada has collapsed. Air pollution, increases in harmful ultraviolet radiation (UV-B), introduced predators, and emerging diseases have all been proposed as key factors that may explain the enigmatic declines in this protected landscape.

The first reports of amphibian collapse in the Sierra Nevada came from Yosemite Toads *Bufo canorus* (EN) (Stebbins and Cohen 1995). Hundreds of animals were found dead and dying, and many populations simply disappeared. A similar pattern was found with Mountain Yellow-legged Frogs (Stebbins and Cohen 1995), while Western Toads *Bufo boreas* (NT), Foothill Yellow-legged Frogs, and even Long-toed Salamanders *Ambystoma macrodactylum* (LC) also suddenly declined throughout their ranges. On the other hand, Pacific Chorus Frogs *Pseudacris regilla* (LC) remained abundant (Stebbins and Cohen 1995).

The Sierra Nevada became a testing ground for hypotheses that could account for disappearances in remote, seemingly pristine, habitats. One example is the UV-B hypothesis, which states that human-induced climate modification results in increased levels of harmful UV-B that can kill amphibian eggs exposed to direct sunlight. A correlational analysis showed that there was no negative pattern between expected high UV-B dose and disappearance of frogs, but did reveal that frog populations occurring closer to pesticide and fertilizer sources were more likely to have gone extinct than populations in more remote areas (Davidson *et al.* 2001). Disease, in particular chytridiomycosis, is also a factor and responsible for the collapse of amphibian populations in Central and South America (Berger *et al.* 1998; Lips *et al.* 2006), and Australia (Berger *et al.* 1998). This disease was found in collapsing populations of Mountain Yellow-legged Frogs in the Sierra Nevada (Rachowicz *et al.* 2006), although it also appears to be endemic in other amphibian species that have stable populations.

Amphibian declines may be the window into the future of what we can expect as humans continue to alter their environment on a global scale. As we learn more about the mechanisms responsible for declines, we may be able to reverse some of them, though there remain few examples. In the Sierra Nevada, one study has shown that, in the absence of disease, population recovery of threatened frogs is possible (Vredenburg 2004). Trout have been extensively introduced throughout the Sierra Nevada for sport fishing, and more than 90% of the naturally fishless lakes now contain non-native trout. The Mountain Yellow-legged Frog, which is adapted to living in environments without any fish, has declined dramatically (more than 93% of historical populations are now extinct; Vredenburg *et. al.* 2007), and while there are several potential causes, removal of introduced trout from entire lakes leads to recovery of local frog populations.

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The Mountain Yellow-legged Frog Rana muscosa *(Critically Endangered) from California and Nevada, USA, has declined by the loss of over 93% of historic populations. This frog is extinct in the state of Nevada, but scattered populations remain in the Sierra Nevada along eastern California and in three mountain tops surrounding Los Angeles (fewer than 200 individuals survive in only eight populations in the southern mountains). Major threats to remaining populations include air pollution, disease and introduced predators (trout). © Vance Vredenburg*

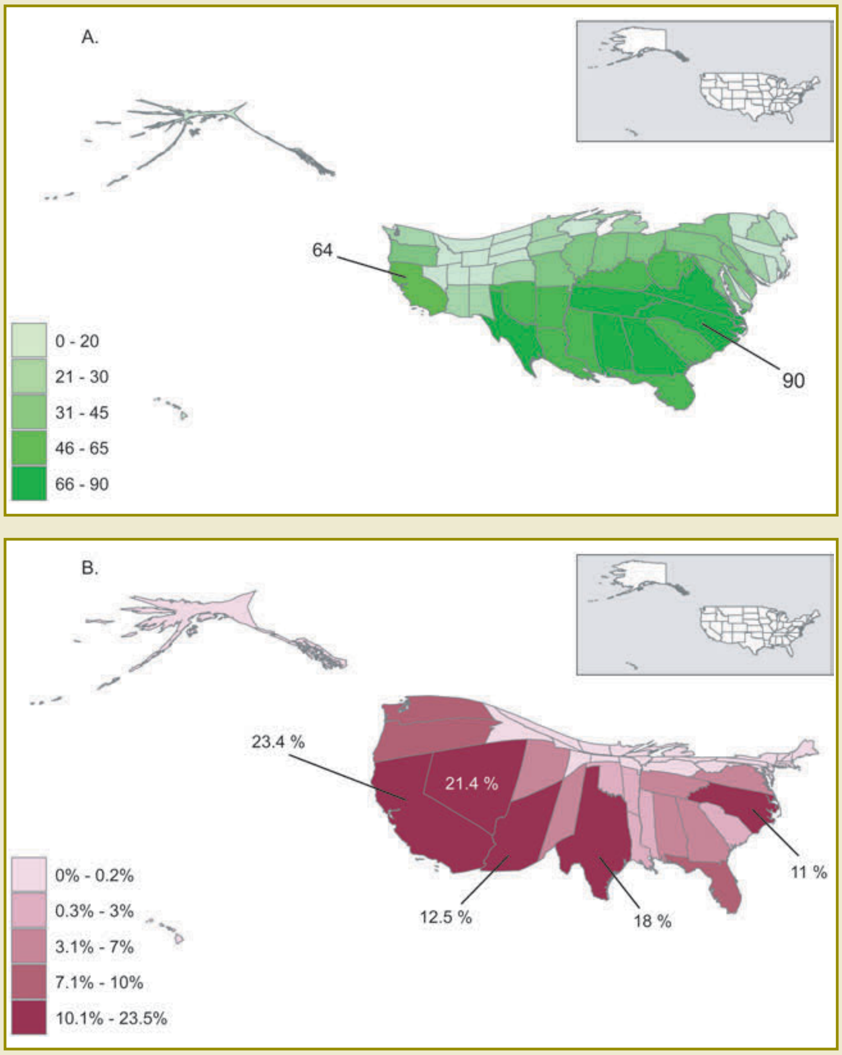


Figure 1. *Amphibian species diversity by U.S. state (A), and percent of threatened amphibian species by state (b) visualized using density equalizing cartograms (technique after Gastner and Newman 2004). State size and shape are purposefully distorted in proportion to (in A) the total number of amphibian species, and (B) the percentage of threatened species by state (data sources; A: AmphibiaWeb 2006; B: Stuart* et al. *2004).*

CHAPTER 9. AMPHIBIANS OF THE NEOTROPICAL REALM

Cochranella vozmedianoi *(Data Deficient) is a poorly known species endemic to Cerro El Humo, in the Península de Paria, in northern Venezuela. It is a glass frog from the Family Centrolenidae that inhabits tropical humid forests, along streams. It lays its eggs on the upper side of leaves overhanging streams. The larvae fall into the stream below after hatching. © Juan Manuel Guayasamin*

Federico Bolaños, Fernando Castro, Claudia Cortez, Ignacio De la Riva, Taran Grant, Blair Hedges, Ronald Heyer, Roberto Ibáñez, Enrique La Marca, Esteban Lavilla, Debora Leite Silvano, Stefan Lötters, Gabriela Parra Olea, Steffen Reichle, Robert Reynolds, Lily Rodríguez, Georgina Santos Barrera, Norman Scott, Carmen Ubeda, Alberto Veloso, Mark Wilkinson and Bruce Young

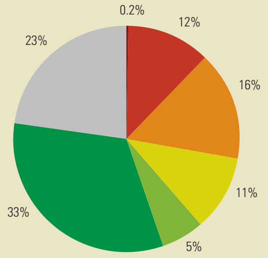
THE GEOGRAPHIC AND HUMAN CONTEXT

The Neotropical Realm includes all of mainland South America, much of Mesoamerica (except parts of northern Mexico), all of the Caribbean islands, and extreme southern Texas and Florida in the United States.

South America has a long history of geographic isolation that began when this continent separated from other Southern Hemisphere land masses 40-30 Ma. The Andes, one of the largest mountain ranges on earth and reaching 6,962m at Acongagua in Argentina, began to uplift 80-65Ma as South America drifted west from Africa. The other prominent mountainous areas on the continent are the Tepuis of the Guianan Shield, and the highlands of south-eastern Brazil. The complex patterns of wet and dry habitats on the continent are the result of an array of factors, including the climatic effects of cold ocean currents interacting with these mountain ranges, orographic barriers to winds carrying humidity within the continent, and the constant shifting of the intertropical convergence zone, among others.

Figure 1. *Summary of Red List categories for amphibians in the Neotropical Realm.*

Red List Category	Number of species
🟥 Extinct (EX)	7
Extinct in the Wild (EW)	0
🟥 Critically Endangered (CR)	358
🟧 Endangered (EN)	456
🟨 Vulnerable (VU)	324
🟩 Near Threatened (NT)	140
🟩 Least Concern (LC)	956
⬜ Data Deficient (DD)	675
Total Number of Species	**2,916**



The geological history of Mesoamerica is very complex and still not completely understood. The land north of the Isthmus of Tehuantepec in southern Mexico is historically part of the North American continent, with the highest point at Pico de Orizaba at 5,610m asl. The land south of the Isthmus to the southern Nicaragua lowlands is a mosaic of plates that have rearranged themselves and alternately been submerged and exposed by the sea several times during the last 65 million years. The region encompassed by Panama, Costa Rica, and southern Nicaragua formed over the last three to ten million years through a combination of volcanic activity and uplift. The result is a jumble of mountain ranges interrupted by valleys and lowlands, with the highest point being Volcán Tajumulco at 4,220m asl in Guatemala. The closing of these different blocks of land in present-day Nicaragua during the Pliocene (5.3 - 1.8 Ma) has had a marked impact on the distribution of amphibians today.

The geological history of the Caribbean also remains under intense study, but most geologists now agree that the Greater Antilles (Cuba, Jamaica, Hispaniola, and Puerto Rico) are geological cousins of the plates that make up northern Central America. Some 100 Ma, these islands were lined up more or less between North and South America in approximately the location of present day Central America. Over the last 70 million years, these islands have drifted east to their current positions. The trailing edge of this parade of islands has fused to North America and now makes up northern Central America. Some of the Greater Antilles may have had temporary land connections with North and/or South America as they drifted eastward. The Lesser Antilles formed in a completely different manner. As the Caribbean Plate carrying the Greater Antilles moved eastward, the America Plate subducted beneath it, creating an island arc known today as the Lesser Antilles.

The region is enormously varied ecologically. Equatorial South America is dominated by the lowland rainforest of the Amazon Basin. South of this the habitats become progressively drier and less suitable for amphibians, with the exception of the now extensively cleared Atlantic Forest of southern and eastern Brazil, eastern Paraguay, and north-eastern Argentina, and the temperate forests of Chile. There are important wetland areas in the Llanos of Venezuela and Colombia, and the Pantanal of Brazil, Paraguay and Bolivia. The topographically varied Andean region includes all varieties of habitats, from some of the wettest lowland rainforest in the Pacific lowlands of Colombia to the Atacama Desert in northern Chile (the driest place on earth), and from cold temperate habitats in the extreme south of the continent to high mountain paramos in the tropics. In Mesoamerica there is a very complex patchwork of natural habitats, with humid mountain slopes rising above both dry (generally on the Pacific side) and wet (Caribbean side) lowland habitats. The Caribbean islands are also a complex mosaic of habitats, with low-lying islands tending to be semi-arid, and wetter environments occurring where trade winds encounter the higher Caribbean mountains giving rise to a variety of moist tropical forest types.

On average, the Neotropics have a relatively low human population density (approximately 27 people per square kilometre in 2005), only 22% of which lives in rural areas, and a population growth rate (1.4% per annum) that is decreasing. However, some Caribbean islands are among the most densely populated places on Earth. Historically, South America has been subject to relatively low levels of anthropogenic disturbance, but human impact has been higher in northern Mesoamerica and on the Caribbean islands. The low impact in much of the region is related to low human population densities. The gross income per capita was around US$3,500 in the region in 2004. However, 33% of the region's Gross Domestic Product is concentrated in Mexico and a further 30% in Brazil, where the human impacts on natural ecosystems and biodiversity have been much more severe. Economic growth rates in the region have been modest (2.7% in 2003).

The human impact on ecosystems is very variable through the region. Natural habitats have been particularly severely damaged on many of the Caribbean islands (and especially in Haiti), and in the northern part of Mesoamerica (from central Mexico, south to Guatemala, Honduras and El Salvador). There has also been extensive habitat loss through much of the Andes, and especially in the Atlantic Forests and Cerrado of central, southern and eastern Brazil, and in the native southern temperate forests of Chile. The forests of the Amazon Basin and Guianan Shield are still largely intact, although there is much clearance currently taking place along the southern edge of the forest zone in Brazil. Habitat loss in the region has been driven largely by expanding subsistence agriculture to support growing human populations, and also by commercial agriculture and logging.

GLOBAL CONSERVATION STATUS

A total of 2,916 amphibian species (49% of the world's total) are recorded from the Neotropical Realm, of which 1,145 (39%) are considered to be globally threatened (Figure 1). This is significantly more than the global average of 33%[1]. As is the case globally, the percentage of threatened species is expected to increase as the status of DD species is clarified, as new species (some of which are likely to be rare, and/or have small ranges) are discovered, and as the taxonomic status of many species complexes is resolved.

Table 1. *The Critically Endangered (Possibly Extinct) amphibian species in the Neotropical Realm (*denotes species that also occur in the Nearctic Region). A full list of CR(PE) species can be found in Appendix IX.*

ANURA
Bufonidae
Andinophryne colomai
Atelopus arthuri
Atelopus balios
Atelopus carbonerensis
Atelopus chiriquiensis
Atelopus chrysocorallus
Atelopus coynei
Atelopus famelicus
Atelopus guanujo
Atelopus halihelos
Atelopus lozanoi
Atelopus lynchi
Atelopus mindoensis
Atelopus muisca
Atelopus nanay
Atelopus oxyrhynchus
Atelopus pachydermus
Atelopus peruensis
Atelopus pinangoi
Atelopus planispina
Atelopus sorianoi
Atelopus senex
Atelopus sernai
Bufo fastidiosus
Bufo fluviaticus
Bufo holdridgei
Melanophryniscus macrogranulosus[2]
Rhamphophryne rostrata
Centrolenidae
Centrolene ballux
Centrolene heloderma
Hyalinobatrachium crybetes
Dendrobatidae
Aromobates nocturnes
Colostethus dunni
Colostethus edwardsi
Colostethus jacobuspetersi
Colostethus ruizi
Colostethus vertebralis
Dendrobates abditus
Mannophryne neblina
Hylidae
Aplastodiscus flumineus
Bromeliohyla dendroscarta
Bokermannohyla claresignata
Bokermannohyla izecksohni
Charadrahyla altipotens
Charadrahyla trux
Ecnomiohyla echinata
Hyla bocourti
Hyla chlorostea
Hypsiboas cymbalum
Isthmohyla calypsa
Isthmohyla debilis
Isthmohyla graceae
Isthmohyla rivularis
Isthmohyla tica
Megastomatohyla pellita
Plectrohyla calvicollina
Plectrohyla celata
Plectrohyla cembra
Plectrohyla cyanomma
Plectrohyla ephemera
Plectrohyla hazelae
Plectrohyla siopela
Plectrohyla thorectes
Scinax heyeri
Leptodactylidae
Craugastor anciano
Craugastor andi
Craugastor angelicus
Craugastor coffeus
Craugastor cruzi
Craugastor escoces
Craugastor fecundus
Craugastor fleischmanni
Craugastor guerreroensis
Craugastor merendonensis
Craugastor omoaensis
Craugastor polymniae
Craugastor saltuarius
Craugastor stadelmani
Craugastor trachydermus
Crossodactylus trachystomus
Cryptobatrachus nicefori
Cycloramphus ohausi
Eleutherodactylus bernali
Eleutherodactylus emleni
Eleutherodactylus eneidae
Eleutherodactylus glanduliferoides
Eleutherodactylus jasperi
Eleutherodactylus karlschmidti
Eleutherodactylus olanchano
Eleutherodactylus orcutti
Eleutherodactylus schmidti
Eleutherodactylus semipalmatus
Eleutherodactylus zongoensis
Gastrotheca lauzuricae
Holoaden bradei
Odontophrynus moratoi
Paratelmatobius lutzii
Paratelmatobius mantiqueira
Phrynopus spectabilis
Telmatobius cirrhacelis
Telmatobius niger
Telmatobius vellardi
Ranidae
Rana omiltemana
Rana pueblae
*Rana tlaloci**
Rhinodermatidae
Rhinoderma rufum

CAUDATA
Plethodontidae
Bolitoglossa jacksoni
Bradytriton silus
*Chiropterotriton magnipes**
Ixalotriton parva
Oedipina paucidentata
Pseudoeurycea aquatica
Pseudoeurycea naucampatepetl
Pseudoeurycea nigromaculata
Pseudoeurycea praecellens
Thorius infernalis
Thorius magnipes
Thorius narismagnus
Thorius narisovalis

The Neotropical Realm contains 60% (1,145) of all globally threatened amphibians. The region accounts for a massive 79% of CR species, 59% of the EN species, and 48% of the VU species in the world. In other words, unlike the case elsewhere, threatened Neotropical amphibians are more likely to be in a higher category of threat (CR or EN), when compared with the global distribution of threatened species amongst categories. This tendency for threatened species to be in CR and EN is probably explained in part by the effects of habitat loss on species with very small ranges, in particular in the Andes, Mesoamerica, and the Caribbean islands, and also the very severe impact of enigmatic declines that are probably due to the synergistic effects of the pathogenic chytrid fungus and climate change, especially through the higher elevations of the region.

There have been seven recorded recent extinctions of amphibians in the Neotropical Realm (21% of the global total): *Atelopus ignescens* (the Jambato Toad from Ecuador); *Atelopus longirostris* (Ecuador); *Atelopus vogli* (Venezuela); *Bufo periglenes* (the famous Golden Toad from Monteverde, Costa Rica); *Phrynomedusa fimbriata* (southern Brazil); *Craugastor chrysozetetes* (Honduras); and *Craugastor milesi* (Honduras). With the exception of the Golden Toad, all of these were stream-associated species that occurred at middle to high elevations (above 700m asl) – the typical ecological profile of species that have experienced rapid declines (Lips *et al.* 2003; Ron *et al.* 2003; Burrowes *et al.* 2004; Stuart *et al.* 2004; La Marca *et al.* 2005). Some additional undescribed species are possibly extinct, especially in the genus *Atelopus* (see Pounds *et al.* [2006] for details).

In addition, 121 Critically Endangered species in the Neotropics are considered possibly extinct. This represents 93% of the 130 possibly extinct species in the world, thus dramatically highlighting the extinction crisis that has unfolded with the Neotropical amphibians. Most of the Critically Endangered (Possibly Extinct) species (listed in Table 1) share the same ecological characteristics as those that have gone extinct. Of the 121 possibly extinct species, 22 are harlequin toads in the genus *Atelopus* (representing 29% of the described species in the genus), which have experienced catastrophic declines, especially in southern Mesoamerica, and in the Andes south at least to Peru (La Marca *et al.* 2005; Pounds *et al.* 2006; and see Essay 9.1). Four genera concentrated in Mesoamerica also have large proportions of possibly extinct species: *Isthmohyla* (36%), *Plectrohyla* (20%), *Craugastor* (14%) and *Thorius* (17%) (see, for example, Lips *et al.* [2004, 2006] and Mendelson *et al.* [2004]). In each of these cases, further work is likely to show that the percentage of possibly extinct species has been underestimated. Another genus for which the percentage of possibly extinct species might have been underestimated is *Cycloramphus* from southern Brazil (see Eterovick *et al.* [2005] and Heyer *et al.* [1988] for more details). The genus *Telmatobius*, which occurs in the Andes from Ecuador southwards, is also subject to extensive disappearances, but much of this information is only just now becoming available, and for the most part is not yet included in these results (De la Riva 2005; and see Essay 9.2). Possibly extinct species range very widely in the Neotropics, generally in mountainous regions from southern Mexico (for example, *Plectrohyla cyanomma*) south to Chile (for example, *Rhinoderma rufum*). A number of recent declines and possible extinctions in Colombia have come to light since the GAA data were collected (F. Castro pers. obs.).

The percentage of DD species is very similar to the global average of 23%. As mentioned above, many of these DD species are likely to be threatened, but many others could be LC, especially those that occur in poorly surveyed low-lying areas, such as in parts of the Amazon basin, and the Cerrado of Brazil.

SPECIES RICHNESS AND ENDEMISM

Species Richness and Endemism Across Taxa

Of the 2,916 native amphibian species in the Neotropical Realm, 2,808 (or 96%) are endemic to the Neotropics (Table 2). All three orders of amphibians are represented in the Neotropical Realm. The overwhelming majority of Neotropical amphibians (89%) are frogs and toads (Anura), 97% of which are endemic. All species of Neotropical caecilians (Gymnophiona), and 91% of Neotropical salamanders (Caudata), are endemic. Only 392 species (13%) are members of families that are endemic to the region, but this low percentage is really a reflection of the fact that the very large family Leptodactylidae (accounting for 42% of Neotropical amphibian species) marginally occurs in the Nearctic Region.

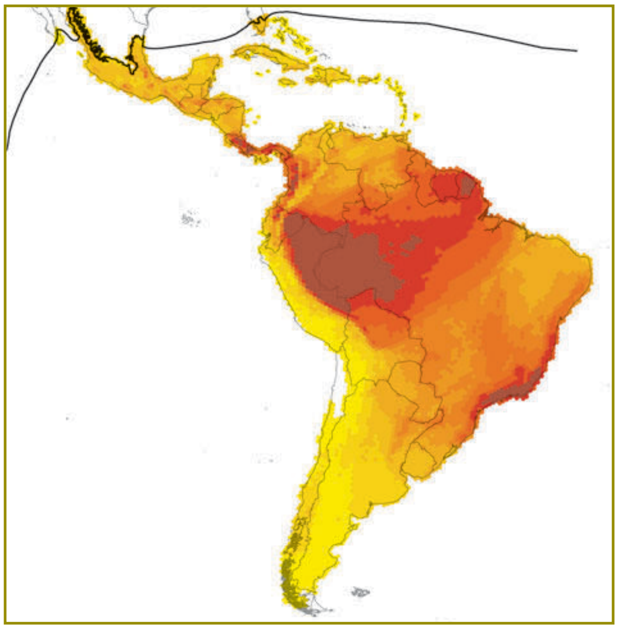


Figure 2. *The species richness of amphibians in the Neotropical Realm, with darker colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes; maximum richness equals 144 species.*

The Strawberry Poison Frog Dendrobates pumilio *(Least Concern) is a poison frog from the Family Dendrobatidae, a Family famous for the stunning coloration of its species. This species lives on the floor of lowland rainforest in Nicaragua, Costa Rica and Panama. The females lay egg clutches on the forest floor, and carry the larvae, after hatching, to water-filled bromeliads, where they complete their development. © Piotr Naskrecki*

The Burrowing Toad Rhinophrynus dorsalis *(Least Concern) is the only member of the Family Rhinophrynidae. It is a lowland species ranging from southern Texas to Costa Rica. It can be found in forest, thorn scrub, savannah, and cultivated areas with friable soils. It is usually subterranean, except after heavy rains, when it emerges to breed explosively in temporary pools. © Paddy Ryan*

Under current climatic conditions, there is less isolation between the Neotropical and Nearctic Regions than there is between the Afrotropical and Palaearctic Regions, and there are points of contact between the two faunas along the Caribbean coast of Mexico, and Florida (although the transvolcanic belt in central Mexico does form a barrier to faunal dispersal). The result of this indistinct boundary is to reduce the level of endemism of each region. The families Leptodactylidae and Rhinophrynidae are nearly endemic to the Neotropics, and Scaphiopodidae, Ambystomatidae, Amphiumidae and Sirenidae are almost endemic to the Nearctic. Salamandridae is also a northern element that is only marginally present in the Neotropics. Of the 20 families that are native to the region, six are endemic. Amphibian family-level diversity is higher than in any other biogeographic realm, but endemism is lower than in the Afrotropics (where there are nine endemic families) because of the relative lack of isolation. From the perspective of amphibian biogeography, the region is almost defined by the distribution of the Neotropical frogs (family Leptodactylidae), which are present through nearly all of Mexico, Central America, South America, and the Caribbean islands. Summaries of the amphibian fauna of the Neotropics are provided by Campbell (1999a), Duellman (1999) and Hedges (1999).

There are 189 genera occurring in the region (41% of the global total), of which 157 are also endemic. These endemic genera represent over one-third (34%) of the 460 amphibian genera worldwide. The Neotropics, therefore, account for a larger proportion of the overall diversity of amphibians at the species level than at the generic level. The most species-rich genus in the region is *Eleutherodactylus* (607 species, and 715 if the genus *Craugastor* is included within it, *contra* Crawford and Smith [2005]). At the opposite end of the spectrum, there are 46 monotypic genera endemic to the Neotropical Realm, which equates to just over one-third (33%) of the 126 monotypic genera of amphibians worldwide. Interestingly, nine of these monotypic genera are in the family Microhylidae, which is not particularly diverse in the region. The 32 non-endemic genera in the Neotropics include 13 genera from Hylidae, four from Plethodontidae, three from Leptodactylidae, two each from Microhylidae, Scaphiopodidae and Sirenidae, and one each from Bufonidae, Ranidae, Rhinophrynidae, Ambystomatidae, Amphiumidae and Salamandridae. These non-endemics include the widespread genera *Bufo* and *Rana*.

Of the 20 amphibian families that occur in the Neotropics (42% of the global total), six are endemic to the region: Allophrynidae, Brachycephalidae, Centrolenidae, Dendrobatidae, Rhinodermatidae, and Rhinatrematidae.[3] The characteristics of these families are provided in Chapter 1.

Among the non-endemic families, the majority of Neotropical species are in Bufonidae, Hylidae, Leptodactylidae and Microhylidae. Of the Neotropical Bufonidae, 121 species (47% of those occurring in the region) are within the widespread genus *Bufo*. There are 77

Table 2. *The number of Neotropical amphibians in each taxonomic Family present in the region.*

Family	Native species (endemics to region)	Percentage of species in region that are endemic	Percentage of species in family that are endemic to region	Native genera (endemics to region)	Percentage of genera in region that are endemic	Percentage of genera in family that are endemic to region
Anura						
Allophrynidae	1 (1)	100	100	1 (1)	100	100
Brachycephalidae	8 (8)	100	100	1 (1)	100	100
Bufonidae	256 (240)	94	50	13 (12)	92	35
Centrolenidae	138 (138)	100	100	3 (3)	100	100
Dendrobatidae	234 (234)	100	100	9 (9)	100	100
Hylidae	610 (585)	96	73	46 (33)	72	67
Leptodactylidae	1,235 (1,215)	98	98	55 (52)	95	95
Microhylidae	56 (52)	93	12	19 (17)	89	25
Pipidae	7 (7)	100	23	1 (1)	100	14
Ranidae	34 (17)	50	3	1 (0)	0	0
Rhinodermatidae	2 (2)	100	100	1 (1)	100	100
Rhinophrynidae	1 (0)	0	0	1 (0)	0	0
Scaphiopodidae	3 (0)	0	0	2 (0)	0	0
TOTAL ANURA	**2,585 (2,499)**	**97**	**48**	**153 (130)**	**85**	**36**
Caudata						
Ambystomatidae	15 (9)	60	30	1 (0)	0	0
Amphiumidae	1 (0)	0	0	1 (0)	0	0
Plethodontidae	221 (210)	95	58	14 (10)	71	34
Salamandridae	2 (0)	0	0	1 (0)	0	0
Sirenidae	2 (0)	0	0	2 (0)	0	0
TOTAL CAUDATA	**241 (219)**	**91**	**41**	**19 (10)**	**53**	**16**
Gymnophiona						
Caeciliidae	81 (81)	100	72	15 (15)	100	58
Rhinatrematidae	9 (9)	100	100	2 (2)	100	100
TOTAL GYMNOPHIONA	**90 (90)**	**100**	**52**	**17 (17)**	**100**	**52**
TOTAL ALL AMPHIBIANS	**2,916 (2,808)**	**96**	**47**	**189 (157)**	**83**	**34**

Family	EX	CR	EN	VU	NT	LC	DD	Total number of species	Number Threatened or Extinct	% Threatened or Extinct
Anura										
Allophrynidae	0	0	0	0	0	1	0	1	0	0
Brachycephalidae	0	0	0	1	1	1	5	8	1	13
Bufonidae	4	73	29	30	10	77	33	256	136	53
Centrolenidae	0	6	16	29	10	28	49	138	51	37
Dendrobatidae	0	20	29	16	14	58	97	234	65	28
Hylidae	1	65	58	35	24	312	115	610	159	26
Leptodactylidae	2	145	246	172	61	350	259	1,235	565	46
Microhylidae	0	0	2	5	2	37	10	56	7	13
Pipidae	0	0	1	0	0	6	0	7	1	14
Ranidae	0	5	2	7	4	14	2	34	14	41
Rhinodermatidae	0	1	0	1	0	0	0	2	2	100
Rhinophrynidae	0	0	0	0	0	1	0	1	0	0
Scaphiopodidae	0	0	0	0	0	3	0	3	0	0
TOTAL ANURA	**7**	**315**	**383**	**296**	**126**	**888**	**570**	**2,585**	**1,001**	**39**
Caudata										
Ambystomatidae	0	8	2	0	0	3	2	15	10	67
Amphiumidae	0	0	0	0	0	1	0	1	0	0
Plethodontidae	0	35	70	28	14	28	46	221	133	60
Salamandridae	0	0	1	0	0	1	0	2	1	50
Sirenidae	0	0	0	0	0	2	0	2	0	0
TOTAL CAUDATA	**0**	**43**	**73**	**28**	**14**	**35**	**48**	**240**	**144**	**60**
Gymnophiona										
Caeciliidae	0	0	0	0	0	29	52	81	0	0
Rhinatrematidae	0	0	0	0	0	4	5	9	0	0
TOTAL GYMNOPHIONA	**0**	**0**	**0**	**0**	**0**	**33**	**57**	**90**	**0**	**0**
TOTAL ALL AMPHIBIANS	**7**	**358**	**456**	**324**	**140**	**956**	**675**	**2,915**	**1,145**	**39**

Table 3. *The number of species within each IUCN Red List Category in each Family and Order in the Neotropical Realm. Introduced species are not included.*

species in *Atelopus*, 19 in *Melanophryniscus*, and 10 in *Rhamphopryne*, but the remaining nine genera have small numbers of species. Most of the Neotropical species breed by larval development, but breeding (where it is known) is by direct development in *Metaphryniscus*, *Oreophrynella* and *Osornophryne* and unknown in *Andinophryne*, *Crepidophryne*, *Rhamphopryne* and *Truebella*. The family is widely distributed through most of the Neotropics, with highest species richness in the equatorial regions.

Hylidae is overwhelmingly a Neotropical family, the main radiation outside the region occurring in Australia and New Guinea. At the species level, 73% of the family (585 species) is endemic to the Neotropics, where it occurs widely through most of the region (excluding Chile), with especially high species richness in Brazil (over 300 species, with very high diversity in the Atlantic Forest). There are over 160 species in Mesoamerica. Two subfamilies, Phyllomedusinae and Hylinae, occur in the Neotropics (and see Essay 1.5). The genera have recently been extensively revised (Faivovich *et al.* 2005), and under this new arrangement, the genera *Dendropsophus*, *Scinax*, *Hypsiboas*, *Plectrohyla*, *Hyloscirtus*, *Phyllomedusa*, *Hyla* and *Bokermannohyla* all have more than 20 species. The Neotropical hylids are associated with many different habitats, but species richness is highest in forests, and all known breeding is by larval development.

The family Leptodactylidae, which is almost endemic to the Neotropics, is by far the largest family of amphibians worldwide. It ranges widely throughout the region, with the highest species richness in the tropical Andes from Venezuela and Colombia south to Bolivia (over 550 species), with significant diversity in Brazil (nearly 300 species), Mesoamerica (*c.* 160 species), the Caribbean islands (*c.* 160 species) and the Southern Cone (*c.* 130 species). The family includes the largest genus of vertebrates, *Eleutherodactylus* (607 species) with the following genera including more than 20 species: *Craugastor*, *Leptodactylus*, *Gastrotheca*, *Telmatobius*, *Physalaemus*, *Phrynopus*, *Cycloramphus*, and *Hylodes*. The family includes species that breed by direct development and larval development. Although these frogs occur in many habitats, species richness is highest in forests.[4]

The Neotropical Microhylidae species are widely distributed within the region, from Mexico south to central Argentina, but not on the Caribbean islands (except Trinidad). With the exception of *Chiasmocleis* (19 species), all genera are small. Most species occur at low elevations, with highest species richness in the equatorial regions. In the Neotropics, all species breed by larval development, and many are subterranean when not breeding.

The Neotropical Ranidae species (all of which are in the widespread genus *Rana*) are all larval developers, and occur predominantly in Mesoamerica, with three species reaching South America, and none on the Caribbean islands (except Trinidad). Of the remaining families, the highly aquatic Pipidae, with a single genus in the region, *Pipa*, ranges from Panama south to Bolivia. Scaphiopodidae, Amphiumidae, Salamandridae and Sirenidae are Nearctic taxa that only marginally occur in the northern Neotropics. Ambystomatidae (mole salamanders) is also a Nearctic element, but there is an important radiation of species in central Mexico, including the famous Axolotl *Ambystoma mexicanum* (CR). Ambystomatidae breed by larval development, and some retain their aquatic larval features throughout their life cycles.

Most Neotropical salamanders are in the large family Plethodontidae (lungless salamanders). This family has its highest species richness in the Nearctic, but there are *c.* 110 species in Mexico, *c.* 40 in Guatemala, *c.* 25 in Honduras, *c.* 40 in Costa Rica, *c.* 25 in Panama, but only 28 in the whole of South America (12 of these being endemic to Colombia). The largest Neotropical genus is *Bolitoglossa* (91 species), with *Pseudoeurycea*, *Oedipina* and *Thorius* each having more than 20 species. Lungless salamanders occur as far south as Bolivia. With the possible (but even then unlikely) exception of a single species (*Pseudoeurycea aquatica*), all Neotropical species breed by direct development, and almost all are associated with forest habitats (and see Essay 9.3).

The caecilian family Caeciliidae is very poorly known in the Neotropics, as in other parts of the world. A total of 81 species (in 15 genera) is recorded from the region, comprising 72% of the family at the species level. Species richness is highest in the Amazon Basin, with only 16 species in Mesoamerica (as far north as southern Mexico), and four species reaching northern Argentina. The species exhibit a wide variety of reproductive modes, from larval and direct development, to live-bearing. The majority are subterranean species in the forest floor, but certain species (in the genera *Atretochoana*, *Potomotyphlus* and *Typhlonectes*) are aquatic, sometimes referred to as "rubber eels".

Not surprisingly, the larger families – Bufonidae, Centrolenidae, Dendrobatidae, Hylidae, Leptodactylidae and Plethodontidae – have the largest absolute numbers of globally threatened species (Table 3). The percentage of threatened species ranges greatly between the families, from zero for the Allophrynidae, Rhinophrynidae, Scaphiopodidae, Amphiumidae, Sirenidae, Caeciliidae, and Rhinatrematidae, to 100% for the endemic Rhinodermatidae of Chile and Argentina. The zero percentages of threatened species in the caecilian families is probably because these species are so poorly known (with >50% of species Data Deficient in both the Caeciliidae and Rhinatrematidae). The percentages of threatened species are also very high in the salamander families Ambystomatidae (67% - reflecting the serious conservation problems on the Mexican plateau) and Plethodontidae (60% - reflecting the poor state of forest conservation in the pine-oak regions of Mexico, Guatemala, and Honduras). The percentage levels of threat are also high (>30%) in the Bufonidae (53% - reflecting, in part, the devastating declines in the genus *Atelopus*), Leptodactylidae (46% - with several genera, including *Craugastor*, *Eleutherodactylus* and *Telmatobius* showing high levels of threat), Ranidae (41%), and Centrolenidae (37%).

Some of the larger families have more species in the Endangered category than in Critically Endangered or Vulnerable (e.g., Dendrobatidae, Leptodactylidae, Plethodontidae). However, Centrolenidae show a similar pattern to birds and mammals (Baillie *et al.* 2004), with least in Critically Endangered and most in Vulnerable. Conversely, Bufonidae and Hylidae have most in Critically Endangered and least in Vulnerable, showing how severely impacted these families have been by recent dramatic declines (indeed, 55% of threatened Neotropical Bufonidae are Critically Endangered). Among the smaller families, there is also a high percentage of Critically Endangered species in Rhinodermatidae and Ambystomatidae.

Geographic Patterns of Species Richness and Endemism

A map of overall species richness of amphibians in the Neotropical Realm (Figure 2), shows that species richness is highest in the tropical regions, notably Costa Rica and Panama, the Pacific lowlands of western Colombia and north-western Ecuador, the Guianan Shield, the Atlantic Forest of southern Brazil, and in particular in the Amazon Basin (especially in the west). Species richness is lowest in more temperate regions (Mexico, Argentina and Chile), on the Caribbean islands, and especially in arid regions, such as northern Mexico and northern Chile (there being no amphibians at all in most of the Atacama Desert region). The higher taxon diversity is particularly low in the Caribbean islands, where there are just four families and five genera (compared with 15 families and 67 genera in Mesoamerica). The vast majority (88%) of the Caribbean's amphibian species belong to just one genus, *Eleutherodactylus*. No salamanders or caecilians occur on these islands.

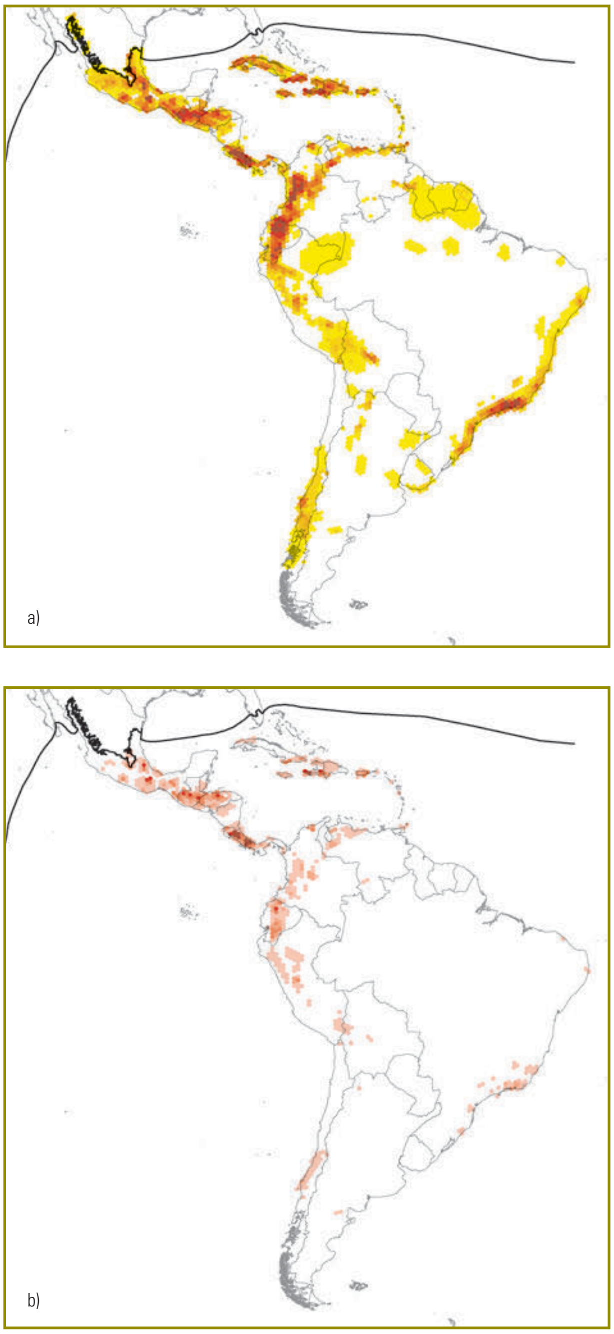


Figure 3. *a) The richness of threatened amphibians in the Neotropical Realm, with darker colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes; maximum richness equals 42 species. b) The richness of CR amphibians in the Neotropical Realm. Colour scale based on five quantile classes; maximum richness equals 18 species.*

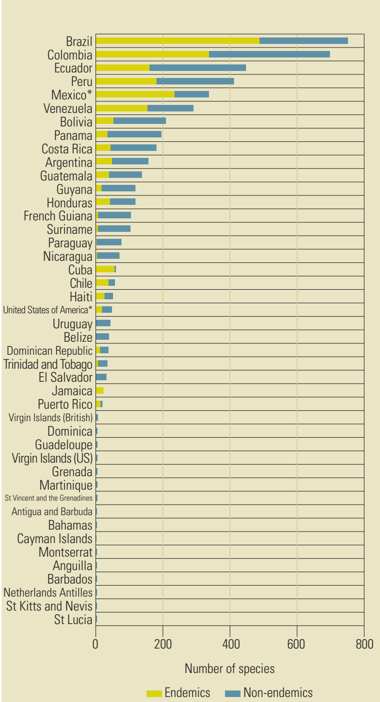


Figure 4

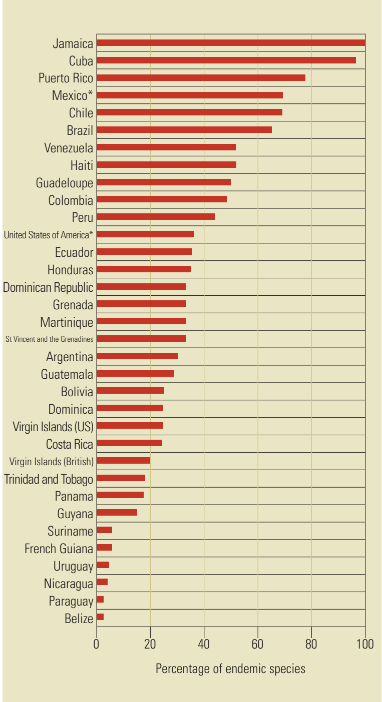


Figure 5

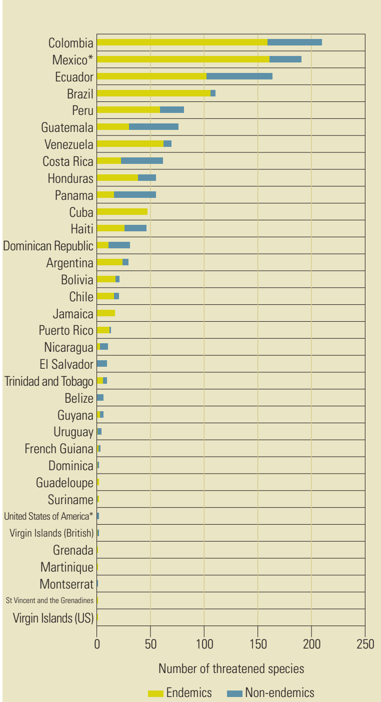


Figure 6

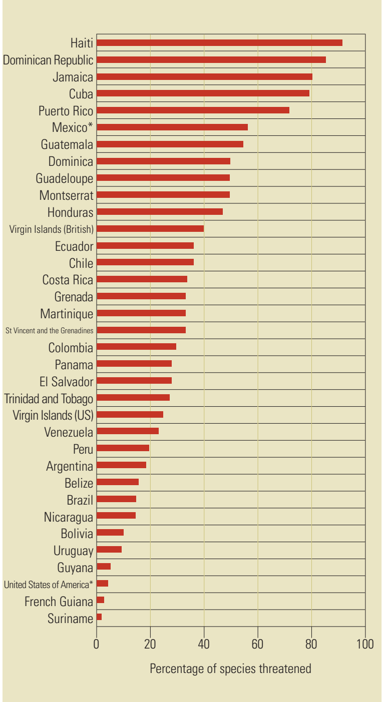


Figure 7

Figure 4. *The number of amphibians present in and endemic to each Neotropical country. *denotes countries not entirely within the Neotropical Realm, hence only the species whose ranges fall within the region are included.*

Figure 5. *Percentage of species endemic to each Neotropical country. *denotes countries not entirely within the Neotropical Realm, hence only the species whose ranges fall within the region are included.*

Figure 6. *The number of threatened amphibians present in and endemic to each Neotropical country. Countries with no threatened species are not included in the diagram. *denotes countries not entirely within the Neotropical Realm, hence only the species whose ranges fall within the region are included.*

Figure 7. *Percentage of native species that are threatened. Countries with no threatened species are not included in the diagram. *denotes countries not entirely within the Neotropical Realm, hence only the species whose ranges fall within the region are included.*

As with other parts of the tropics, Figure 2 probably does not reflect genuine patterns of amphibian species richness everywhere in the region, due to uneven survey effort. In particular, species richness is probably under-sampled in the Guianan Shield, in the Venezuelan, Colombian and Bolivian Amazon, in the Peruvian and Bolivian Andes, and in the Cerrado of Brazil. However, sampling appears to be less uneven than in the Old World tropics (similar maps for the Afrotropical, Indomalayan and Australasian Realms make much less overall biogeographic sense). New species continue to be discovered at a rapid rate almost everywhere in the Neotropics, but nevertheless the overall patterns of species richness are probably reasonably clear.

Over 85% of the threatened amphibian species in the Neotropics occur in the region from southern Mexico to Ecuador and northern Venezuela, and on the Greater Antilles (Cuba, Hispaniola, Jamaica and Puerto Rico) (see Figure 3a). This region represents by far the greatest concentration of threatened amphibian species anywhere in the world. Within this region there are peaks of threatened species in montane areas in southern Mexico, Guatemala, Honduras, Costa Rica, western Panama, Cuba, Hispaniola, Jamaica, Puerto Rico, and the Andes of Venezuela, Colombia and Ecuador. Outside this region, the largest concentration of threatened amphibian species in the Neotropics is in the Atlantic Forests of southern Brazil. There are lesser concentrations in the Peruvian and Bolivian Andes, and in the austral forest zone of Chile. It is possible that, due to the poor state of knowledge, the levels of threat have been under-estimated in the Peruvian and Bolivian Andes; further, with very recently recorded declines in *Telmatobius* species (De la Riva 2005), and probably in other species too, not yet included in our data, it is likely that a new concentration of threatened species will soon be identified in the Andes running from Peru south to Bolivia, Chile, and Argentina. These concentrations of threatened species correlate with those for other taxa (Baillie *et al.* 2004). These geographic concentrations reflect the topographically diverse (usually montane) parts of the region where amphibians have naturally small ranges, and where habitat destruction is ongoing (and in central and southern Peru is in part a reflection of the over-harvesting of some frogs (e.g., in the genus *Telmatobius*) for human consumption). However, these are also the places where rapid population declines and disappearances have been noted due to chytridiomycosis and climate change (Heyer *et al.* 1988; La Marca and Reinthaler 1991; Young *et al.* 2001; Lips *et al.* 2003, 2004, 2006; Ron *et al.* 2003; Burrowes *et al.* 2004; Mendelson *et al.* 2004; De la Riva 2005; Eterovick *et al.* 2005; La Marca *et al.* 2005; Pounds *et al.* 2006).

The concentrations of Critically Endangered species (Figure 3b) broadly match those of threatened species as a whole. The greatest concentrations of these most severely threatened species are in southern Mexico (in particular Veracruz and Oaxaca), Guatemala, Honduras, Costa Rica, western Panama, the Ecuadorian Andes, and Haiti (especially the Massif de la Hotte and Massif de la Selle). Lesser concentrations of Critically Endangered species are found in the Andes of Venezuela, Colombia, Peru, southern Brazil, central Chile, Puerto Rico, Dominican Republic, Jamaica, and eastern Cuba (although recent data from the Colombian Andes suggest that the next update of the GAA might reveal this region to be a major concentration of Critically Endangered species (F. Castro pers. obs.).

Species Richness and Endemism within Countries

Amphibians occur naturally in every mainland country in Mesoamerica and South America, and on all but the smallest Caribbean islands (Figure 4). However, only one extant species occurs naturally in St. Lucia, St. Kitts and Nevis, the Netherlands Antilles, Barbados and Anguilla, and only two on Antigua and Barbuda, the Bahamas, the Cayman Islands and Montserrat. There are no indigenous amphibians on the Galapagos Islands.

The two countries with the largest number of species in the Neotropical Realm are Brazil (751 species; and see Essay 9.4) and Colombia (697 species; see Essay 9.5). There is also very high species richness in Ecuador (447 species), Peru (411), Mexico (336), Venezuela (298) and Bolivia (209). Brazil, Colombia, Ecuador, Peru, and Mexico are the top five countries in the world in terms of amphibian species richness. Another eight Neotropical countries have more than 100 species (Panama – 195, Costa Rica – 179, Argentina – 157, Guatemala – 138, Guyana – 118, Honduras – 116, French Guiana – 104, Suriname – 103).

These figures are, of course, a reflection of current knowledge, and as mentioned earlier, certain regions and countries have been better studied than others. In certain places, the existing knowledge has been well summarized in review literature, and in books, including: Mexico (Flores-Villela 1993; Flores-Villela *et al.* 1995; Calderon Mandujano *et al.* 2005); Yucatán (Campbell 1999b; Lee 1996, 2000); Guatemala (Lee 2000, Campbell 1999b, 2001); Belize (Campbell 1999b, Lee 2000); Honduras (McCranie and Wilson 2002; McCranie *et al.* 2006); El Salvador (Köhler *et al.* 2005); Nicaragua (Köhler 2001); Costa Rica (Savage 2002; Guyer and Donnelly 2005); Panama (Ibáñez *et al.* 1999, 2000); Colombia (Ruiz-Carranza *et al.* 1996); Venezuela (La Marca 1992, 1997; Barrio Amorós 2004); Ecuador (Coloma 2005); Peru (Lehr 2002); Bolivia (De la Riva *et al.* 2000, Köhler 2000); Argentina (Cei 1980, 1987; Lavilla *et al.* 2000; Lavilla and Cei 2001); Chile (Veloso and Navarro 1988; Formas 1995); Brazil (Sociedade Brasileira de Herpetologia 2004); the Guianas (Hoogmoed 1979); the Guianas (Señaris and MacCulloch 2005); French Guiana (Lescure and Marty 2000); the Caribbean islands (Crother 1999; Schwartz and Henderson 1988; Powell and Henderson 1999); the Lesser Antilles (Malhotra and Thorpe 1999); Guadeloupe (Breuil 2002); Netherlands Antilles (Powell *et al.* 2005; van Buurt 2005); and Trinidad and Tobago (Murphy 1997). There have also been some important reviews of particular taxonomic groups, for example on the Hylidae of Mesoamerica (Duellman 2001), on the western Ecuadorian *Eleutherodactylus* (Lynch and Duellman 1997), and Neotropical plethodontid salamanders (Wake and Lynch 1976; Wake 2003).

Brazil has more endemic species (489) than any other country in the Neotropics (Figure 4), or in the world, followed by Colombia (337), Mexico (234), Peru (181), Ecuador (159), and Venezuela (155). More than 50 endemic species are also known from Cuba and Bolivia. In terms of percentage of the fauna being endemic, the highest endemism is on the Greater Antilles (Figure 5), with Jamaica at 100%, Cuba at 97% and Puerto Rico at 78%. Although the percentage endemism in Haiti and the Dominican Republic is lower, for the island of Hispaniola as a whole it is 100%. On the mainland the highest percentage endemism is found in Mexico (70%), Chile (69%), and Brazil (65%), with levels over 40% in Venezuela, Haiti, Guadeloupe, Colombia, and Peru (Figure 5).

Threatened species occur in 35 of the 44 countries in which there are native amphibians (Figure 6). In fact, threatened species are concentrated in relatively few countries. Colombia has more threatened amphibian species than any other country in the Neotropics (209), followed by Mexico (190), Ecuador (163) and Brazil (110). A further 12 countries have 20 or more threatened species: Peru, Guatemala, Venezuela, Costa Rica, Panama, Honduras, Cuba, Haiti, Dominican Republic, Argentina, Bolivia and Chile. The percentage of threatened amphibian species is highest in the Greater Antilles (Figure 7), with Haiti at a staggering 92%, the Dominican Republic at 86%, Jamaica at 81%, Cuba at 80% and Puerto Rico at 72%. Overall, the percentage threat levels for amphibians on the Caribbean islands are worse than anywhere else in the world, and is a reflection of the very poor state of habitat conservation, coupled with chytridiomycosis in some places (see Essay 9.6) (of course, in these relatively species-poor countries, even a limited number of threatened species can result in a high percentage of species at risk of extinction). The highest percentage of threatened species on the mainland is in Mexico (57%), closely followed by Guatemala (55%), with a further 12 countries having levels greater than 30%: Guadeloupe, Dominica,

Rhinatrema bivittatum *(Least Concern) is a caecilian from the small Family Rhinatrematidae, occurring in Brazil, Guyana, Suriname and French Guiana. It is a subterranean species in lowland rainforest, and is presumed to breed in streams by larval development, like other members of its Family. © Peter Stafford*

The Upland Coqui Eleutherodactylus portoricensis *(Endangered) is one of more than 600 species in the genus Eleutherodactylus in the Family Leptodactylidae. It occurs in mesic, upland broadleaf forests, and calls from bushes and tree trunks, and has not been recorded outside forest habitat. The eggs are laid in bromeliads, and these develop directly without a free-living larval stage. © Alejandro Sanchez*

Montserrat, Honduras, British Virgin Islands, Ecuador, Chile, Costa Rica, St Vincent and the Grenadines, Martinique, Grenada, and Colombia (Figure 7). Overall, percentage threat levels are high in the Neotropics compared with the rest of the world, but the overall levels of threat do appear to be lower in the Guianan Shield and Amazonian Brazil.

Assessments of the conservation status of Neotropical amphibians at national level are still at an early stage, but there have been assessments in El Salvador (Greenbaum and Komar 2005), Panama (Young *et al.* 1999), Venezuela (Rodríguez and Rojas-Suárez 1995), Brazil (Ministério do Meio Ambiente 2003), Argentina (Lavilla *et al.* 2000), Chile (Glade 1993) and Bolivia (Reichle 2006). An official Mexican red list of amphibians is in preparation (the draft is on http://www.semarnat.gob.mx/leyesynormas/Normas%20Oficiales%20Mexicanas%20vigentes/NOM-ECOL-059-2001.pdf. Hedges (2006) provided an overview of the conservation of Caribbean amphibians.

Some countries have particularly high proportions of Critically Endangered species. The most extreme example is Haiti, where 31 species are CR, 10 are EN and five are VU (out of a total amphibian fauna of 50 species). In the neighbouring Dominican Republic, the situation is marginally less severe (10 CR, 16 EN, 5 VU out of 36 species), though still very serious. Puerto Rico has 7 CR, 5 EN and 1 VU out of a fauna of 18 species. On the mainland, things are particularly bad in Honduras (30 CR, 24 EN, 19 VU out of 116 species), and also very disturbing in Chile (9 CR, 4 EN, 7 VU out of 55), Mexico (69 CR, 80 EN, 41 VU out of 335), Guatemala (27 CR, 30 EN, 19 VU out of 140), and Costa Rica (19 CR, 22 EN, 20 VU out of 179).

In general, the levels of threat are worse in Mesoamerica than South America, because habitat loss has in general been more severe in the former, and also chytridiomycosis has been especially severe in this region (and see Essay 9.7). The situation is also serious and deteriorating in the Andean countries, where there is also significant habitat loss, and chytridiomycosis is currently spreading (De la Riva 2005; La Marca *et al.* 2005). However, because most of the Andean countries also have large, intact Amazonian amphibian faunas, the percentage of threatened species is not usually as high as in some of the Mesoamerican countries. The percentage of threatened species in Peru and Bolivia is almost certainly underestimated due to paucity in knowledge.

HABITAT AND ECOLOGY

Habitat Preferences

Most Neotropical amphibians (85%) occur in forests, and only just over 20% can survive in secondary terrestrial habitats (Table 4; Figure 8). Compared with Afrotropical species, for example, Neotropical amphibians appear to be less able to survive in disturbed areas. They also appear to make more use of flowing water habitats than still, open freshwater habitats, or marshes and swamps. This is presumably a reflection of the great diversity of stream-associated species in the Andes and Mesoamerica. Forest-dwelling amphibians are more likely to be threatened than those occurring in any other terrestrial habitats, with over 40% of them being globally threatened. A similar percentage of amphibians associated with flowing water (generally streams) is threatened. Forest-associated amphibians that live along streams are particularly likely to be threatened, a combination that has also been associated with rapid declines worldwide (Stuart *et al.* 2004).

The percentage of threatened species varies considerably between different types of forest. In montane tropical forest, over 50% of known species are threatened, compared with just over 30% in lowland tropical forest. These figures probably reflect smaller range sizes of montane species, the lack of effective habitat conservation measures in many mountainous parts of the region, and the high incidence of chytridiomycosis in montane areas (Lips *et al.* 2003; Burrowes *et al.* 2004). Amphibians occurring in savannahs, marshes and swamps, still open freshwater habitats, and secondary terrestrial habitats are much less likely to be threatened than those occurring in other habitats (Table 4; Figure 8).

Habitat type	Number of species in each habitat	% of all species occurring in the habitat	Threatened or Extinct species	% of species occurring in habitat that are Threatened or Extinct
Forest	2,478	85	1,029	42
All tropical forest	2,407	83	1,007	42
Lowland tropical forest	1,405	48	427	30
Montane tropical forest	1,494	51	773	52
Savannah	200	7	6	3
Grassland	429	15	120	28
Shrubland	343	12	73	21
Secondary terrestrial habitats	621	21	110	18
Flowing freshwater	1,133	39	505	45
Marsh/swamp	168	6	23	14
Still open freshwater	746	26	116	16
Arid and semi-arid habitats	25	1	5	21

Table 4. *The habitat preferences of amphibians in the Neotropical Realm.*

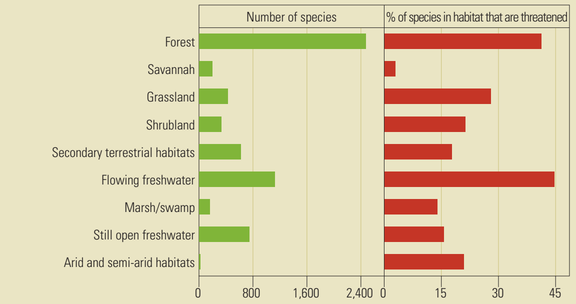


Figure 8. *The habitat preferences of Neotropical amphibians. The plot on the left-hand side shows the number of species in the region in each habitat type. On the right-hand side, the percentage of these species which are threatened is given.*

Reproductive mode	All species	Threatened or Extinct species	% Threatened or Extinct
Direct development	1,105	584	53
Larval development	1,719	555	32
Live-bearing	24	1	4
Not known	68	5	7

Table 5. *Neotropical amphibians categorized by reproductive mode.*

Reproductive Modes

Of those species where reproduction is known or reasonably inferred, larval development is the most common reproductive mode in the Neotropics (59% of species), compared with 38% for direct development and 1% live-bearing (this compares with the global picture of 68% larval development, 30% direct development, and 1% live-bearing) (Table 5). The Neotropical amphibians clearly have a larger proportion of direct-developing species than the global average, and this is largely because of the enormous genus *Eleutherodactylus* (607 species), all but one of which (the possibly extinct *Eleutherodactylus jasperi* from Puerto Rico) are believed to be direct developers, but also because of other large genera such as *Craugastor* and *Phrynopus*. In addition, all but one of the 221 Neotropical plethodontid salamanders are believed to be direct developers. Although live-bearing is uncommon, the Neotropics account for 39% of the world's known live-bearing amphibians (all but one of these live-bearing species are caecilians, with the exception of the aforementioned *E. jasperi*).

In the Neotropics, the percentage of globally threatened direct-developing amphibians is much higher than for larval-developing species. This is probably because direct-developing species have smaller ranges on average, and are therefore more seriously impacted by habitat loss. This result is interesting because chytridiomycosis appears to have its greatest impact on stream-associated, usually larval-developing species (Lips *et al.* 2003) (though it should be noted that some stream-associated species, such as the species in the *Craugastor rugulosus* group, are direct-developers, and have been severely impacted by chytridiomycosis). The low percentage of threatened live-bearing species in the Neotropics could be a reflection of the high number of Data Deficient caecilians.

MAJOR THREATS

Habitat loss is overwhelmingly the major threat to amphibians in the Neotropics (Table 6; Figure 9), affecting nearly 90% of the threatened species. The two other most commonly recorded threats are pollution and disease (both affecting nearly 30% of threatened species). With the exception of fire (17%), all other threats are of minor importance. Over-utilization appears to be a minor threat in the region as a whole (at least, based on current knowledge), but it can have a serious impact on some species (e.g., on the genus *Telmatobius* in Peru, and probably elsewhere).

In terms of the types of habitat loss that are impacting amphibians in the Neotropics, the impacts of expanding croplands (affecting just over 70% of threatened species) and vegetation removal (mainly logging) (64%) are the most severe, but urbanization / industrial development and livestock grazing are each affecting more than 40% of threatened species. However, the importance of different types of habitat loss varies within the region. For example, removal of vegetation for charcoal production is a major mechanism of habitat loss in the Greater Antilles, especially in Haiti (Hedges 2006).

The distribution of chytridiomycosis in the Neotropics is only gradually becoming clear. Ron (2005) documented confirmed records of the disease widely in Mesoamerica (southern Mexico, Guatemala, Costa Rica, Panama), the Caribbean (Dominican Republic, Puerto Rico), and north-western South America (Ecuador, Venezuela). More recently the

Threat type	Threatened species	% Threatened Species
Habitat loss	1,007	89
Agriculture – Crops	806	71
Agriculture – Tree plantations	143	13
Agriculture – Livestock	478	42
Timber and other vegetation removal	728	64
Urbanization and industrial development	538	47
Invasive species	81	7
Utilization	34	3
Accidental mortality	3	0.3
Pollution	336	29
Natural disasters	73	6
Disease	324	28
Human disturbance	101	9
Changes in native species dynamics (excluding disease)	1	0.1
Fire	197	17

Table 6. *The major threats to globally threatened amphibians in the Neotropical Realm. Only present threats to species are tallied.*

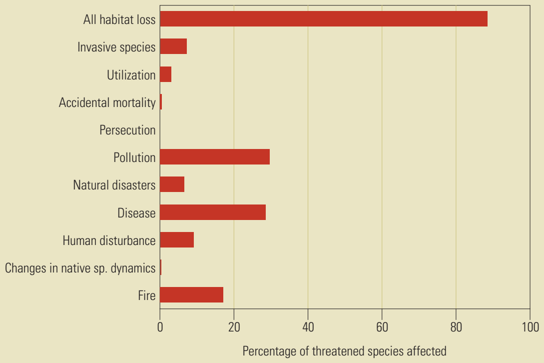


Figure 9. *The major threats impacting threatened amphibians in the Neotropical Realm.*

Purpose	Subsistence	Sub-national/ National	Regional/ International	Number of species
Food – human	41 (20)	16 (7)	5 (1)	44 (21)
Food – animal	1 (0)	1 (1)	0	2 (1)
Medicine – human and veterinary	15 (12*)	5 (2)	4 (1)	19 (13*)
Poisons	5 (0)	0	2 (0)	7 (0)
Wearing apparel, accessories	1 (0)	0	0	1 (0)
Handicrafts, curios, etc.	2 (0)	1 (0)	1 (0)	2 (0)
Pets, display animals	10 (2)	29 (8)	125 (38*)	132 (38*)
Research	0	6 (1)	6 (1)	11 (1)
Specimen collecting	0	0	1 (1)	1 (1)

Table 7. *The purposes for which amphibians are used in the Neotropical Realm. The numbers in brackets are the number of species within the total that are threatened species. *One of the species in the brackets is actually now listed as Extinct.*

disease has been recorded more widely in the continent, for example in southern Peru (Seimon *et al.* 2005), southern Brazil (Carnaval *et al.* 2005) and the Pampas region of Argentina (Herrera *et al.* 2005). The earliest records of the fungus in the region date from the early 1980s, and coincide roughly with the onset of amphibian declines (Carnaval *et al.* 2006; Lips *et al.* 2006).

A total of 181 species are recorded as being used for some or other purpose in the region (61 of which are threatened (though not necessarily by use) and one now considered Extinct). The most common reason for harvesting Neotropical amphibians is for the international pet trade, followed by local human consumption (Table 7). Well-known examples of utilization in the region include the pet trade in colourful, poisonous frogs in the genera *Dendrobates*, *Epipedobates* and *Phyllobates*, and the horned frogs (in the genus *Ceratophrys*), and harvesting *Telmatobius* frogs for local human consumption in parts of the Andes. Much of the harvesting of amphibians in the region is not considered to constitute a major threat to the species, but there are exceptions (for example, in the case of several species of *Telmatobius*). Of the 180 extant species being harvested, utilization is considered to be a major threat for 71 (of which only 34 are threatened species for which harvesting is believed to be contributing to deterioration in their status).

POPULATION STATUS AND TRENDS

Estimates of Population Trends

A summary of the inferred population trends of Neotropical amphibians is presented in Table 8. In the absence of more rigorous population monitoring studies, these trends are largely inferred from trends in the state of the habitats on which the species depend (though in some cases, dramatic population declines have been noted). Species with decreasing populations are typically forest-dependent species that can tolerate little disturbance to their habitats. The overall trends of Neotropical amphibians are very similar to the global results.

The Titicaca Water Frog Telmatobius culeus *(Critically Endangered) in the Family Leptodactylidae is endemic to Lake Titicaca in Peru and Bolivia. It is a wholly aquatic species, breeding in shallow waters close to the shoreline. It was previously common, but has declined massively due to the over-harvesting of adults, the presumed predation of larvae by introduced trout, water extraction from the lake, and domestic and agricultural water pollution. © Mikael Lundberg*

Population Trend	Number of species	% of species
Decreasing	1313	45
Stable	725	25
Increasing	15	0.5
Unknown	856	29

Table 8. *The population trends for all extant Neotropical amphibians.*

Family	Number of species in "rapid decline"	Percentage of species in family in "rapid decline"	Number of species in "enigmatic decline"	Percentage of species in family in "enigmatic decline"
Bufonidae	89	35	76	30
Centrolenidae	4	3	4	3
Dendrobatidae	17	7	11	5
Hylidae	53	9	39	6
Leptodactylidae	110	9	53	4
Ranidae	6	18	4	12
Rhinodermatidae	1	50	1	50
Ambystomatidae	5	36	0	0
Plethodontidae	20	9	6	3

Table 9. *The number of species in "rapid decline" and "enigmatic decline" in the Neotropical Realm by Family.*

"Rapidly declining" species

The Neotropics are home not only to nearly 50% of the world's amphibian species, but to nearly two-thirds (65%; 305 species) of the world's "rapidly declining" species (Stuart *et al.* 2004) (a full list of all "rapidly declining" species is provided in Appendix IV and includes their occurrence within each of the regions). The Neotropics are the global epicentre for amphibians in catastrophic decline. Twelve of these 305 species are in decline due to over-exploitation, 99 due to reduced habitat, and 194 due to so-called "enigmatic declines", which are currently attributed to chytridiomycosis and climate change (Lips *et al.* 2006; Pounds *et al.* 2006).

The "rapidly declining" species show a distinct taxonomic pattern (Table 9). Among the larger families, Bufonidae show by far the highest percentage of species in serious decline, and in particular in "enigmatic decline". Most of this very serious situation can be accounted for by the genus *Atelopus* (73 species in "rapid decline", 72 in "enigmatic decline"). There are many species in serious decline in Hylidae and Leptodactylidae, but percentage wise these families are much less seriously affected than Bufonidae. However, some genera seem to be particularly affected, notably *Isthmohyla* (6 out of 14 species in serious decline), *Plectrohyla* (21 out of 41), *Craugastor* (22 out of 108), *Telmatobius* (14 out of 52), and *Thoropa* (3 out of 6). The 43 species of *Eleutherodactylus* (especially from the Caribbean islands) in rapid decline should be seen in the context of a genus of 610 species. Some small families have high percentages of species in serious decline, most notably Rhinodermatidae and Ambystomatidae. The two species in the Rhinodermatidae, in particular, require comment. One of them, Darwin's Frog *Rhinoderma darwinii* (VU) is currently in "enigmatic decline". The other, *Rhinoderma rufum* (CR), also has declined enigmatically and was last seen in 1978; however, it is not recorded as a "rapidly declining" species, as its population crashed prior to 1980, the year from which "rapid declines" have been measured (Stuart *et al.* 2004).

The "rapid declines" in the Neotropics are concentrated in particular regions, most especially in Mesoamerica (from central Mexico south to Panama, as typified by the genera *Isthmohyla*, *Plectrohyla* and *Craugastor*) and the Andes (as typified by *Atelopus* and

Flectonotus pygmaeus *(Least Concern), in the Family Leptodactylidae, occurs in Venezuela and Colombia. It is a species of pre-montane humid forests, and is particularly associated with bromeliads. The eggs are carried on the back of the female in a pouch, and the larvae are deposited in bromeliad axils. © Francisco José López-López*

Bolitoglossa pesrubra *(Endangered) is a lungless salamander from the Family Plethodontidae, and is restricted to the Cordillera de Talamanca in Costa Rica. It still occurs in many places within its range, but has drastically declined in some sites where it was formerly abundant, while appearing to be stable in others. © Twan Leenders*

Telmatobius). There have also been many declines in the Greater Antilles, for the most part in the genus *Eleutherodactylus*. In addition, there are some smaller foci of "rapid declines" in Chile (especially in *Alsodes* and *Rhinoderma*) and the Brazilian Atlantic Forest (where declines are still poorly documented, but involve several genera, including *Cycloramphus* and *Thoropa* (Heyer *et al.* 1988; Eterovick *et al.* 2005). The growing evidence suggests that the Neotropics is in the process of losing most of its montane, stream-associated amphibian fauna in the space of just a few decades.

KEY FINDINGS

- A total of 2,916 species are recorded from the Neotropical Realm, of which 1,145 (39%) are considered threatened.
- At the species level, 2,808 amphibians (96% of those present) are endemic to the Neotropics - roughly half of all recognized amphibians worldwide; of the 20 families found in the region, six are endemic, and of 189 amphibian genera occurring, 157 are endemic.
- The percentage of threatened species is very high in the families Rhinodermatidae (100%), Ambystomatidae (67%), Plethodontidae (60%), Bufonidae (53%), Salamandridae (50%), Leptodactylidae (46%) and Ranidae (41%), reflecting both habitat loss and declines most likely related to chytridiomycosis and climate change.
- Geographic concentrations of threatened species occur in the Greater Antilles (Cuba, Hispaniola, Jamaica and Puerto Rico); Mesoamerica (Central America south to Panama); the tropical Andes (especially in Colombia and Ecuador, but also increasingly in Peru and Bolivia); the Venezuelan highlands; central Chile; and the Atlantic Forests of southern Brazil.
- Brazil has the largest number of species in the Neotropical Realm (751 species), and has more endemics than any other country (489). Thirteen other countries have more than 100 species (Colombia, Ecuador, Peru, Venezuela, Bolivia, Panama, Costa Rica, Argentina, Guatemala, Guyana, Honduras, French Guiana, and Suriname), with the first five of these countries having more than 50 endemics.
- Colombia has the largest number of threatened species (209), followed by Mexico (190), Ecuador (163), and Brazil (110). Peru, Guatemala, Venezuela, Costa Rica, Panama, Honduras, Cuba, Haiti, Dominican Republic, Argentina, Bolivia, and Chile each have 20 or more globally threatened species.
- Among species occurring in tropical forests, 52% of species in montane tropical forest are threatened, compared with 30% in lowland tropical forest, probably reflecting smaller range sizes of montane species, the lack of effective habitat conservation in many montane regions, higher human population densities in mountainous areas, the widespread incidence of chytridiomycosis, and the increased vulnerability of montane species to the impacts of climate change. Further, 45% of Neotropical amphibians associated with flowing water (most of which are montane) are threatened.
- Habitat loss, primarily due to expanding croplands, vegetation removal (mainly logging), urbanization/industrial development, and livestock grazing, is affecting almost 90% of the threatened species in the region. Disease (usually chytridiomycosis) and pollution are both impacting nearly 30% of globally threatened species.
- A massive 65% of the 470 globally "rapidly declining" species occur within the region; these are concentrated in Mesoamerica, the Andes and the Greater Antilles where habitat loss and chytridiomycosis have been especially severe. A total of 63% of the "rapid declines" in the Neotropics are classified as "enigmatic declines" (probably due to chytridiomycosis and climate change).
- Seven amphibian extinctions have been recorded from the Neotropics, and a further 121 species are possibly extinct (again concentrated in Mesoamerica, the Andes, and the Greater Antilles).

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The Suriname Toad Pipa pipa *(Least Concern) occurs widely in the Amazon Basin and the Guianan Shield, and is an aquatic species that lives in slow-flowing watercourses and pools in tropical rainforest. The fertilized eggs are placed by the male on the female's back, where they become embedded in the skin, and develop directly without a free-living larval stage. © Manfred Beier*

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The Pumpkin Toadlet Brachycephalus ephippium *(Least Concern) is a member of the small Family Brachycephalidae from the Atlantic Forests of southern and eastern Brazil. It is a common species in leaf-litter on the floor of primary and secondary forest. The egg clutches are deposited on the forest floor, and these develop directly without a free-living larval stage. © Juarez Silva*

Endnotes

1 $P<0.01$ (binomial test)

2 This species was assessed as Vulnerable at the GAA workshop in Brazil and this is the official category as listed on the Red List website. It is listed here as Critically Endangered which is the category determined by the GAA coordinating team.

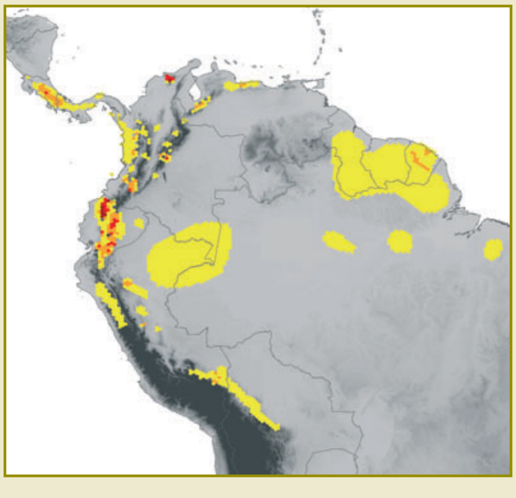
3 Frost *et al.*'s (2006) and Grant *et al.*'s (2006) proposed taxonomic changes result in 26 families in the Neotropics, of which 13 are endemic: Amphignathodontidae; Aromobatidae; Batrachophrynidae; Brachycephalidae; Centrolenidae; Ceratophryidae; Cryptobatrachidae; Cycloramphidae; Dendrobatidae; Hemiphractidae; Hylodidae; Leiuperidae; and Rhinatrematidae. However, in this section we follow the former taxonomic arrangement of families based on Frost (2004).

4 Frost *et al.* (2006) and Grant *et al.* (2006) split the Leptodactylidae into nine families (also comprising the current Brachycephalidae and Rhinodermatidae). Three small genera (collectively comprising just six species), *Batrachophrynus*, *Caudiverbera* and *Telmatobufo*, from southern Chile and north into southern Andean Peru and Bolivia are separated to form a new family Batrachophrynidae. The genus *Hemiphractus* (six species) from Panama to the upper Amazon Basin forms a new family Hemiphractidae. The genera *Adelophryne*, *Atopophrynus*, *Barycholos*, *Dischidodactylus*, *Craugastor*, *Eleutherodactylus*, *Euparkerella*, *Geobatrachus*, *Holoaden*, *Ischnocnema*, *Phrynopus*, *Phyllonastes* and *Phyzelaphryne* are transferred to the existing family Brachycephalidae, creating a new grouping of nearly 800 species covering almost the same geographic range as the former Leptodactylidae. The genera *Cryptobatrachus* and *Stefania* are transferred to the new family Cryptobatrachidae (21 species) endemic to northern South America. The genera *Flectonotus* and *Gastrotheca* are transferred to the new family Amphignathodontidae (nearly 60 species), ranging from Costa Rica south to Argentina. The genera *Atelognathus*, *Batrachyla*, *Ceratophrys*, *Insuetophrynus*, *Lepidobatrachus*, and *Telmatobius* are transferred to the new family Ceratophryidae (*c.* 80 species) ranging from Colombia south to Chile and Argentina. The genera *Alsodes*, *Crossodactylodes*, *Crossodactylus*, *Cycloramphus*, *Eupsophus*, *Hylodes*, *Hylorina*, *Limnomedusa*, *Macrogenioglottus*, *Megaelosia*, *Odontophrynus*, *Proceratophrys, Thoropa,* and *Zachaenus* are transferred to the new family Cycloramphidae (together with *Rhinoderma* from Rhinodermatidae), with c. 130 species, in southern tropical and temperate South America. The genera *Edalorhina*, *Engystomops*, *Eupemphix*, *Physalaemus*, *Pleurodema*, *Pseudopaludicola*, and *Sumuncuria* are transferred to Leiuperidae (75 species) ranging from southern Mexico throughout Central and South America south to central Chile and central Argentina. With these changes, the family Leptodactylidae is reduced to including the genera *Hydrolaetare*, *Leptodactylus* (including the subgenus *Lithodytes* for the former genera *Adenomera* and *Lithodytes*), *Paratelmatobius* and *Scythrophrys*, comprising *c.* 90 species through much of the Neotropics and southern Nearctic, including on some Caribbean islands.

ESSAY 9.1. THE EXTRAORDINARY CASE OF THE NEOTROPICAL HARLEQUIN FROGS *(ATELOPUS)*: MASS EXTINCTION WITHIN A GENUS

Atelopus sorianoi *(Critically Endangered) has the most restricted geographic range of any Venezuelan* Atelopus *species, being known from a single stream in an isolated cloud forest in the Cordillera de Mérida. The last record of the species was in 1990. © Pascual Soriani*

Figure 1. *Richness map of species in the genus Atelopus, with dark red colours corresponding to regions of higher richness. Maximum richness equals four species.*



The harlequin frogs (genus *Atelopus*) are small, colourful "jewels" distributed in the humid forests and paramos of Central and South America. The genus is the largest in the family Bufonidae, with about 80 described species distributed from Costa Rica south to Bolivia and eastward through the Amazon basin into the Guianas (Figure 1). Despite interest by scientists in these species, their conservative morphology and variable coloration have often obscured their taxonomy. Many species have highly variable colour patterns, and different species frequently have similar colour patterns. Recent genetic studies reveal both unappreciated genetic diversity among populations, but also great variation within a given taxon. More than 30 previously unrecognized species are currently in the process of being described or being elevated to the species level.

Most *Atelopus* species are associated with streams, although many occur part time of the year in terrestrial habitats (Lötters 1996). They range from sea level to approximately 4,800m elevation, but the majority live in highlands at 1,500-3,000m. Some species, such as *A. varius* (CR), *A. chiriquiensis* (CR), *A. carbonerensis* (CR), and the now Extinct *A. ignescens* and *A. vogli*, have been characterized as locally abundant, with hundreds of animals seen in a few hundred meters, often during annual breeding events (La Marca and Reinthaler 1991; Manzanilla and La Marca 2004; Pounds and Crump 1994; Ron *et al.* 2003). Local endemism is common in the genus, making species particularly vulnerable to extinction. At least 26 species are known from only one site (per Ricketts *et al.* 2005).

Sadly, these beautiful and once common diurnal amphibians are now vanishing. A recent study based on 113 *Atelopus* species (i.e., including also undescribed forms and a few just recently named), revealed that 37% of these species have undergone significant declines, and only 10 species have what are believed to be stable populations (La Marca *et al.* 2005). The majority of the declining species have disappeared in the last two decades only, and many, such as *Atelopus sorianoi* (CR) are feared extinct; at least 30 species have been missing from all known localities for at least eight years. All species restricted to elevations of above 1000m have declined and 75 percent have disappeared. At least three *Atelopus* species are considered as Extinct according to the IUCN Red List Categories and Criteria, namely *Atelopus ignescens* and *A. longirostris* from Ecuador, and *A. vogli* from Venezuela (Lötters *et al.* 2004). To put things in perspective, harlequin frogs represent about 15% of the 442 Critically Endangered (CR) amphibian species on the IUCN Red List.

The first red flag that something was amiss came many years ago (La Marca and Reinthaler 1991). Several potential causes were then discussed trying to explain the observed declines, but today the most commonly cited cause is the pathogenic chytrid fungus *Batrachochytrium dendrobatidis*, which strikes even in undisturbed montane habitats. Habitat loss may explain a few of the disappearances. However, it is not considered to be a major cause in the case of the *Atelopus* species, since almost 20% of the harlequin frogs have disappeared from protected areas. Other potential causes of declines, such as introduced species, trade, and pollution may partly explain a few cases, too, but are unlikely to have affected the majority of the species. Synergistic combinations of factors are expected to affect some harlequin frogs, as illustrated by the case of *Atelopus zeteki* (CR), believed to be nearly extinct in the wild due to the combined effects of habitat change, illegal collecting, and fungal disease (Mendelson *et al.* 2006).

A recent finding suggests that large-scale warming of our planet is correlated with mass extinction in *Atelopus* (Pounds *et al.* 2006). The warming trend, estimated at about 0.18ºC per decade, has been to the benefit of the fungal pathogen. The rise in temperatures has most probably increased the amount of evaporation in the tropical montane environments inhabited by harlequin frogs, which in turn has been translated into increased cloud formation. Increased cloud cover in turn leads to a decrease in incoming solar radiation, thus reducing daytime temperatures, and by night may result in a green-house effect that impedes natural heat loss from the ground, with resulting warmer night-time temperatures. These cooler days and warmer nights brings the pathogenic fungus to near optimum thermal conditions, believed to be between17 and 25ºC, thereby encouraging its growth, reproduction and propagation. The theory gains support since most of the species have disappeared in the altitudinal band between 1,000 and 2,400m elevation, while recent "re-appearances" have occurred either in low-elevation (humid lowland forests) or high-elevation (paramo) habitats (Lötters *et al.* 2005). Both extremes in temperature conditions for the fungal pathogen may act as "thermal refuges" for the few surviving *Atelopus* populations.

Unfortunately, the problem of declines and extinctions in *Atelopus* is not likely to diminish in the foreseeable future. Under a scenario of double CO$_2$ concentrations within the next century (Malcolm *et al.* 2006), the rate of amphibian extinctions is expected to increase in many regions, including the Tropical Andes, where most harlequin frogs are known to occur. *Atelopus* may actually be a good indicator of what is happening to other less conspicuous species that could experience similar declines. The loss of these important links in the trophic web has unforeseeable consequences (Ranvestel *et al.* 2004). Furthermore, the resulting impoverished biodiversity may also represent a loss in potential advances in biomedicine and biotechnology (Mendelson *et al.* 2006).

Currently, there is no known effective protection against *Batrachochytrium dendrobatidis* in the wild. Therefore, one of the most tempting alternatives to cope with the *Atelopus* declines is to initiate captive-breeding programmes (see Essay 11.5). The success with the Panamanian Golden Frog, *Atelopus zeteki* (Zippel 2002), which is now available in breeding colonies in numerous zoos, is promising in this regard. Nevertheless, comprehensive captive-breeding programs for all *Atelopus* species threatened with extinction appear to be impossible due to the many species involved.

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ESSAY 9.2. CONSERVATION STATUS OF THE ANDEAN FROGS OF THE GENERA *TELMATOBIUS* AND *BATRACHOPHRYNUS*

The frogs of the genera *Telmatobius* and *Batrachophrynus* constitute a remarkable group of endemic Andean anurans that occur from central Ecuador in the north, to northern Chile and Argentina in the south (Figure 1). The most recent classification of *Telmatobius* (Lavilla 2005) includes 56 species, with Peru harbouring the highest diversity (23 species), followed by Bolivia (15 species), Argentina (14 species), Chile (9 species; the description of an additional species was in press at the time of writing this report) and Ecuador (3 species). *Batrachophrynus* includes two species (endemic to central Peru), and while we treat it as distinct in the current essay, recent studies have indicated that *Batrachophrynus* is not a valid genus and should rather be included in *Telmatobius* (Aguilar and Pacheco 2005; Córdova and Descailleaux 2005; Sinsch *et al.* 2005).

The genus *Telmatobius* is mostly aquatic, occupying a wide, albeit montane, altitudinal range (1,300-5,000m asl), and inhabiting habitats as diverse as cloud forests to humid paramos and dry puna. Many species have co-existed with humans for centuries, and, undoubtedly, habitat destruction, mining, agricultural practices and livestock (especially camelids) have influenced the distribution and local abundance of some taxa (De la Riva 2005). Several species are captured either for food or because of certain putative medicinal or magical properties; other potential threats include water pollution and the introduction of trout for fishing. Particularly concerning is the case of the giant Lake Titicaca Frog (*Telmatobius culeus*, CR) and the even larger Lake Junin Frog (*B. macrostomus*, EN), both of which have been affected by over-fishing and other problems. Although some protection measures have been implemented (such as captive breeding), they have proved to be mostly unsuccessful (Pérez 2005).

Since *Telmatobius* and *Batrachophrynus* frogs inhabit montane areas and are stream- or lake-breeders, their biology and ecology render them particularly susceptible to chytrid infection. Indeed, there is growing evidence that chytridiomycosis is having a direct impact on populations of these frogs. Reports of serious population declines in *Telmatobius* first came from Ecuador, and a recent summary of the conservation status of Ecuadorian *Telmatobius* yields conclusive evidence of a catastrophic decline of the three species endemic to that country (Merino-Viteri *et al.* 2005). Specimens found in the 1980s and 1990s had malformations and symptoms of diseases, including chytridiomycosis. Despite intensive surveys for living animals in recent years (including 2005), the last living *Telmatobius* specimen seen in Ecuador was a tadpole of *T. niger* (CR) with severe epidermal damages, collected on 1 December 1994; *T. vellardi* (CR) was last seen in 1987, and *T. cirrhacelis* (CR) in 1981. The three Ecuadorian *Telmatobius* are now likely extinct.

While the situation in Ecuador has been thoroughly investigated, there is almost no published information for other range countries. In Perú, Lehr (2005) stated that these frogs are threatened due to agricultural practices, water pollution, and commercial utilization. Seimon *et al.* (2005) reported a case of chytridiomycosis affecting *T. marmoratus* (VU), collected in July 2002 in the department of Cusco, although without reference to population declines. This species has the broadest distribution of any *Telmatobius*, and occurs in the Altiplano and Puna highlands above the tree line. Healthy specimens were found in the department of Puno in southern Peru during recent fieldwork (February 2006; De la Riva, unpubl.), and although it is plausible that some populations of this widespread species are extinct or have declined due to chytridiomycosis, the presence of larvae and adults in many sites indicates that, overall, the species is not severely threatened. However, this situation could change in the future if climate change facilitates a shift to favorable conditions for chytrid in previously unsuitable zones.

Unfortunately, more alarming data, albeit preliminary, concern species from the humid paramos and upper cloud forest regions of Peru. In 1999-2001, *Telmatobius* were largely extirpated from the department of Cajamarca, where farmers frequently encountered dead animals (R. Schulte, in. litt.). Recent fieldwork (February 2006) by a team of five herpetologists surveying nine Andean valleys in the department of Puno and southern Cusco did not yield a single specimen of *Telmatobius*, despite thorough searches in appropriate sites. In several places, local people explained that all "kaylas" frogs (=*Telmatobius*) vanished two years ago.

In Bolivia, the situation seems to be similar. De la Riva (2005) documented a severe decline of a newly described upper cloud forest species, *T. espadai*. Tadpoles of this species were extremely abundant in Río Apaza (Cochabamba) in 1990, but no tadpoles were found in 1994 and 1999, and only a single one in 1998. A recent examination of the oral structures of this individual showed an almost complete destruction of keratinized structures, which is consistent with chytridiomycosis. Another paramo/upper cloud forest species, *T. sanborni*, occurred at least between Pelechuco (La Paz, Bolivia), where it was abundant at least in 2001, and Ollachea (Puno, Peru) (De la Riva 2005). No trace of this species was found during the recent surveys in Peru in February 2006, although it has yet to be searched for in Bolivia. The last records of two other threatened species, *T. sibiricus* (EN) and *T. verrucosus* (VU), are from 2004 (De la Riva 2005).

Chilean species of *Telmatobius* occur in mostly desertic conditions and dry puna, and are subject to the same general threats as other highland species (Formas *et al.* 2005). At present, there is no direct or indirect evidence of chytrid infection in Chilean *Telmatobius*. The available information in Argentina is not promising (Lavilla and Barrionuevo 2005). Early in 2006, S. Barrionuevo (pers. comm.) found evidence of chytrid fungus in individuals of *Telmatobius atacamensis* (CR; a species already threatened by mining activities) in the environs of San Antonio de los Cobres (Salta) and in a population of *Telmatobius pisanoi* (EN) near El Pichao (Tucumán). Another species, *T. laticeps* (EN), fairly common in the past in the area of Tafí del Valle (Tucumán) disappeared from its range in the last few years due to unknown causes; the same might have happened with the forest-dwelling *T. ceiorum* (EN; S. Barrionuevo and M.L. Ponssa, pers. comm.).

In summary, frogs of the genera *Telmatobius* (and *Batrachophynus*) are severely threatened, and at a scale comparable only to the bufonid genus *Atelopus* (see Essay 9.1). In *Telmatobius*, as with *Atelopus*, many species are still to be named, many of those already described are known only from the type locality or nearby, and several extinctions have already taken place. However, there is one important difference: *Telmatobius* has no lowland species, and thus the entire genus faces the very real danger of extinction in the very near future. Unfortunately, the case of *Telmatobius* frogs seems to strongly support Lips *et al.*'s (2006) statement: "…it is no longer correct to speak of global amphibian declines but, more appropriately, of global amphibian extinctions."

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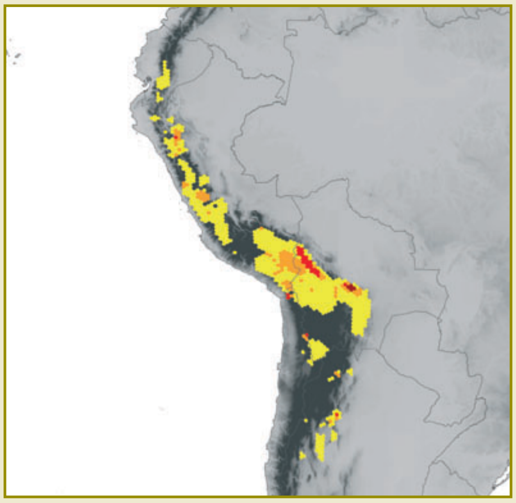
Telmatobius marmoratus *(Vulnerable) has the widest range of any species in the genus, being known from the Andean region of southern Peru, northern and central Bolivia, and northern Chile. © Ignacio de la Riva*

Figure 1. *Richness map of species in the genera* Telmatobius *and* Batrachophrynus*, with dark red colours corresponding to areas of higher richness. Maximum richness equals four species.*



ESSAY 9.3. NEOTROPICAL SALAMANDERS

Living salamanders comprise about 550 species, representing approximately one-tenth of living amphibians. The order Caudata hosts the largest amphibian, the Chinese Giant Salamander (*Andrias davidianus*, CR), in which adults measure 180cm from nose to tip of tail (and see Essay 4.7), as well as one of the smallest, *Thorius arboreus* (EN), one of several species of the genus that achieve sexual maturity at about 15mm in length. Although the number of salamander species is small compared with that of frogs, the diversity of species and life histories, coupled with late 20th century declines and disappearances worldwide, make salamanders an important model for understanding the causes of global change (i.e., climate change, pollution, habitat loss, etc) and their effect on biodiversity.

Salamanders are more commonly representatives of the northern temperate regions. Only a few groups have colonized tropical regions: the Salamandridae in south-eastern Asia and the Plethodontidae in tropical America. The magnitude and extent of these tropical invasions differs greatly. While tropical Asia has been colonized by only a few species, the Neotropics have been the stage for a large-scale radiation encompassing almost 40% of all salamander species.

The main Neotropical salamander radiation is restricted to a single clade, the supergenus *Bolitoglossa* (Parra-Olea *et al.* 2004), which is represented by more than 180 species and 12 genera, and ranges from northern México to Brazil (Figure 1). Bolitoglossine salamanders share fully terrestrial life histories, internal fertilization, direct development within encapsulated eggs, and a highly specialized feeding mechanism. These derived traits have played a major role in the success of bolitoglossines in the tropics (Wake 1987). A second radiation in the Neotropics can be found in the genus *Ambystoma* in the Transvolcanic Axis of central Mexico. Although this radiation has produced relatively few species, it includes several independently evolved paedomorphic lineages. A prime example is the Axolotl (*Ambystoma mexicanum*, CR), which is widely used to illustrate paedomorphosis in vertebrate evolution.

"Cryptic speciation" is common in salamanders. Their morphological evolution is conservative, and different populations often share traits that have arisen through convergence or that have evolved in parallel. Genetic studies are thus often necessary to identify new species. Such studies, coupled with fieldwork, have shown that salamanders in the tropics often exhibit a pattern of local isolation, with extreme genetic differentiation occurring over short distances ("tropicality" syndrome) (Garcia-Paris *et al.* 2000). Units that have been previously treated as single species often comprise multiple and genetically distinct lineages. Accordingly, the total number of salamander species remains unknown, and new forms are steadily being described. In Mexico, for example, the number of recognized species has risen from 93 to 128 in the past 10 years — a 39% increase (Flores-Villela and Canseco 2004).

Amphibian populations are declining worldwide and Neotropical salamanders are no exception. In several localities where salamanders were seen or collected by the hundreds in the 1970s and 1980s, it is now difficult to find a single individual. Some declines have occurred in seemingly pristine areas, such as Cerro San Felipe in Oaxaca, Mexico, and Reserva de Monte Verde in Costa Rica (Parra-Olea *et al.* 1999). The results of the Global Amphibian Assessment found that out of a total of 226 species in the Neotropics, 36 are Critically Endangered, 74 Endangered, and 28 Vulnerable. An additional 42 were listed as Data Deficient. Habitat loss and water pollution is the major threat to most species of salamanders, and, for some species, over-collecting (e.g., for food), the introduction of exotic species, and urban development are significant threats. Other factors such as climate change, increased UV-B radiation, chemical contamination, and emerging infectious disease are currently being evaluated.

To date, the chytrid fungus *Batrachochytrium dendrobatidis* has been found in four species of plethodontid salamanders (Lips *et al.* 2006) and in four ambystomatid species (G. Parra-Olea, unpubl.), but massive die offs of salamanders have, as yet, not been linked to this pathogen. Climate change and forest fragmentation could have important impacts on salamanders, especially considering the limited dispersal abilities of these animals. Bioclimatic envelope modelling suggests that the terrestrial salamander *Pseudoeurycea leprosa* (VU) in Mexico could lose almost 75% of its range area over the next 50 years because of climate change (Parra-Olea *et al.* 2005). This will be true for all terrestrial salamanders that inhabit pine and/or pine-oak forests, and will be exacerbated for the majority of species with small distributional ranges.

Traditionally, aquatic salamanders of the genus *Ambystoma*, such as the Axolotl and the Achoque, *A. mexicanum*, have played an important role in local communities. The Aztecs considered the Axolotl as the transfiguration of the deity Xolotl, and both species are exploited by local communities as a food source and as a remedy for respiratory infections (see Essay 2.3). The main threats to most *Ambystoma* species include contamination and drying out of their aquatic habitats, the introduction of exotic species, and over-exploitation. For example, the local conditions of Lake Pátzcuaro, to which the Achoque is endemic, have changed following an increase in water temperature, a decrease in the mean depth of the lake, and the introduction of exotic fish (Centrarchidae, Cyprinidae and Cyclidae) and their accompanying parasites (i.e. *Bothriocephalus acheilognathi*) (García *et al.* 1993). Furthermore, between 1987 and 2000 the harvest of the Achoque was approximately 27,592 kg (Huacuz 2002). A management plan has been proposed for the Achoque and a captive-breeding program was started by a group of nuns from the Pátzcuaro convent, with the main objective of sustainably harvesting the species from the wild for the production of cough syrup for the community. However, we still know little about the size of the population, its genetic structure, or its dynamics, so evaluating its chances of survival is difficult.

Given the alarming declines and disappearances that have been witnessed among Neotropical salamanders, examining the various potential threats is urgent, particularly where these threats act in synergy (Pounds *et al.* 2006). Most importantly, we cannot begin to propose adequate management plans for species, unless we know and understand the taxonomic and phylogenetic identity of the species of concern. Resolving taxonomic uncertainties is thus fundamentally important. Studies involving the use of phylogenetics for uncovering cryptic species diversity will help reveal the true diversity of the group, and in turn also help identify unique lineages and hot spots of diversity. Finally, they will identify the affinities of individual populations, thus facilitating appropriate decisions about the translocation or reintroduction of salamanders.

Gabriela Parra-Olea

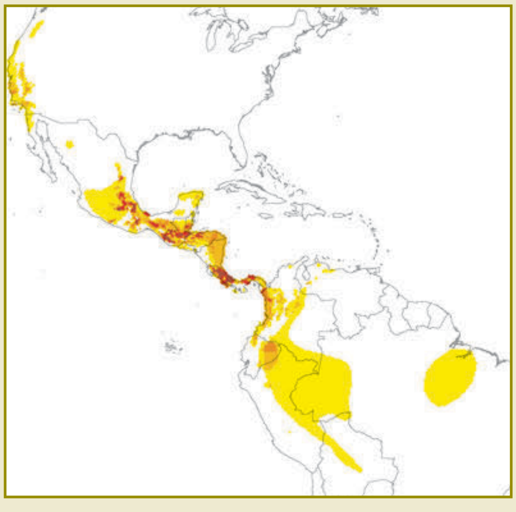


***Figure 1.** Richness map of Neotropical salamander species (n=242) in the genera* Batrachoseps, Bolitoglossa, Chiropterotriton, Cryptotriton, Dendrotriton, Ixalotriton, Nototriton, Nyctanolis, Oedipina, Parvimolge, Pseudoeurycea *and* Thorius*. Dark red colours correspond to higher richness. Colour scale based on five quantile classes. Maximum richness equals 17 species.*

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ESSAY 9.4. BRAZIL: THE WORLD LEADER IN AMPHIBIAN DIVERSITY

More than 8.5 million km^2 in size, Brazil is the fifth largest country in the world and the largest among those in the tropics. It has the largest continental biota on Earth, and inspired the concept of Megadiversity countries (Mittermeier *et al.* 1997). Conservative estimates indicate that Brazil is home to 13% of global biodiversity, and has the richest flora with more than 56,000 species.

Not surprisingly, then, Brazil is also the world leader in amphibian diversity and endemism. The Global Amphibian Assessment records 751 native species, of which around 65% are endemic. However, the rate of description of new species is very high, and according to an updated list of the Brazilian Society of Herpetology (SBH) there are now 794 amphibian species in Brazil. Only Colombia can come close to rivaling Brazil in terms of absolute numbers of amphibians present (see Essay 9.5). Further, even the current number of recognized amphibians is an underestimate, as evidenced by the number of species that have been discovered and described just in recent years. Several areas have never been inventoried and likely would reveal many new species waiting to be described, including large areas in the Cerrado and Amazon, such as southern Pará and Maranhão states, western Bahia state, northern Mato Grosso, and almost all of Tocantins state.

Amphibian diversity is not evenly distributed across the country, and there is a noticeable concentration of species in some regions, for example in the Atlantic Forest (Figure 1). Unfortunately, the Atlantic Forest is also the center of origin for reports of amphibian declines in Brazil (Eterovick *et al.* 2005) (Figure 2). The Atlantic Forest (or *Mata Atlântica*) stretches along Brazil's Atlantic coast from the northern state of Rio Grande do Norte south to Rio Grande do Sul, extending from 4° to 32°S. Long isolated from other major rainforest blocks in South America, the Atlantic Forest has an extremely diverse and unique mix of vegetation and forest types, with elevation varying from the sea level to about 2,900m. Unfortunately, this biome has been largely destroyed, and only about 7% of its original native forest cover remains intact, and it is regarded as a recognized global biodiversity hotspot (Mittermeier *et al.* 2004).

In a recent review of amphibian declines in Brazil, Eterovick *et al.* (2005) found that most species experiencing declines in the Atlantic Forest are recorded at elevations up to 1,000m, some of them associated with streams (*Colostethus olfersioides* VU, *Bokermannohyla langei* DD, *Crossodactylus dispar* DD, *C. gaudichaudii* LC, *Hylodes babax* DD, *Cycloramphus boraceiensis* LC, *C. mirandaribeiroi* DD, *C. semipalmatus* NT, *Hyalinobatrachium uranoscopum* LC), others with cliffs dripping with water for tadpole development (*Cycloramphus duseni* DD, *Thoropa lutzi* EN, *T. petropolitana* VU). The species are either direct developers (*Adelophryne baturitensis* VU), or their mode of reproduction is unknown (*Colostethus carioca* DD, *Cycloramphus eleutherodactylus* DD). A few species are recorded only above 1,500m (*Eleutherodactylus paranaensis* DD, *Cycloramphus granulosus* DD, *Paratelmatobius lutzii* DD).

But declines are not only reported from the Atlantic Forest. The Brazilian Cerrado, another global biodiversity hotspot, makes up one-fifth of the country, and is the most extensive woodland-savannah in South America. The Cerrado receives abundant rainfall between October and April, while the rest of the year is characterized by a pronounced dry season. The Cerrado also contains a rich montane meadow vegetation found at higher portions of some of the mountain ranges in south-eastern Brazil, such as the Serra do Espinhaço. Eterovick *et al.* (2005) reported the first declines of amphibians in the Cerrado, among the species *Crossodactylus bokermanni* (DD) and *Epipedobates flavopictus* (LC). They recorded only a few adult individuals of *Crossodactylus bokermanni*, from the Serra do Cipó in 2001 in the Parque Nacional da Serra do Cipó, and yet the species was known to be common in the same study area in 1971-1974.

The main cause for declines in amphibians in Brazil is undoubtedly habitat destruction, largely as a consequence of deforestation, agricultural expansion, mining, fire, and infrastructure development and urbanization. However, other factors, such as severe winters, pollution and acid rain, and extended dry periods, are all possible causative factors (Eterovick *et al.* 2005). Furthermore, disease may also play an important role. Carnaval *et al.* (2006) conducted histological screenings of 96 preserved specimens of anurans collected at 10 sites in the Atlantic Forest and found chytrid fungus to be widely distributed, having recorded the disease in specimens of *Colostethus olfersioides*, *Bokermannohyla gouveai* DD and *Hypsiboas freicanecae* DD, as well as *Thoropa miliaris* LC and *Crossodactylus caramaschii* LC. More concerningly, the altitudinal range is broad, spanning from less than 100m to about 2,400m (in the Parque Nacional do Itatiaia). The widespread occurrence of chytrid in the Atlantic Forest adds to the challenge of conserving an already threatened biome. More recently, Toledo *et al.* (2006) extended the distribution of the fungus in Brazil ca. 630km southward from the previous southernmost record of Carnaval *et al.* (2006), reaching São Francisco de Paula in the state of Rio Grande do Sul (the southernmost limits of the Atlantic rainforest), and speculated on its distribution in the Cerrado and Pantanal (and see Ron 2005).

The Brazilian politics of conservation include important legal instruments, such as lists of threatened species and the selection of priority areas for conservation in all Brazilian biomes. On the other hand, the country still has much to do to improve its protected areas network, particularly given the noticeable gaps in coverage in the Atlantic Forest. The Cerrado biome deserves special attention because of the scarce knowledge about amphibians and its high rate of habitat loss due to the rapid advance of the agricultural frontier. Brazilian herpetologists have clearly made dramatic strides forward in the last two decades in improving our knowledge on natural history, ecology, and basic life-history of many species, but a great deal remains to be done to better understand the causes of the declines being witnessed among the country's amphibians, and the most appropriate means to mitigate these threats.

Débora Leite Silvano

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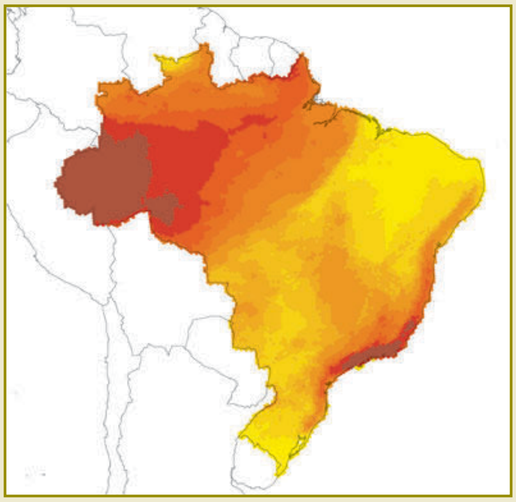


Figure 1. *Richness map of all amphibian species in Brazil, with dark red colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes. Maximum richness equals 139 species.*

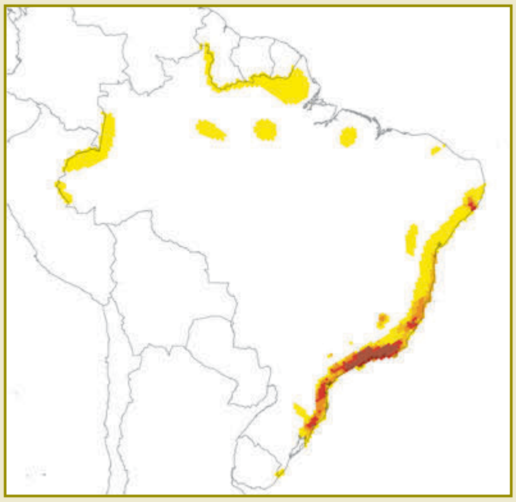


Figure 2. *Richness map of all threatened amphibian species in Brazil, with dark red colours corresponding to regions of higher richness. Colour scale based on five quantile classes. Maximum richness equals 24 species.*

ESSAY 9.5. A BRIEF OVERVIEW OF THE AMPHIBIANS OF COLOMBIA

The amphibian fauna of Colombia is among the largest and most diverse on the planet. According to the results of the Global Amphibian Assessment, nearly 700 recognized species of amphibians are known from, or expected to occur in, Colombia, and our current estimate stands at 732. The diversity of amphibians in Colombia is, to a certain degree, the fortuitous consequence of human politics – it is as if Colombia's borders were drawn with the specific intent of maximizing its amphibian diversity. That is, Colombia's amphibian diversity is a function not only of the area of this tropical country, but also its specific location. For example, the two countries with the greatest number of amphibian species are Brazil and Colombia (Ecuador is a distant third, with "only" 449 species). With 752 recognized species listed in the GAA, Brazil has a slightly larger amphibian fauna, but its area is over eight times greater than that of Colombia. Consequently, Brazil has 8.8X10^{-5} species per km^2, whereas Colombia has 6.1X10^{-4} species per km^2 – a full order of magnitude more.

In occupying the north-western-most portion of South America, Colombia includes the rich amphibian fauna of the rain-soaked Pacific lowlands and adjacent Andean foothills, and this is augmented by capturing many species (e.g., the dendrobatid *Colostethus panamensis*, LC) and lineages (e.g., the brachycephalid genus *Craugastor*) that extend into Colombia from Central America. The eastern borders reach far into Amazonia, and further north the Llanos secure fauna associated with the Orinoco river drainage. Predominantly Venezuelan lineages, such as the aromobatid *Aromobates*, extend into Colombia in the Serranía de Perijá, and the isolated Sierra Nevada de Santa Marta harbors an endemic fauna that includes such enigmatic species as the brachycephalid *Geobatrachus walkeri* (EN).

Nevertheless, although Colombia's regional span contributes greatly to the diversity of amphibians, it is the Andean backbone that is most significant (Lynch *et al.* 1997). Whereas to the south and north-east the Andes form comparatively simple systems, in Colombia they divide into three isolated ranges that radiate from the Nudo de Pasto, and these ranges harbor about two-thirds of Colombian amphibians. Among the Andean species, most occur in the cool, moist cloud forests between 1,200 and 2,500m asl, and many are confined to extremely small areas. Although experimental data are lacking, it is assumed that this isolation is due to the adaptation of species to specific environments and their inability to survive under even mildly different conditions. For example, although two adjacent mountains may share identical environmental conditions, the different environment (e.g., higher temperature and lower precipitation) of the intervening valley would serve as a barrier to dispersion and gene flow (Lynch and Duellman 1997).

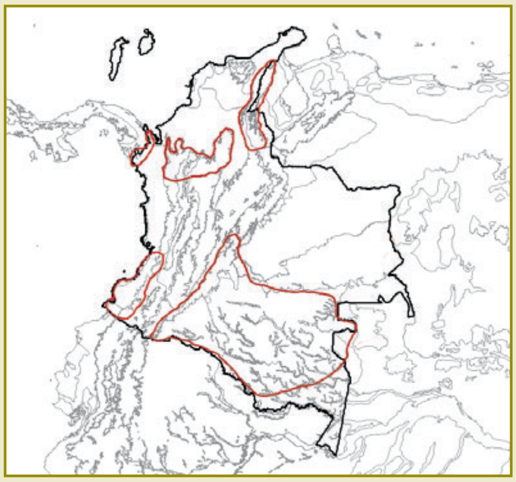
The limited geographic distribution of most Colombian amphibians makes them extremely susceptible to habitat alteration and destruction. This poses a special challenge for Colombian policy makers because humans have targeted precisely the same elevations of the Andes for their development activities. For many Andean species, the removal of a single remaining patch of forest may mean the extinction of the species. For example, *Atopophrynus syntomopus* (CR) is the only species of its genus and is known from a single locality in the Cordillera Central of Antioquia in an area that has been subjected to extreme deforestation. In addition to the habitat alteration that accompanies human development, other actual or potential threats to Colombian amphibians include the introduction of exotic species (including the illicit introduction of the North American Bull frog, *Lithobates catesbeiana*, for commercial purposes), global climate change and increased exposure to ultraviolet radiation, and infectious disease – especially chytridiomycosis, caused by the chytrid fungus *Batrachochytrium dendrobatidis* (Rueda-Almonacid *et al.* 2004).

According to the IUCN Red List, just less than half (47%) of all Colombian amphibian species are classified as Least Concern. Of the remainder, 18% are Endangered or Critically Endangered, and another 18% are Near threatened or Vulnerable. Quantitative data derived from rigorous monitoring studies are lacking for all of those species, but data are so scant for an additional 17% of Colombian species that not even a rough estimate of their status could be made, and they are designated as Data Deficient.

Given the state of knowledge of Colombian amphibians, two areas of research are in urgent need of increased attention. First, taxonomic research – including the exploration of under-sampled areas and the production of revisionary, monographic studies of groups and regions – must be expanded to complete the identification of Colombian amphibians. Although few localities can be considered thoroughly sampled, Acosta-Galvis (2000) highlighted a number of high-priority regions, including mid- to high-elevations of the central

Geobatrachus walkeri *(Endangered) is a frog known only from the north-western and western slopes of the Sierra Nevada de Santa Marta in northern Colombia. © Taran Grant*

Figure 1. *Priority regions for further inventory and survey work in Colombia.*



and northern Cordillera Central and Cordillera Occidental, higher elevations along the length of the Serranía de Perijá, the páramos of the Cordillera Oriental in southern Cundinamarca and Tolima departments, the Serranía del Darién along the Colombo-Panamanian border, the southern Cordillera Occidental and adjacent lowlands in Cauca and Nariño departments, and the Cordillera Oriental and rainforests of Putumayo, Amazonas, Caquetá, Guaviare, Vaupés, and Gauinía departments (Figure 1).

The discovery and identification of previously unknown species in all major groups of Colombian amphibians shows no sign of slowing in the foreseeable future. Indeed, as the expansion of institutional (e.g., natural history collections, molecular laboratories, GIS databases, parallel computing facilities) and human resources (e.g., active scientists and hyperactive students trained in amphibian systematics) continues, we anticipate that the current rate of discovery will continue or increase in the coming years. For example, although it once seemed that the Amazonian fauna was spatially quite uniform (albeit highly diverse), denser sampling, exploration of previously unstudied localities, and analysis of non-traditional data – especially DNA sequences – are revealing much greater complexity, and what were believed to be widespread species are frequently found to involve numerous, even distantly related species of more modest distributions. As our appreciation of the diversity of Colombian species increases, so too does our understanding of their basic biology so crucial to implementing effective conservation strategies to ensure their survival.

A second critical area of research in need of attention is the establishment of long-term, reliably funded studies that monitor natural populations at key localities in both pristine and fragmented, or otherwise developing, areas. Such monitoring programs would allow researchers to track the spread of infectious diseases, understand the response of individual species to differing pressures, and distinguish natural and normal population fluctuations from extreme and abnormal declines, all of which is necessary to design and implement an efficient conservation strategy to ensure the survival of one of the world's most diverse and fascinating amphibian faunas.

Taran Grant, Andrés R. Acosta-Galvis and John D. Lynch

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ESSAY 9.6. THREATENED AMPHIBIANS OF THE WEST INDIES

Eleutherodactylus orientalis *(Critically Endangered) from a small flat top mountain in eastern Cuba called El Yunque de Baracoa. The very small range and declining quality of habitat in the region are causes for concern. Adults are only 11mm long, only one millimetre longer than the smallest frog in the world,* E. iberia*, which also occurs in eastern Cuba. © S. Blair Hedges, Penn State*

The West Indies is a complex assortment of islands and countries located between North and South America. In total land area (224,000km²) it is similar in size to Great Britain and includes three major island groups: a chain of four large and old islands (the Greater Antilles), a relatively flat limestone bank to the north (Bahamas and Turks and Caicos Islands), and a classical volcanic island-arc in the east (the Lesser Antilles). The Greater and Lesser Antilles are located within, or at the border of the Caribbean Sea, but the Bahamas Bank is within the Atlantic Ocean. From the standpoint of biodiversity, the West Indies – sometimes called the "Caribbean Islands" – includes the Cayman and Swan Islands, but usually excludes islands neighboring Central and South America (e.g., Aruba, Curaçao, Trinidad and Tobago, etc.), which have faunas that more closely resemble those on the continents (Figure 1).

The origin of the West Indian fauna has been debated for more than a century, and continues to be an area of active research. Because the Greater Antilles were once connected, as a geological unit, with North and South America in the late Cretaceous (~60-70 million years ago), it has been suggested that the present fauna arose by "vicariance" – in other words, traveled with the islands as they broke away from the continents. But fossil and genetic research has failed to identify more than a few West Indian groups that fit this model, if any. Most, or all, groups probably arrived to the West Indies by flying, swimming, or floating on flotsam (mats of vegetation). The east to west direction of ocean currents means that the source for almost all flotsam in the West Indies is South America (or, more rarely, Africa), and this agrees with the evolutionary affinities of much of the non-flying land fauna (Hedges 2001, 2006).

With its 172 native species, the amphibian fauna of the West Indies is remarkably diverse for such a small land area. Yet it is also peculiar in that all the native amphibians are frogs – there are no salamanders or caecilians – and most (147 species) belong to a single genus of direct-developing leptodactylid frogs, *Eleutherodactylus* (Schwartz and Henderson 1991; Hedges 1999). West Indian amphibians range in adult size, from the smallest frog in the world, *Eleutherodactylus iberia* of eastern Cuba, at 10mm, to the giant ditch frog *Leptodactylus fallax* (the "Mountain Chicken") of the Lesser Antilles, reaching 210mm.

Frogs of the genus *Eleutherodactylus* (see Essay 1.4) lay their eggs on land, bypassing the aquatic tadpole stage, which eventually hatch into miniatures of the adults. One species of *Eleutherodactylus* in Puerto Rico even gives birth to living froglets. Parental care is common among the species, and many guard their eggs during development. The sex of the egg-guarder follows evolutionary lines, with the father having this job in the Puerto Rican group of species, whereas in Jamaica the mother is usually the guarder (Townsend 1996). Individual species are adapted to a great many terrestrial niches, including underground burrows, rock caves, cliffs, salt marshes, waterfalls, bromeliads, tree holes, leaf litter, and vegetation of all types. The term "ecomorph" has been used with West Indian *Eleutherodactylus* to recognize the morphological and ecological convergence in species from different islands and their adaptations to these niches.

Other native amphibians include a modest radiation of toads (11 species, family Bufonidae) and an assortment of treefrogs (nine species, family Hylidae). With eight species, Cuba is the center of diversity for toads, whereas Jamaica and Hispaniola are hot spots of hylid frog diversity, with four species each. There are several species of aquatic ditch frogs (*Leptodactylus*) as well, including the Mountain Chicken that occurs on Montserrat and Dominica. A single species of dendrobatid frog occurs on Martinique. All but a few species of West Indian amphibians are endemic to a single island.

Many species occur in the lowlands, but a peak in species density occurs between 550 and 1,150m elevation, usually corresponding to cloud forest habitat. On average, species body size decreases by about one mm per 100m of increasing elevation, so a lowland species is typically twice as long (~56mm) as one on a mountaintop at 2,500m (Hedges 1999). The number of sympatric (co-occurring) species varies among and within islands, with the highest number recorded being 24 species near the Haitian village of Castillon, in the Massif de la Hotte of Hispaniola.

From a conservation standpoint, the West Indies is one of the hottest biodiversity hotspots (Smith *et al.* 2005). On average humans have destroyed more than 90% of the original native habitat in the West Indies and it is no surprise that these forest-dwelling species have been decimated. Clearing of land is often for subsistence farming, but trees are also sold for building materials or made into charcoal for cooking fuel. Charcoaling is practiced in Jamaica, Cuba, and Hispaniola and is one of the major sources of income in Haiti where the human population has soared to over eight million and where essentially no original forests remain (Hedges and Woods 1993; Young *et al.* 2004).

A recent assessment of the status of West Indian amphibians found that 84% of the species are threatened (Young *et al.* 2004), with 37% listed as Critically Endangered, 36% as Endangered, and 11% as Vulnerable. There is no other region of the world that has such a high proportion of threatened species. Among those 63 species listed as Critically Endangered, eight are considered to be "possibly extinct" because they have not been seen in many years (Hedges 1993, 1999; Young *et al.* 2004). These include the live-bearing species *Eleutherodactylus jasperi* of Puerto Rico, as well as several stream-dwelling species.

Besides the major threat from deforestation, a few species have disappeared from forested areas and the reason for this is unclear. Certainly, no forests in the West Indies are pristine because of introduced flora and fauna that impact the native biota. For example, Old World rats and mongooses can be encountered throughout forested areas high on mountains in the Greater Antilles and these species are known to prey on amphibians. Still, it remains to be established whether introduced predators, climate change, a chytrid fungus, another threat, or rather a combination of these factors is the primary cause for the presumed extinctions of these amphibians (Burrowes *et al.* 2004).

Most countries have made some efforts to control deforestation, such as the designation of national parks and protected areas. These efforts are to be applauded, but unfortunately most have had limited or no success in slowing the destruction of habitat. This is especially true in the countries such as Haiti and the Dominican Republic, where clear-cutting and charcoaling continue within protected areas, mostly because budgets allocated to environmental protection are insufficient. Essentially no original forests remain in Haiti (Hedges and Woods 1993), and therefore many endemic species – including those not found in the Dominican Republic – will likely become extinct in the near future unless something is done soon. Species in other countries may not be far behind.

It is imperative that international agencies, both conservation-based and

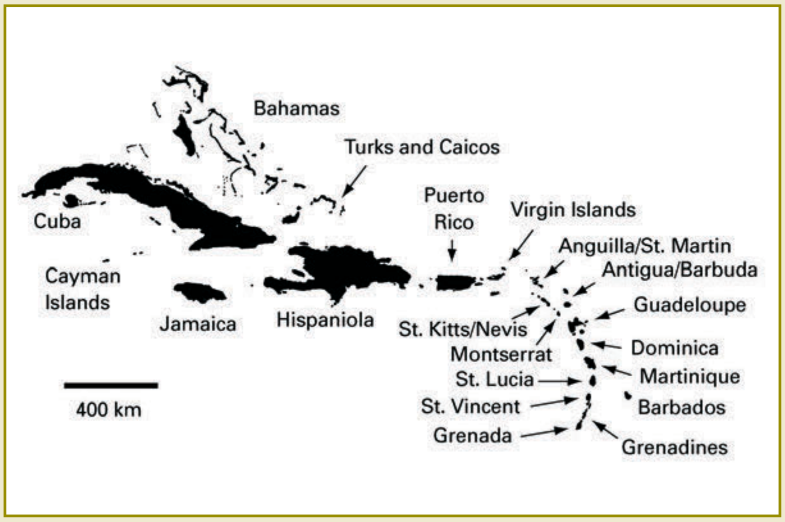

Figure 1. *Map of the West Indies (Caribbean Islands).*

Eleutherodactylus glanduliferoides *(Critically Endangered) from the Massif de La Selle of Haiti. This species is only known from a few places on the northern slope of these mountains, just above the densely populated capital city of Port-au-Prince. The region is completely deforested and this species is possibly extinct. © S. Blair Hedges, Penn State* otherwise, step in to help protect the environment in Haiti and elsewhere in the West Indies before it disappears. Salaries for park guards and logistical support (e.g., vehicles, communication equipment, and supplies) for existing parks would provide the most immediate benefit. An accurate knowledge of the amphibian fauna is also a pre-requisite for conservation efforts, as is basic systematic work, which needs to be supported through increased training of local scientists, better education of government officials charged with protecting the environment (e.g., scientists do not pose a threat!), and greater facilitation of work by foreign scientists. Together with prompt and vigorous support directed towards existing protected areas, the real threats facing the amphibian fauna of the West Indies may be reduced – if we are lucky.

S. Blair Hedges

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ESSAY 9.7. SPREAD OF DISEASE IN LATIN AMERICAN AMPHIBIAN POPULATIONS

In 2005-2006, the world watched as avian flu spread across Asia and into Europe. As we write this, Americans are expecting the disease to cross the Atlantic and infect birds in the United States. Fortunately, at least in the case of bird flu, we have an example of a global monitoring system that can track the spread of disease across geopolitical boundaries, as well as a network of health-care providers that are prepared to treat patients infected by the virus. Although many people will be saved, many will still suffer from this emerging infectious disease despite the benefit of advanced warning systems, treatment facilities, and trained personnel. But let us consider a different hypothetical situation. What would happen if:

- Entire populations of humans were dying from an unknown disease in remote regions of the world?
- Few scientists or doctors were aware of the situation?
- Nobody contacted the news media or policy makers?
- We realized that this was an epidemic, but we had no monitoring network or treatment facilities?
- The few personnel trained to detect and potentially treat the disease were distantly located and had neither financial resources nor sufficient infrastructure to offer any help?
- We could prevent deaths in hospitals, but nowhere else?

Where and how could we even begin to offer help? With few data, no dedicated sources of funding, and no infrastructure, the situation would seem impossible. Yet, to do nothing would clearly be unacceptable. In all respects, this is the situation for Latin American amphibians, as population after population succumbs to the frog-killing fungal disease, chytridiomycosis.

The current crisis of global amphibian extinctions is the result of multiple causal factors (Collins and Storfer 2003), but none is more insidious than chytridiomycosis. Considered an emerging infectious disease (Daszak *et al.* 2000), caused by a recently discovered fungal pathogen, *Batrachochytrium dendrobatidis* (*Bd*), chytridiomycosis has been found infecting more than 80 species of amphibians in Latin America and over 150 species worldwide, and more areas and species are predicted to be affected in the future (Ron 2005). The disease has been directly implicated in numerous population declines and extinctions, and is acknowledged to have caused many other such catastrophes that were not observed. Yet, we still lack a complete understanding of *Bd's* basic biology, pathology, epidemiology, and taxonomic/geographic distribution.

A case study from El Copé, Panama (Lips *et al.* 2006) illustrates the devastation that *Bd* can inflict upon diverse tropical amphibian communities that are typical of upland areas in Central and South America. Following a period of eight years of monitoring both amphibian abundance and disease prevalence, field crews obtained the first *Bd*-positive sample on 23 September 2004 (Figure 1). Within one week, several dead frogs had been found, and shortly thereafter as many as 19 dead frogs were found in a single day. After four months, researchers had found 350 dead frogs, representing 40 species among eight families of anurans and salamanders, all of which were heavily infected with *Bd*. This report was the first definitive link between catastrophic population declines of amphibians and the sudden appearance of *Bd* at a site. Within six months, amphibian abundance had been reduced by more than 75%, with 50% of species missing and almost all species affected to some degree. Nocturnal surveys prior to October 2004 often produced as many as 170 captures, representing as many as 23 species, but those same transects now produce no more than five or six frogs, representing only two or three species. Within a remarkably short space of time, the amphibian community of El Copé has been devastated by this disease, and is not anticipated to recover, because populations have been greatly reduced and because *Bd* persists at this site.

Although many diseases can impact host populations by causing temporary or permanent declines in abundance, only recently has disease been considered a major cause of species extinctions (de Castro and Bolker 2005). Theoretical work on disease ecology predicts that, as an epidemic infectious disease reduces the abundance of its hosts, there is an increase in the relative abundance of immune individuals; thus, disease transmission is reduced to zero, such that the pathogen becomes extinct before the host. *Bd* is unusual in that it affects a broad taxonomic array of species, and is highly virulent killing most infected individuals. These are classic traits of invasive or novel pathogens, and the arrival of *Bd* in the Neotropics, and its subsequent extermination of the native fauna, is similar to the effect smallpox had when it was introduced from Europe to the Americas by Christopher Columbus and his crew.

A large number of amphibian species have already been identified as hosts of *Bd*, and it is likely that both the environment and the frogs are potential disease reservoirs (Lips *et al.* 2006). When populations begin to decline, they can be wiped out in a short period of time with little chance of recovery or replenishment from other populations. It is this lethal combination of an exotic virulent pathogen (with a broad host range) invading a highly endemic amphibian fauna with small geographic distributions that produces high levels of species extinction in very short periods of time. In conclusion, we can expect to see many more losses of amphibian species from the Neotropics, as this disease continues to expand its range. Worse yet, bioclimatic modeling (e.g., Ron 2005; and see Essay 11.4) suggests that *Bd* can survive in many other parts of the globe, and is likely to infect hundreds, if not thousands, of additional species in Africa and Asia.

Many questions remain regarding how the relationships among *Bd*, amphibian hosts, and environmental conditions produce such a wide range of amphibian population responses. We are beginning to appreciate the complex challenges involved in mitigating or even reversing impacts of emerging infectious diseases. We also know that traditional conservation efforts that are tied to habitat protection are inadequate by themselves in such instances, so effective solutions remain elusive. Trade and transport of amphibians and other wildlife may spread *Bd* (Hanselmann *et al.* 2004), but the actual frequency and impact of these factors is not known. Regional and local climatic conditions may influence the growth and survival of *Bd* (Pounds *et al.* 2006), but until a mechanism is identified that can link global or regional climate changes to individual mortality or reduced population growth, we cannot hope to design effective conservation measures that would mitigate these impacts. At this time, while we can effectively treat animals in captivity (Nichols *et al.* 2001), we cannot control the spread of *Bd* in the wild, or treat animals or ecosystems *in situ*. Another problem is that *Bd* is difficult to detect because it is microscopic and may persist in ecosystems for undetermined periods of time.

Chytridiomycosis is an alarming model system for disease-driven extinctions of an entire fauna. For one emerging infectious disease to appear so suddenly and have such uncontrollable effects on global biodiversity, demands an immediate response. We are facing the synchronous extinction of a significant proportion of an entire group of vertebrates, and we propose that it is no longer correct to speak of global amphibian declines but, more appropriately, of global amphibian extinctions.

Karen R. Lips and Joseph R. Mendelson III

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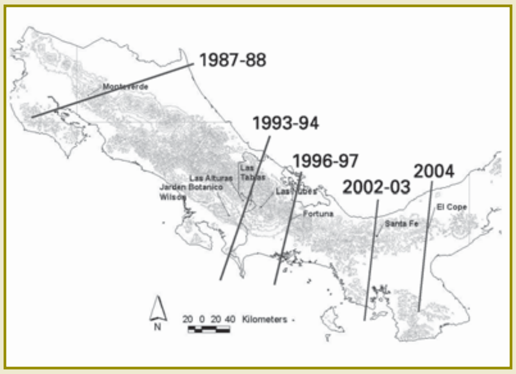


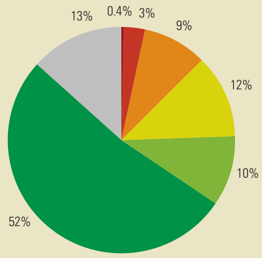
Figure 1. *Timelines of sequential catastrophic declines of amphibians, as a result of chytridiomycosis, in Costa Rica and Panama. Modified from Lips* et al. *(2006).*

An undescribed species of Eleutherodactylus *found dead floating in a stream during a die off near El Cope, Panama in 2004. © Forrest Brem & Roberto Brenes*

CHAPTER 10. AMPHIBIANS OF THE PALAEARCTIC REALM

Figure 1. *Summary of Red List categories for amphibians in the Palaearctic Realm. The percentage of species in each category is also given.*

Red List Category	Number of species
🟥 Extinct (EX)	2
Extinct in the Wild (EW)	0
🟥 Critically Endangered (CR)	13
🟧 Endangered (EN)	40
🟨 Vulnerable (VU)	58
🟩 Near Threatened (NT)	48
🟩 Least Concern (LC)	245
⬜ Data Deficient (DD)	62
Total Number of Species	**468**



Pachyhynobius shangchengensis (Vulnerable) *is a member of the Asian salamander Family Hynobiidae. It is known only from the Dabieshan area in central China, and it lives in slow-flowing hill streams in forested areas, where its larvae also develop. Over-harvesting for human consumption is a major threat to this species. © Arnaud Jamin*

Brandon Anthony, J.W. Arntzen, Sherif Baha El Din, Wolfgang Böhme, Dan Cogălniceanu, Jelka Crnobrnja-Isailovic, Pierre-André Crochet, Claudia Corti, Richard Griffiths, Yoshio Kaneko, Sergei Kuzmin, Michael Wai Neng Lau, Pipeng Li, Petros Lymberakis, Rafael Marquez, Theodore Papenfuss, Juan Manuel Pleguezuelos, Nasrullah Rastegar, Benedikt Schmidt, Tahar Slimani, Max Sparreboom, İsmail Uğurtaş, Yehudah Werner and Feng Xie

THE GEOGRAPHIC AND HUMAN CONTEXT

The Palaearctic Realm includes northern Africa, all of Europe, and much of Asia, excluding the southern extremities of the Arabian Peninsula, the Indian Subcontinent (south of the crest of the Himalaya), Southeast Asia, and the southern parts of China. It is by far the largest of the six biogeographic realms.

The Palaearctic Realm is dominated by the Eurasian tectonic plate, which comprises all of Europe and most of Asia. Over the past 60 million years, the African, Arabian and Indian plates have collided with and compressed the Eurasian plate, forming an extensive array of mountain ranges, generally running in an east-west direction. These ranges include: the Pyrenees; the Alps; the Carpathians; the Balkan mountains; the Caucasus; the mountains of Turkey, Iran, Afghanistan, Pakistan and central Asia; and the Himalaya. The northern part of the African Plate and most of the Arabian plate are now dominated by a Palaearctic fauna, whereas the fauna on the Indian Plate is overwhelmingly Indomalayan (as is the fauna on the south-eastern part of the Eurasian Plate). Although the Palaearctic has an extensive land connection with the Afrotropical Region, there is relatively little mixing of the faunas, due to the barrier to dispersal formed by the Sahara and Arabian Deserts, particularly for organisms such as amphibians. However, there is much more overlap with the Indomalayan fauna, and the boundary between the two regions is hard to delineate in China.

For the reasons given above, the southern part of the region is much more mountainous than the northern part, and includes the highest mountains in the world, peaking at Sagarmatha (Mount Everest) at 8,850m. All of the world's mountains higher than 8,000m occur in the Himalayan and Karakorum ranges.

Boreal coniferous forests dominate the northern part of the region, through Scandinavia and Russia. Further to the south, both the western and eastern parts of the region were originally covered in mixed and broad-leaved temperate forests, giving way to steppe lands in the central part of the region. However, very little remains of the original temperate forest habitat through most of the region. In keeping with the topography, habitat diversity is greater in the southern part of the region, ranging from deserts, to grassland, to Mediterranean-type scrubland, and to coniferous forests.

The Palaearctic Realm has a very uneven human population density (approximately 32 people per square kilometre in Europe in 2005, compared with 137 in China, 339 in Japan, but only 8 in Russia and 11 in Saudi Arabia). The percentage of the population living in rural areas also varies greatly, ranging from 11.5% in Saudi Arabia, to 26.7% in Europe and Russia, 34.3% in Japan, and 59.5% in China. In general, most of the people in the region are concentrated in eastern Asia and western Europe. The gross income per capita also varies hugely across the region, from US$1,740 in China in 2005, to US$4,460 in Russia, US$11,770 in Saudi Arabia, US$27,900 in western Europe, and US$38,390 in Japan. Economic growth rates are very high in China (reaching 10% annually), and now averaging 6% in eastern Europe, Russia, and central Asia, but much lower (<3%) in western Europe and Japan.

The high economic growth rate in China, and high overall wealth in Europe, as well as high human population densities, explain why damage to natural ecosystems has been so extensive in the eastern and western parts of the region. In China, but in Europe and the Middle East to an even greater extent, humans modified extensive areas of natural habitat over 1,000 years ago. High levels of habitat modification are still ongoing in China and many other parts of the region. Conversely, in the central and northern parts of the region, many ecosystems are still largely intact.

GLOBAL CONSERVATION STATUS

A total of 113 species (24%) of amphibian in the Palaearctic Realm is considered to be globally threatened or Extinct (see Figure 1). This is significantly less than the global average of 33%[1]. The Palaearctic Realm contains 6% of all globally threatened amphibians. The Palaearctic accounts for only 3% of CR species and 5% of the EN species, but 9% of the VU species. Hence, on the basis of current knowledge, threatened Palaearctic amphibians are more likely to be in a lower category of threat, when compared with the global distribution of threatened species amongst categories. The percentage of DD species, 13% (62 species), is also much less than the global average of 23%, which is not surprising given that parts of the region have been well surveyed. Nevertheless, the percentage of DD species is much higher than in the Nearctic.

Two of the world's 34 documented amphibian extinctions have occurred in this region: the Hula Painted Frog *Discoglossus nigriventer* from Israel and the Yunnan Lake Newt *Cynops wolterstorffi* from around Kunming Lake in Yunnan Province, China. In addition, one Critically Endangered species in the Palaearctic Realm is considered possibly extinct, *Scutiger maculatus* from central China. This represents 1% of the 130 possibly extinct species in the world. Clearly, as with the Nearctic, there is little in the way of overall discernible pattern so far in Palaearctic amphibian extinctions.

Despite a lower overall threat to the amphibian fauna in the Palaearctic compared with some other regions, many widespread Least Concern species are seriously threatened in many parts of their ranges. Many countries in Europe, report high levels of threat to their amphibian faunas. For example, Switzerland lists 70% of its species as nationally threatened (Schmidt and Zumbach 2005), even though only one of these species is globally threatened.

SPECIES RICHNESS AND ENDEMISM

Species Richness and Endemism Across Taxa

The 468 native amphibian species in the Palaearctic Realm represent 8% of the currently known global total of 5,915 species. Of these 468 species, 260 (or 56%) are endemic to the Palaearctic (Table 1). Salamanders, newts, frogs and toads are present in the region, but there are no caecilians. Anurans account for over three-quarters (77%) of the species. Endemism is much higher in the salamanders and newts (86%) compared with the frogs and toads (47%). This is presumably a reflection of the generally much smaller range sizes among salamanders, and that the families Salamandridae and Hynobiidae radiated mainly in the Palaearctic (see, for example, Weisrock *et al.* 2006). Of the 15 amphibian families that are native to the region, only three are endemic (Table 1). Only 19 species (4% of the species in the region) are members of these endemic families, although the salamander family Hynobiidae occurs only marginally in the Indomalayan Region and is predominantly Palaearctic.

Under current climatic conditions, there is essentially no isolation between the Palaearctic and Indomalayan Regions, especially in China, and the boundary between these two faunas is somewhat arbitrary. The effect of this indistinct boundary is to reduce the level of endemism of both regions. Summaries of the amphibian fauna of the Palaearctic are provided by Borkin (1999) and Zhao (1999).

There are 66 genera (14% of the global total) occurring in the region, of which 22 (33%) are also endemic. Endemism at the generic level is much higher among the salamanders and newts (72%) than it is among the frogs and toads (10%), a pattern mirrored in the Nearctic. The most speciose genera in the region are *Rana*[2] (83 species), *Bufo*[2] (39 species), *Paa* (24 species), *Hynobius* (24 species), *Xenophrys* (23 species) and *Amolops* (20 species). There are eight monotypic genera endemic to the Palaearctic Realm, all of which are salamanders. The 44 non-endemic genera in the Palaearctic include 37 frog genera (14 genera from the Ranidae, nine from the Megophryidae, seven from the Rhacophoridae, four from the Microhylidae, and one each from the Bombinatoridae, Bufonidae and Hylidae) and seven salamander genera (five from the Salamandridae, and one each from the Cryptobranchidae and the Hynobiidae).

As noted, 15 of the world's 48 amphibian families (31%) occur in the Palaearctic, of which three are endemic: Discoglossidae, Pelobatidae, and Pelodytidae. The characteristics of these families are provided in Chapter 1.

Among the non-endemic families, the majority of Palaearctic species are in the Bufonidae, Megophryidae, Ranidae, Rhacophoridae, Hynobiidae and Salamandridae. Of the Palaearctic Bufonidae, all 39 species are in the widespread genus *Bufo*[3]. This family occurs through most of the region, and 20 species (51%) are shared with other regions (mainly Indomalayan, but also Afrotropical). All Palaearctic bufonids breed by larval development, and some of these occur in a wide variety of different habitats.

There are 72 species of Megophryidae in the Palaearctic in nine genera. This family is predominantly Indomalayan, but 30% of the species are endemic to the Palaearctic, occurring mainly in central China. They occur especially in mountainous regions, and the genus *Scutiger* occurs as high as 4,000m in eastern Tibet.

The Ranidae (true frogs) constitute the largest family in the Palaearctic, accounting for just over one-third of the total amphibian fauna of the region. Just over half of the species are in the genus *Rana*[4]. The family is found in almost all parts of the region, occurring in most habitats, and breeds by larval development (except the genus *Ingerana* (four species in the Palaearctic) which are believed to breed by direct development).[5]

The Rhacophoridae (Asian treefrogs) is another predominantly Indomalayan family, with 39 species occurring in the Palaearctic, only six of which are endemic. All the Palaearctic species are in the east of the region (mainly in China). In this region, most of the species breed by larval development, some using foam nests, but a few in the genus *Philautus* are probably direct developers.

The Asian salamanders (Hynobiidae) are mainly a Palaearctic family centred on Japan and China, with a few species ranging further west as far as Iran, Afghanistan, ex-Soviet Central Asia and north of European Russia. There are 43 species (87% of the global total for the family) in the region, 40 of which are endemic (and see Essay 10.1).

The Salamandridae are more diverse in the Palaearctic than elsewhere, with 61% of the species occurring in the region. The family also occurs in the northern part of the Indomalayan region, and there are also six species in the Nearctic. They are widespread in the region, but are especially diverse in Europe and China. Most species lay eggs and have free-living aquatic larvae, but 12 species (in the genera *Salamandra* and *Lyciasalamandra*) are live-bearers that do not lay eggs. In some of these species, the young are nourished inside the mother from the embryos of their siblings that die before birth, a unique process in amphibians.

The Palaearctic is also important for three other smaller families. The fire-bellied toads (Bombinatoridae), 60% of which occur in the Palaearctic, are widespread in the region,

Table 1. *The number of Palaearctic amphibians in each taxonomic Family present in the region.*

Family	Native species (endemics to region)	Percentage of species in region that are endemic	Percentage of species in family that are endemic to region	Native genera (endemics to region)	Percentage of genera in region that are endemic	Percentage of genera in family that are endemic to region
Anura						
Bombinatoridae	7 (6)	86	60	1 (0)	0	0
Bufonidae	39 (19)	49	4	1 (0)	0	0
Discoglossidae	12 (12)	100	100	2 (2)	100	100
Hylidae	13 (6)	46	14	1 (0)	0	0
Megophryidae	72 (38)	53	30	9 (0)	0	0
Microhylidae	13 (2)	15	0.5	4 (0)	0	0
Pelobatidae	4 (4)	100	100	1 (1)	100	100
Pelodytidae	3 (3)	100	100	1 (1)	100	100
Ranidae	158 (71)	45	11	14 (0)	0	0
Rhacophoridae	39 (6)	15	2	7 (0)	0	0
TOTAL ANURA	**360 (168)**	**47**	**3**	**41 (4)**	**10**	**1**
Caudata						
Cryptobranchidae	2 (1)	50	33	1 (0)	0	0
Hynobiidae	43 (40)	93	87	7 (6)	86	86
Plethodontidae	8 (8)	100	2	2 (2)	100	7
Proteidae	1 (1)	100	17	1 (1)	100	50
Salamandridae	54 (43)	80	61	14 (9)	64	56
TOTAL CAUDATA	**108 (93)**	**86**	**17**	**25 (18)**	**72**	**29**
TOTAL ALL AMPHIBIANS	**468 (260)**	**56**	**4**	**66 (22)**	**33**	**5**

and also extend into Indomalaya. Two of the three species of Cryptobranchidae (giant salamanders) occur in the Palaearctic, one in China, the other in Japan. These are the largest amphibians in the world, and are associated with clear streams where they breed by larval development. Finally, one of the six species of Proteidae occurs in the Palaearctic (the other five being in the Nearctic). The Palaearctic species is the Olm *Proteus anguinus* (VU) which occurs in underground streams in karstic landscapes, in north-eastern Italy, Slovenia, Croatia and a few locations in Bosnia-Herzegovina. It lays eggs, and the adults retain their larval form.

The remaining families include the Hylidae (treefrogs: a large family occurring mainly in the Americas, New Guinea and Australia, with just 13 species in the region, all in the genus *Hyla*), Microhylidae (narrow-mouthed frogs: globally widespread, with just 13 species in the region, none of which are endemic), and the Plethodontidae (lungless salamanders: a large mainly Nearctic and Neotropical family, with just eight species in the region, seven centred on Italy and one in Korea).

The threatened and extinct species in the Palaearctic show very distinct taxonomic patterns (Table 2). Salamanders, which account for less than one-quarter of the species in the region, constitute 45% of the threatened or extinct species, with high levels of threat in all families. Among the larger salamander families, 56% of the Hynobiidae are threatened, and over 40% of the Salamandridae. In both cases, habitat loss and the impact of excessive utilization are the most common threats. This tendency for salamanders to show very high levels of threat is found also in the Indomalayan, Nearctic and the Neotropical Realms. The high level of threat in the Hynobiidae is probably related to the small geographic ranges of many of the species, and their narrow ecological niches in mountainous regions

Most of the threatened frog species occur in the larger families, Megophryidae and Ranidae (Table 2). The Megophryidae (Asian spadefoots) has a high percentage (one-third) of threatened species, largely due to habitat loss in China, and often very small geographic ranges. These species are usually dependent on clear mountain streams for breeding, a very threatened habitat. The threatened Palaearctic Ranidae (which account for half of the threatened frogs in the region) are overwhelmingly concentrated in China, where they are generally threatened both by over-harvesting for human food, and by habitat loss.

Remarkably, the toads (Bufonidae), which in most other regions show high levels of threat, have no threatened species at all in the Palaearctic. In this region, the family is dominated by widespread, generally adaptable species. There are also low levels of threat in the Rhacophoridae. There are no globally threatened Palaearctic species in the Hylidae and the Microhylidae. Among the small endemic families, threat levels are 25% in the Discoglossidae (painted frogs and midwife toads) and Pelobatidae (European spadefoots), but, at least on the basis of current knowledge, negligible in the Pelodytidae (parsley frogs). It is perhaps noteworthy that 31% of Palaearctic species in the primitive suborder Archaeobatrachia (Bombinatoridae, Discoglossidae, Megophryidae, Pelobatidae and Pelodytidae) are globally threatened, compared with an average of 17% for anurans as a whole in the Palaearctic.

The great majority (87%) of the threatened amphibians in the Palaearctic are in the Endangered and Vulnerable categories. Again, the generally low number of Critically Endangered species masks some important family-level differences, with 12% of the Palaearctic Hynobiidae, and 50% of the Palaearctic Cryptobranchidae falling into this category. Salamanders account for 69% of the Critically Endangered species in the region.

Geographic Patterns of Species Richness and Endemism

A map of overall species richness of amphibians in the Palaearctic Realm (Figure 2) shows that species richness is low through most of the region, especially in most of Russia and central Asia. In dry areas, such as in much of the Arabian Peninsula and on the Tibetan Plateau, and in very cold areas such as the northernmost belt of the region, there are no amphibians at all. Species richness is highest in China, and moderate in parts of Europe, Japan, and Korea. The high richness in China is partly a reflection of certain species of Indomalayan origin occurring there, as well as the absence of glaciations in much of central and southern China during the Pleistocene ice ages. The Palaearctic Realm is generally well studied, and Figure 2 probably reflects genuine overall patterns of amphibian species richness, though more species are still being discovered regularly, especially in the eastern parts of the region, and sometimes even in western Europe.

Threatened species (Figure 3a) in the Palaearctic are overwhelmingly concentrated in central China (especially in Sichuan and northern Yunnan). Elsewhere, there is little discernible pattern, but with some threatened species in Mediterranean Europe, north-west Africa, Asia Minor, central Asia, and Japan. Not surprisingly, given the small number of species involved, there are no noteworthy concentrations of Critically Endangered species in the region (Figure 3b) (much of the apparent concentration in China reflects the wide distribution of one species, the Chinese Giant Salamander *Andrias davidianus*, which is subject to over-exploitation as a food source).

The Oriental Fire-bellied Toad Bombina orientalis *(Least Concern) is one of ten species in the Family Bombinatoridae. It is widespread in the Korean peninsula, north-eastern China, and parts of the Russian Far East. Although generally common, there is concern about the level of harvest for traditional Chinese medicine, and for the international pet trade. © Twan Leenders*

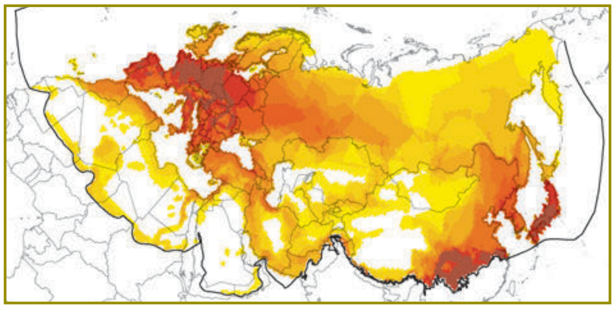


Figure 2. *The species richness of amphibians in the Palaearctic Realm, with darker colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes; maximum richness equals 40 species.*

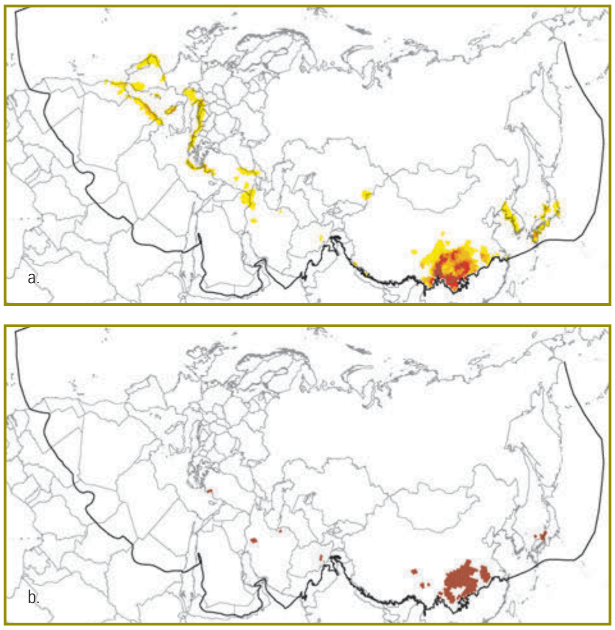


Figure 3. *a) The richness of threatened amphibians in the Palaearctic Realm, with darker colours corresponding to regions of higher richness. Colour scale based on five quantile classes; maximum richness equals 11 species. b) The richness of CR amphibians in the Palaearctic Realm. Maximum richness equals one species.*

Species Richness and Endemism within Countries

Amphibians are native in 81 countries and territories in the Palaearctic Realm (Figure 4). China has by far the largest number of species and of endemics in the region (265 species, of which 137 are endemic). More than half (57%) of Palaearctic species occur in China, and 29% are endemic to this country (see Essay 10.2). India, although second on the list, extends only marginally into the Palaearctic, and consequently has no endemics in the region. Only four other countries (Japan, Italy, France and Spain) have more than 30 species; remarkably, the Russian Federation, despite its huge size, has only 28 species and no endemics, due to the severe continental climate over a large part of its territory. The low number of species and the low level of endemism in most countries are caused in part by low overall species richness, but also by the small size of many of the countries in the region. After China, only Japan and

The Alpine Newt Triturus alpestris *(Least Concern), in the Family Salamandridae, is widely distributed in Europe, occurring in both alpine and lowland habitats including forests, meadows and pastureland. The species breeds, and the larvae develop, in stagnant waters, including shallow ponds, temporary pools, lakes, ditches, drinking troughs, ruts and sometimes slow-moving streams. © Henk Wallays*

Table 2. *The number of species within each IUCN Red List Category in each Family and Order in the Palaearctic Realm. Introduced species are not included.*

Family	EX	CR	EN	VU	NT	LC	DD	Total number of species	Number Threatened or Extinct	% Threatened or Extinct
Anura										
Bombinatoridae	0	0	0	2	0	5	0	7	2	29
Bufonidae	0	0	0	0	3	31	5	39	0	0
Discoglossidae	1	0	0	2	4	5	0	12	3	25
Hylidae	0	0	0	0	0	12	1	13	0	0
Megophryidae	0	2	11	11	5	27	16	72	24	33
Microhylidae	0	0	0	0	0	13	0	13	0	0
Pelobatidae	0	0	1	0	1	2	0	4	1	25
Pelodytidae	0	0	0	0	0	3	0	3	0	0
Ranidae	0	2	11	18	14	89	24	158	31	20
Rhacophoridae	0	0	0	1	5	23	10	39	1	3
TOTAL ANURA	**1**	**4**	**23**	**34**	**32**	**210**	**56**	**360**	**62**	**17**
Caudata										
Cryptobranchidae	0	1	0	0	1	0	0	2	1	50
Hynobiidae	0	5	8	11	2	11	6	43	24	56
Plethodontidae	0	0	1	2	4	1	0	8	3	38
Proteidae	0	0	0	1	0	0	0	1	1	100
Salamandridae	1	3	8	10	9	23	0	54	22	41
TOTAL CAUDATA	**1**	**9**	**17**	**24**	**16**	**35**	**6**	**108**	**51**	**47**
TOTAL ALL AMPHIBIANS	**2**	**13**	**40**	**58**	**48**	**245**	**62**	**468**	**113**	**24**

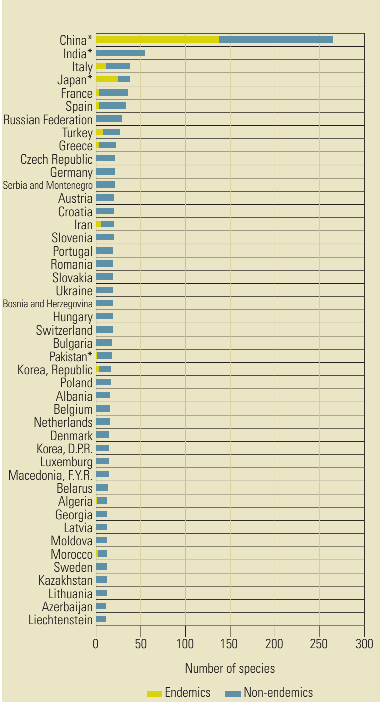


Figure 4

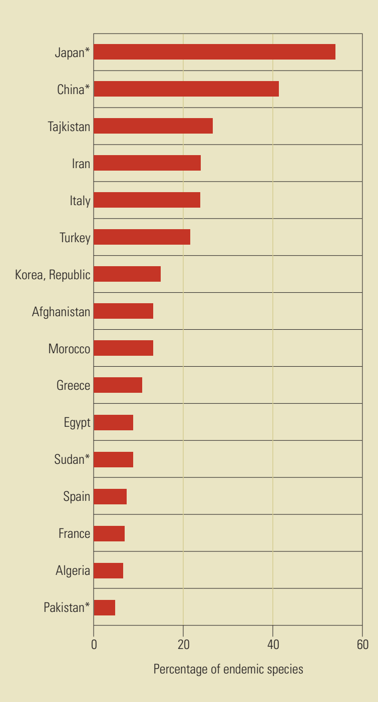


Figure 5

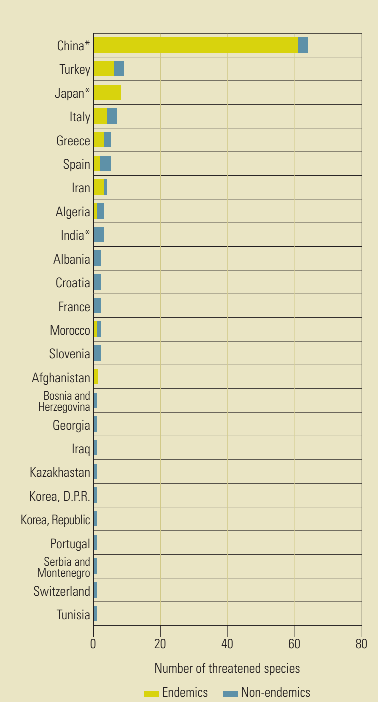


Figure 6

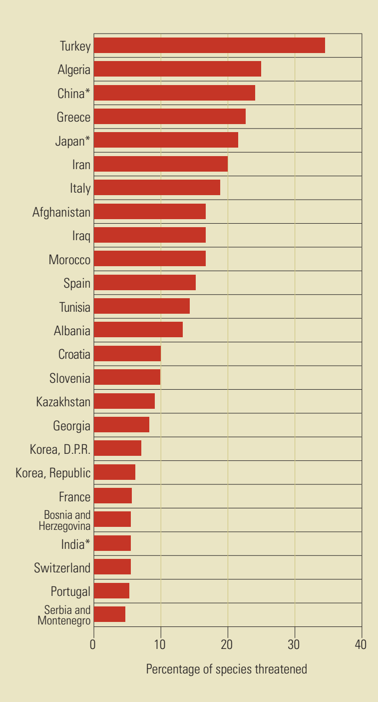


Figure 7

Figure 4. *The number of amphibians present in and endemic to each Palaearctic country. *denotes countries not entirely within the Palaearctic Realm, hence only the species whose ranges fall within the region are included. Only countries with at least 10 native species are included.*

Figure 5. *Percentage of species endemic to each Palaearctic country. *denotes countries not entirely within the Palaearctic Realm, hence only the species whose ranges fall within the region are included. Only countries with at least one endemic species are included.*

Figure 6. *The number of globally threatened amphibians present in and endemic to each Palaearctic country. Countries with no globally threatened species are not included in the diagram. *denotes countries not entirely within the Palaearctic Realm, hence only the species whose ranges fall within the region are included.*

Figure 7. *Percentage of native species that are globally threatened. Countries with no globally threatened species are not included in the diagram. *denotes countries not entirely within the Palaearctic Realm, hence only the species whose ranges fall within the region are included.*

Italy have more than 10 endemic species (25 and 11, respectively). Thirty-six countries in the region have fewer than 10 native amphibian species (not shown on Figure 4), and only four of these (Afghanistan, Egypt, Sudan and Tajikistan) have endemics (one each).

The amphibian fauna of the Palaearctic has been well summarized in extensive review literature. Important regional works include: Ananjeva and Borkin (1981), Arnold (2002, 2003), Balletto *et al.* (1985), Borkin (1984, 1999), Cogălniceanu *et al.* (2000), Corti *et al.* (1999), Duguet and Melki (2003), Gasc *et al.* (1997), Griffiths (1996), Grossenbacher and Thiesmeier (1999, 2003, 2004), Kuzmin (1996, 1999), Kuzmin and Semenov (2006), Leviton *et al.* (1992), Nöllert and Nöllert (1992), Pleguezuelos (1997), Salvador (1996), Schleich *et al.* (1996), Tarkhnishvili and Gokhelashvili (1999), Thorn (1968), Thorn and Raffaëlli (2001) and Zhao (1999). There are numerous national-level publications, including, but by no means limited to: Arnold (1995), Baran and Atatür (1998), Bauwens and Claus (1996), Bons and Geniez (1996), Cabela and Tiedemann (1985), Castanet and Guyetant (1989), Crespo and Oliveira (1989), Disi (2002), Fei *et al.* (1999, 2005), García-París (1985), García-París *et al.* (2004), Geniez *et al.* (2005), Goris and Maeda (2004), Groenveld (1997), Grossenbacher (1988), Khan (2006), Kuzmin *et al.* (1998), Llorente *et al.* 1995, Maeda and Matsui (1999), Malkmus (2004), Moravec (1994), Parent (1979), Pleguezuelos *et al.* (2002), Puky *et al.* (2003), Saleh (1997), Salvador and García-Paris (2001), Schleich and Kästle (2002), Scocciantі (2002), Sindaco *et al.* (2006), Societas Herpetologica Italica (1996), Uchiyama *et al.* (2002), Werner (1988), Ye *et al.* (1993), Zhao and Adler (1993), and Zhao *et al.* (2000).

Although China has many more endemics than any other country in the region, Japan has the highest percentage of endemic species at almost 70% (Figure 5), because of the insular nature of the country. In the Palaearctic part of China, over 50% of the amphibians are endemic. In addition to species-poor Tajikistan (already mentioned), high levels of endemism (>20%) also exist in Iran, Italy, and Turkey. In both Japan and China, the levels of endemism are high in frogs and salamanders. In Iran, Italy and Turkey, the endemics are mainly salamanders.

China has many more threatened species (64) than any other country in the Palaearctic (Figure 6). Well over half of the threatened species in the region (57%) occur in China, and 50% are endemic to China. Endemic species in China are much more threatened (45%) than non-endemics (2%). The number of globally threatened species is less than 10 in all other countries in the region (Figure 6). The percentage of threatened amphibian species is highest in Turkey (35%), and is greater than 20% in Algeria, China, Greece, Japan, and Iran (Figure 7). With the exception of Turkey, in all Palaearctic countries, the level of threat is much lower than the global average of 33%. The high percentage of threatened species in Turkey is a reflection of the presence of nine species of salamanders with small ranges, all threatened by habitat loss.

These figures all relate to the number of globally threatened amphibian species in each country. Many countries, especially in Europe, list many globally Least Concern species as nationally threatened. Assessments of the conservation status of Palaearctic amphibians have been carried out in several countries, including, for example: Switzerland (Grossenbacher 1994; Schmidt and Zumbach 2005); Japan (Japan Agency of Environment 2000; Ota 2000); Spain (Pleguezuelos *et al.* 2002); and China (Zhao 1998; Xie and Wang, 2004). Corbett (1989) published an overview of amphibian conservation in Europe, while Cox *et al.* (2006) presented a review of the status and distributions in the Meditteranean (and see Essay 10.3). Xie *et al.* (2007) proposed a conservation plan for the amphibians of China.

There are only 13 Critically Endangered Palaearctic species, but seven of these occur in China, two each in Iran and Japan, and one each in Afghanistan and Turkey. Outside China, all Critically Endangered species in the Palaearctic are salamanders.

HABITAT AND ECOLOGY

Habitat Preferences

Most Palaearctic amphibians (78%) occur in forests, but almost one-third of the fauna (31%) can survive in secondary terrestrial habitats (Table 3; Figure 8). This latter figure is almost double that of the Nearctic Realm, perhaps suggesting a higher percentage of adaptable species in the Palaearctic. As natural habitats have been completely lost in many parts of the Palaearctic, some amphibian species are now dependent of artificial habitats. As in other regions, forest-dwelling and stream-associated amphibians are more likely to be threatened than those occurring in any other habitats, with over 20% of these species being globally threatened. This is the combination of habitat preferences that has been associated with rapid declines in amphibian populations worldwide (Stuart *et al.* 2004). Amphibians occurring in savannahs, arid and semi-arid habitats, and secondary terrestrial habitats are less likely to be threatened than those occurring in other habitats (Table 3; Figure 8). At least one highly threatened species, *Ranodon sibiricus* (EN), is mainly associated with forests, but is surviving at much reduced densities in secondary habitats due to the loss of forest cover (Kuzmin and Thiesmeier 2001).

Reproductive Modes

Larval development is by far the most common reproductive mode in the Palaearctic (94% of species), compared with 3% for direct development and 3% live-bearing (Table 4; this compares with the global picture of 68% larval development, 30% direct development, and 1% live-bearing). The Palaearctic has a smaller proportion of direct-developing species than in any other region of the world. The direct-developing Palaearctic amphibians include plethodontid salamanders in the genera *Speleomantes* and *Karsenia*, and frogs in the genera *Philautus* and perhaps *Ingerana*. The live-bearing species are all salamandrid salamanders in the genera *Salamandra* and *Lyciasalamandra*. All of the live-bearing salamanders of the world are found only in the Palaearctic Realm.

Table 3. *The habitat preferences of amphibians in the Palaearctic Realm.*

Habitat type	Number of species in each habitat	% of all species occurring in the habitat	Globally Threatened and Extinct species	% of all species in habitat that are globally Threatened or Extinct
Forest	365	78	81	22
Savannah	16	3	0	0
Grassland	114	24	17	15
Shrubland	150	32	23	15
Secondary terrestrial habitats	143	31	15	10
Flowing freshwater	346	74	87	25
Marsh/swamp	127	27	17	13
Still open freshwater	254	54	36	14
Arid and semi-arid habitats	26	6	0	0

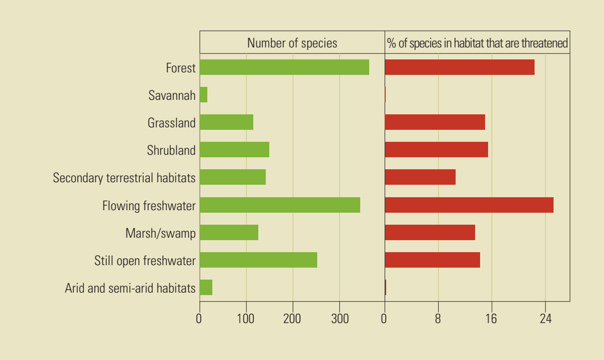


Figure 8. *The habitat preferences of Palaearctic amphibians. The plot on the left-hand side shows the number of species in the region in each habitat type. On the right-hand side, the percentage of these species which are threatened is given.*

The Marsh Frog Rana ridibunda *(Least Concern) occurs widely from western Europe to western China, with invasive populations spreading in several places in the Palaearctic outside its natural range. It is a highly opportunistic semi-aquatic ranid frog, living in most habitats, especially in open, well-warmed areas with abundant herbaceous vegetation. It may also be found in slightly saline water. © Miroslav Samardži*

Reproductive mode	All Species	Threatened or Extinct species	% Threatened or Extinct
Direct development	14	3	21
Larval development	439	101	23
Live-bearing	13	9	69
Not known	2	0	0

Table 4. *Palaearctic amphibians categorized by reproductive mode.*

Threat type	Threatened species	% Threatened species
All habitat loss	90	81
Agriculture – Crops	41	37
Agriculture – Tree plantations	4	4
Agriculture – Livestock	16	14
Timber and other vegetation removal	48	43
Urbanization and industrial development	59	53
Invasive species	9	8
Utilization	41	37
Accidental mortality	5	4
Pollution	41	37
Natural disasters	11	10
Disease	2	2
Human disturbance	11	10
Fire	5	4

Table 5. *The major threats to globally threatened amphibians in the Palaearctic Realm. Only present threats to species are tallied.*

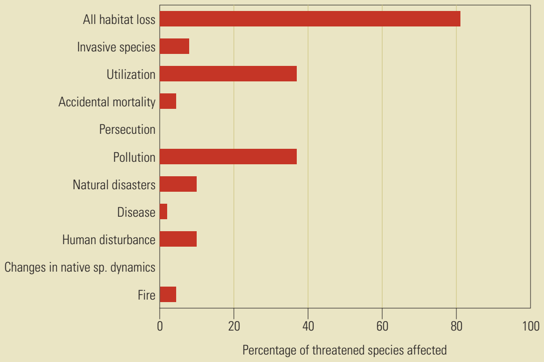


Figure 9. *The major threats impacting threatened amphibians in the Palaearctic Realm.*

In the Palaearctic, the percentage of globally threatened or Extinct live-bearing amphibians is much higher than in direct-developing and larval-developing species (Table 4), though, in view of the small number of species involved, the significance of this finding is not clear.

MAJOR THREATS

Habitat loss is overwhelmingly the major threat to amphibians in the Palaearctic (Table 5; Figure 9), affecting over 80% of the threatened species. Pollution and utilization are the next most serious threats, each impacting over one-third of the threatened species. Invasive species, disease, human disturbance and natural disasters also have significant impacts on certain species. Most other threats are of relatively minor importance. Chytridiomycosis has been recorded in many parts of Europe, with records from seven countries and 20 out of 28 species examined (Garner *et al.* 2005, 2006). It has been associated with some serious declines in Spain, but so far only of non-threatened species (Bosch *et al.* 2001). However, it does not seem to kill amphibians in most areas where it has been recorded in Europe, and so its overall impact currently seems to be less severe than in some other regions.

In terms of the types of habitat loss that are impacting amphibians in the Palaearctic, the impacts of urbanization and industrial development (affecting over half of the threatened species), vegetation removal (mainly logging in Asia) (>40%) and expanding croplands and agricultural intensification (over one-third) are the most severe. Tree plantations and livestock are less important threats in most cases. The heavy impact of urbanization and industrialization reflects the high human population density in China, Japan, and Europe in the areas where amphibian species richness is highest. These factors, as well as the extensive development of agriculture, are also important threats in some parts of the former Soviet Union. The coding of major threats used in the Global Amphibian Assessment does not sufficiently depict habitat loss resulting from the over-exploitation of water resources, which is increasingly affecting amphibians in the south-western part of the Palaearctic (especially in the Iberian Peninsula, Greece and northern Africa), resulting in the widespread loss of breeding sites.

The Green Toad Bufo viridis *(Least Concern) from the Family Bufonidae has an extremely wide range in North Africa, Europe, and West and Central Asia. It is one of the most adaptable amphibians of the Palaearctic, living in forests, steppes, dry grasslands, alpine areas, arid habitats (usually close to oases), and urban areas. © Maik Dobiey*

The Common Spadefoot Pelobates fuscus *(Least Concern), one of four species in the Family Pelobatidae, ranges from western Europe to central Asia. It occurs mostly in open areas, and burrows in loose soil when not breeding. It breeds in small still water bodies, including ditches, ponds and lakes. © Miroslav Samardži*

Table 6. *The purposes for which amphibians are used in the Palaearctic Realm. The numbers in brackets are the number of species within the total that are threatened species.*

Purpose	Subsistence	Sub-national/ National	Regional/ International	Number of species
Food – human	83 (23)	33 (9)	10 (1)	88 (24)
Food – animal	3 (0)	0	0	3 (0)
Medicine – human and veterinary	42 (10)	24 (4)	7 (0)	45 (10)
Pets, display animals	7 (2)	39 (9)	47 (9)	54 (15)
Research	1 (1)	8 (1)	3 (0)	8 (1)
Specimen collecting	1 (1)	7 (7)	8 (8)	9 (9)

Table 7. *The population trends for all extant Palaearctic amphibians.*

Population Trend	Number of species	% of extant species
Decreasing	246	53
Stable	126	27
Increasing	5	1
Unknown	89	19

Table 8. *The number of species in "rapid decline" and "over exploited decline" in the Palaearctic Realm by Family.*

Family	Number of species in "rapid decline"	Percentage of species in family in "rapid decline"	Number of species in "over-exploited decline"	Percentage of species in family in "over-exploited decline"
Bufonidae	1	3	0	0
Discoglossidae	3	25	0	0
Megophryidae	2	3	0	0
Pelobatidae	2	50	0	0
Ranidae	20	13	12	8
Cryptobranchidae	1	50	1	50
Hynobiidae	2	5	1	2
Plethodontidae	1	13	0	0
Salamandridae	10	19	4	7

A total of 153 species (50 of which are threatened) are recorded as being used in the region (Table 6). The most common reasons for harvesting Palaearctic amphibians are for food (88 species, mostly at local and national levels), pet trade (54 species, mostly at national and international levels), and medicinal use (45 species, mostly at local and national levels). Not all of the harvesting of amphibians in the region is considered to constitute a major threat to the species. Of the 153 species being harvested, utilization is considered to be a threat for 96 (of which 46 are threatened species for which harvesting is believed to be contributing to a deterioration in their status). Over 60% of these species seriously threatened by over-harvesting occur in China, where many species of amphibians are extensively harvested for human food and medicines. Examples include the Chinese Giant Salamander (which has undergone catastrophic declines), 12 species of ranid frogs (eight in the genus *Paa*), and six species of hynobiid salamanders. Threatened species outside China that are harvested include six species of hynobiid salamanders (in the genus *Hynobius*) in Japan (mainly pet trade), nine species of salamandrid salamanders (in the genera *Lyciasalamandra* and *Neurergus*) in Iran and Turkey (pet trade), and the hynobiid *Ranodon sibiricus* in Kazakhstan (mainly medicinal use). A much higher percentage of Palaearctic threatened species is negatively impacted by utilization (37%) than in any other region (Indomalaya is the next highest at 8%). Harvesting of non-threatened amphibians in Russia as food and medicine exports to China (mainly *Rana dybowskii*, but also *R. amurensis*, *R. asiatica*, *R. nigromaculata*, *Bufo gargarizans*, *Hyla japonica* and *Bombina orientalis*) has resulted in significant population declines at regional levels in eastern Russia (Maslova and Lyapustin 2005).

POPULATION STATUS AND TRENDS

Estimates of Population Trends

A summary of the inferred population trends of Palaearctic amphibians is presented in Table 7. For the majority of the species, these trends are inferred from trends in the state of the habitats on which the species depend (though in some cases, actual population declines have been noted, especially for species that are being over-harvested). The overall trends of Palaearctic amphibians reflect a worse situation than the global trend (where 42% are decreasing and only 27% are stable). In both cases, the percentage of increasing species is very small. These results suggest that, although the Palaearctic currently has a lower percentage of threatened species than the global average, the situation is probably deteriorating, given the high percentage of decreasing species. One reason for the large number of decreasing species is that the majority of the region's amphibians occur in China, where habitat loss and over-harvesting are both serious threats. Many species in Europe are also in decline, especially due to agricultural intensification.

"Rapidly Declining" Species

Only 42 (9%) of the 470 globally "rapidly declining" species occur within the Palaearctic Realm (a full list of all "rapidly declining" species is provided in Appendix IV and includes their occurrence within each of the realms). Eighteen of these species are in decline due to over-exploitation, 23 due to reduced habitat, and one due to so-called "enigmatic declines". Not surprisingly for this region, more declines are attributed to reduced habitat and over-exploitation than to enigmatic declines. The Palaearctic accounts for 47% of the world's rapid declines due to over-exploitation, but only 11% of the reduced habitat declines, and 0.4% of the enigmatic declines. One species in the region, *Nanorana pleskei* (NT) from Qinghai, Gansu and Sichuan Provinces in China, has been recorded as undergoing an enigmatic decline, the causes of this decline are not known, and have not so far been linked to either chytridiomycosis or climate change (although these two threats have now been associated with many such declines that have taken place elsewhere in the world (Lips *et al.* 2006; Pounds *et al.* 2006)).

The "rapidly declining" species show a distinct taxonomic pattern (Table 8). Among the larger families, the Ranidae and Salamandridae show a higher tendency to serious decline than the Bufonidae, Megophryidae and Hynobiidae. There are no Palaearctic species in rapid decline in the two treefrog families, Hylidae and Rhacophoridae, nor in the Microhylidae. Some small families have high percentages of species in serious decline, most notably the Discoglossidae and Pelobatidae (both families with large tadpoles) and Cryptobranchidae. Among the larger families, "over-exploited declines" are concentrated in the Ranidae and the Salamandridae.

The "rapid declines" in the Palaearctic also show a clear geographic pattern. The major concentration of declines is in China (23 species), followed by Iberia (8), north-western Africa (three), and Iran (two). Of the "over-exploited declines", 16 are in China, and two in Iran (*Neurergus* newts in the pet trade). The rapid declines in Iberia and north-western Africa have been linked to loss of habitat due to a long-term drying trend in the climate (see Pleguezuelos *et al.* 2002), linked with the over-exploitation of water resources, which results in the widespread loss of breeding sites.

KEY FINDINGS

- A total of 468 species are recorded from the Palaearctic Realm, of which 113 (24%) are considered globally threatened or Extinct.
- At the species level, 260 amphibians (56% of those present) are endemic to the Palaearctic; of the 15 families found in the region, three are endemic, and of 66 amphibian genera occurring, 22 are endemic. Endemism is lower in the Palaearctic than some other regions, especially due to the unclear and somewhat arbitrary boundary with the Indomalayan Region, especially in China.
- The percentage of threatened or Extinct species is lower than in many other parts of the world, but highest in the families Proteidae (100%), Hynobiidae (56%), Cryptobranchidae (50%), Salamandridae (41%), Plethodontidae (38%), Megophryidae (33%), Bombinatoridae (29%), Discoglossidae (25%) and Pelobatidae (25%).
- Overall, the threat levels are much higher among salamanders and newts (47%) than frogs and toads (17%).
- Geographic concentrations of threatened species in the Palaearctic are overwhelmingly centred on China; elsewhere there is little discernible pattern, though there are small concentrations in Mediterranean Europe, north-west Africa, Asia Minor, Central Asia and Japan.
- China has the largest number of species in the Palaearctic Realm (265 species), and also has more endemics (137). Another five countries (India, Japan, Italy, France, and Spain) have more than 30 species, but only two of these (Japan and Italy) have more than 10 endemics.
- China also has by far the largest number of threatened species (64), all other countries having fewer than 10 threatened species. However, the percentage of threatened species is higher in Turkey (35% cf. 24% in China).
- Threatened species tend to show distinct habitat preferences, with forest-dwelling and stream-associated species being the most frequently threatened (22% and 25%, respectively). This mirrors patterns seen elsewhere in the world.
- Habitat loss, primarily due to the impacts of urbanization and industrial development, vegetation removal (mainly logging), expanding croplands and agricultural intensification, is affecting over 80% of the threatened species in the region. Over-harvesting and pollution each impact over one-third of the threatened species. Disease has not been recorded as a significant threat in the region so far, although chytridiomycosis is spreading in Europe.
- The overall trends of Palaearctic amphibians are worse than the global situation, with 53% of the species in decline.
- Of the 470 globally "rapidly declining" species, 9% occur within the region. Most of these rapid declines (55%) are caused by severe habitat loss, and 43% are due to over-exploitation. Over-exploitation is a much more serious threat, especially in China, than in any other part of the world.
- Two amphibian extinctions have been recorded from the Palaearctic, one in China, the other in Israel. A third species (from China) is possibly extinct.

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Endnotes

1. $P<0.001$ (binomial test)
2. Frost *et al*. (2006) transfer many of the species to other genera.
3. Frost *et al*. (2006) transfer many of these species to other genera.
4. Frost *et al*. (2006) transfer many of these species to other genera.
5. Under Frost *et al*'s. (2006) arrangement, the Palaearctic species in the genera *Chaparana*, *Euphlyctis*, *Fejervarya*, *Hoplobatrachus*, *Limnonectes*, *Nanorana*, *Occidozyg*a, *Paa*, and *Sphaerotheca* are transferred to the predominantly Indomalayan family Dicroglossidae. Most of these species are in China, but others occur further west in western Asian and even north-western Africa. Some other Palaearctic "ranids" are transferred to other families under Frost *et al.*'s proposed classification: one species to the Afrotropical family Pyxicephalidae (*Tomopterna cryptotis*); four species in the genus *Ingerana* to the Oceanian and Indomalayan Ceratobatrachidae; and two species in the genus *Ptychadena* to the Afrotropical Ptychadenidae. Even with these changes, the Ranidae have just over 100 species in the Palaearctic, and remain easily the largest family in the region.

ESSAY 10.1. CURRENT STATUS OF JAPANESE SMALL SALAMANDERS OF THE GENUS *HYNOBIUS*

The Japanese archipelago includes more than 3,000 islands. In addition to the four main islands – Hokkaido, Honshu, Shikoku and Kyushu – the archipelago includes smaller island groups, such as the Ogasawara-shoto (the Bonin Islands and Iwo or Volcano Islands), and the Nansei-shoto (Ryukyu and Satsunan Islands) (Figure 1).

The amphibian fauna of Japan is represented by 56 species. Endemism is marked, with around 45 species found nowhere else. One-third of the endemic species belong to the genus *Hynobius*, a diverse group of 27 small salamander species in the family Hynobiidae, with its only other representatives in mainland China (six species), the island of Taiwan (three), and the Korean Peninsula (three). Most species in the genus have allopatric distributions (for example, the Hokkaido or Ezo Salamander *H. retardatus* is the only species found on Hokkaido, the most northerly of the Japanese islands) and very small ranges. For example, the Critically Endangered Oki Salamander *Hynobius okiensis* is confined entirely to the island of Dogo in the Oki Islands in Shimane Prefecture, while the Tsushima Salamander *H. tsuensis* (LC) is found only on the island of Tsushima (Figure 1).

Sixteen species of the genus are recorded from Japan, all of which are endemic. As a result of studies involving the use of molecular techniques, three new species have been described since 1984, including *Hynobius katoi* (DD) described only in 2004 from montane regions of the Chubu District in south-central Japan (Matsui *et al.* 2004). More recent studies are also revealing the presence of large genetic variation in wide-ranging species, and the number of species is likely to increase. For example, among the stream-breeding, montane species, the Odaigahara Salamander *H. boulengeri* (VU) has been shown to comprise at least three species, each occurring on different islands of Japan (Nishikawa *et al.* 2001). The Blotched Salamander *Hynobius naevius* (LC) is also known to contain two lineages that are partially syntopic and surely represent different species (Tominaga *et al.* 2003). Similarly, the Hida Salamander *H. kimurae* (LC) is genetically split into two distinct lineages that are morphologically quite different as well (Matsui *et al.* 2000). Likewise, still-water (lentic) breeding, lowland species are known to exhibit a great deal of intraspecific variation. It is certain, for example, that *H. nebulosus* (LC) from western Japan contains more than two species, although delimiting the geographic boundaries between the two is not easy due to their complex variation patterns (Matsui *et al.* 2006). Finally, Tohoku Salamander *Hynobius lichenatus* (LC) from eastern Japan is also split into several distinct genetic lineages that may warrant recognition at the species level (Aoki and Matsui unpubl.).

Hynobiid salamanders are highly aquatic, occurring in streams and pools, and breed by means of external fertilization, with the eggs laid in two distinctive egg-sacs that are attached to rocks or submerged vegetation. The male remains in the vicinity of the egg sacs, possibly for parental care, in some species. The larvae typically hatch and metamorphose in the same year as the eggs are laid, but in most species (e.g., Abe's Salamander *Hynobius abei*, CR), a few larvae may overwinter and only metamorphose the following year. In fact, in the Odaigahara Salamander, the large overwintering larvae sometimes prey on the next year's batch of new larvae (Nishikawa and Matsui unpubl.).

Currently, around one-third (20 species) of Japan's amphibian species are considered threatened, eight of which are from the genus *Hynobius*. However, the impending taxonomic division of several wide-ranging species discussed above will almost certainly result in an increase in the number of species listed as threatened in the near future. Abe's Salamander, currently categorized as Critically Endangered (which together with the Oki Salamander are the only two Critically Endangered amphibians in Japan), has recently been found from several new localities, although these discoveries were made prior to ongoing land development in the area. Today, *H. abei* is specially protected by the Japan Environment Ministry, and the capture of individuals and the modification of its habitats are strictly regulated.

For many years, the ranges of still-water breeding lowland species have been much impacted by increasing land development, including road construction and changes in cultivation practices. In an attempt to increase rice production, cultivation of rice paddies was halted for a season or seasons, and then bulldozed flat and reconstructed into large rectangles with the original fertile substrate mud bulldozed back into the paddies. The result of such development was large-scale devastation of the amphibian fauna, exacerbated by the fact that bulldozing usually took place in autumn and winter, when populations were hibernating (Matsui 2002). Besides lowland species, stream-breeding (lotic) montane species are now also subject to increasing habitat degradation as a result of the construction of montane roads and dams, as well as ongoing deforestation at higher elevations. Over-harvesting of animals for the national pet trade is also an important threat for species such as Tokyo Salamander *H. tokyoensis* (VU) and the Oita Salamander *H. dunni* (EN). As a result of these threats, many local governments are trying to implement legislation to restrict the collection of animals and to prevent land development projects that are detrimental to the salamanders' survival. Habitat restoration and captive-breeding programmes have been attempted for a number of species, but both efforts are currently hampered by an often limited knowledge of species-specific life histories.

Masafumi Matsui

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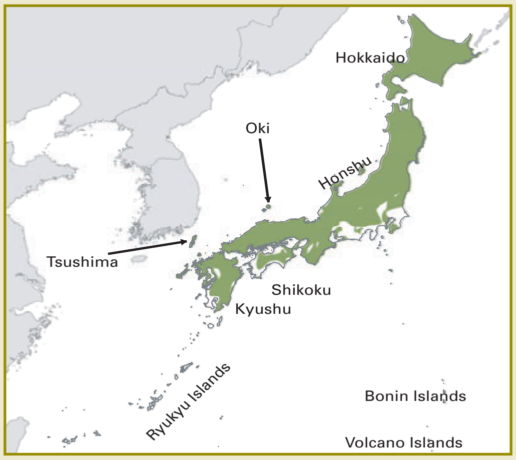

Figure 1. *Map of Japan showing the main islands and island chains, and the distribution of the genus* Hynobius *in the Japanese Archipelago.*

Hynobiid salamanders are highly aquatic, and breed by means of external fertilization. Females deposit a pair of distinctive egg sacs (here Hynobius tokyoensis*), including a full clutch of unfertilized eggs, and males focus on these egg sacs during breeding, rather than on the female. © Henk Wallays*

ESSAY 10.2. CONSERVATION NEEDS OF AMPHIBIANS IN CHINA

China is one of the most geographically varied countries in the world. Its landscapes include the highest mountains and plateaus, vast river basins, deserts and wetlands, the most extensive karstic region on earth, and both temperate and tropical forests. China spans the Indomalayan and Palaearctic Realms, and much of the country is considered to be a transition area between them (Zhao 1999). As a result, the country is particularly rich in biodiversity, with many endemic species, especially in the southern and south-western parts of the country that were never affected by glaciations.

There are 346 extant native amphibians in China[1] comprising 299 species of frog, 46 salamanders and one caecilian, plus two extinct species: *Cynops wolterstorffi* (globally Extinct) (He 1998) and *Echinotriton andersoni* (extinct on Taiwan, still present in the Ryukyu Islands, Japan). China's amphibian diversity is greater than in any other country in the Old World, and is the fifth highest in the world. Further, China has the third highest salamander diversity in the world after the USA and Mexico. Diversity is highest in the centre and south of the country, and lowest in the north. Three of the regions with the highest diversity are Hengduan, Wuyi, and Nanling Mountains, where the faunas comprise Indomalayan and Palaearctic elements. Two other regions of high diversity are in the southern tropical regions of Xishuangbanna and Hainan. China is also important in terms of endemic species, with 198 species occurring nowhere else, putting the country in sixth position globally.

According to the results of the Global Amphibian Assessment, 98 amphibian species in China (28% of the total) are Extinct or globally threatened and 66 species (19%) are categorized as Data Deficient, most of which are likely to prove to be highly threatened. Threatened species are concentrated mostly in the central and southern parts of the country, Hainan Island being the place with the highest concentration of threatened species. Unfortunately, the current protected area network in China (Xie 2003) does not provide adequate coverage for Chinese amphibians (Rodrigues *et al.* 2004). Most of the large nature reserves are in areas with few or no amphibians (especially in the north and west of the country), while many of the most important sites in the central and southern parts of the country are not properly protected. With the exception of the Chinese Giant Salamander *Andrias davidianus* (CR) (and see Essay 4.7), very few nature reserves have been established for amphibians in China and managed appropriately, and those that do exist are usually protected only at the county level.

The eight Critically Endangered species are of very high conservation priority, and occur in scattered locations across central and southern China. Seven of these species (two salamanders: *Echinotriton chinhaiensis* and *Hynobius amjiensis*; and five frogs: *Oreolalax liangbeiensis, Rana chevronta, R. minima, R. wuchuanensis* and *Scutiger maculatus*) have very small distributions, and these can readily be protected in a small number of reserves. Of these, *E. chinhaiensis*, *O. liangbeiensis*, *R. minima* and *R. wuchuanensis* are not present in any nature reserve, and their sites need urgent protection if they are to be saved from extinction. Unlike the other Critically Endangered species, the Chinese Giant Salamander still occurs very widely, but is now extremely rare throughout its range and has disappeared from many areas (Zhang *et al.* 2002; Wang *et al.* 2004). Some other very threatened species that are very high priorities for conservation attention in China, but that also occur in other countries, include *Leptolalax ventripunctatus*, *Rana psaltes* and *Ranodon sibiricus*.

Salamanders (with 59% of species threatened or Extinct) are much more threatened than frogs (24%), and 63% of the salamander species are used in some way by humans. At the family level widely divergent patterns are seen. Over 60% of the threatened species occur in the two largest families, Ranidae and Megophryidae, both of which also have high percentages of threatened species (26% and 34%, respectively). However, several smaller families show a higher propensity to become seriously threatened, especially Bombinatoridae (60% of species threatened), Cryptobranchidae (100%), Hynobiidae (74%) and Salamandridae (40%).

In China, most conservation is implemented at the provincial level. It is, therefore, important to indicate the relative importance of the different provinces for amphibian conservation. Sichuan has easily the largest number of seriously threatened species, followed by Yunnan, and other provinces in central and southern parts of the country are also important. However, the percentage of threatened species shows a somewhat different pattern, with the Provinces of Qinghai, Sichuan, Ningxia and Taiwan scoring the highest, followed by Hainan, Guizhou, Shaanxi, Shanxi and Henan. Sichuan scores more highly in terms of both numbers and percentages of threatened species, reflecting its high level of endemism, with many severely threatened species with very restricted ranges.

Over 80% of the threatened species are associated with forests, and over 80% occur in or around flowing water, usually streams. Streamside species appear to be particularly at risk, and in China these species are threatened by alien invasive species, pollution, dams, over-harvesting, siltation, and general habitat degradation. Forest species are especially threatened because they tend not to be very adaptable, and timber harvests in China have increased 18-fold in the past 50 years, while the area of natural forest has declined by 30% (Li and Wilcove 2005).

Habitat loss is by far the most pervasive threat, affecting 94% of threatened species, compared with utilization (34%) and pollution (23%). However, when utilization is operational, it often drives species to threatened status more rapidly than is the case with the other threats. A total of 78 species of amphibian in China is negatively impacted by utilization (Table 1), of which 16 are *rapidly declining* (as defined by Stuart *et al.* 2004), out of a total of 22 *rapidly declining* species in China. More significantly, utilization is a major factor in 28 out of a total of 34 *category deteriorations* in China (*category deteriorations* are

Family	Number of species adversely impacted by utilization	Number of *rapidly declining* species threatened by utilization	Number of *category deteriorations* for utilized species
Bombinatoridae	2	0	0
Bufonidae	4	0	0
Hylidae	2	0	0
Megophryidae	8	0	0
Microhylidae	0	0	0
Ranidae	33	12	21
Rhacophoridae	3	0	0
Cryptobranchidae	1	1	3
Hynobiidae	12	1	2
Salamandridae	13	2	2
Ichthyophiidae	0	0	0
Grand Total	**78***	**16**	**28**

Table 1. *The impact of utilization on China's amphibians. Rapidly declining species are those that have deteriorated in Red List category since 1980. One category deterioration is a movement of a species by one Red List category since 1980. For example, a movement of one species from Least Concern to Near Threatened is one category deterioration. A movement of two species from Least Concern to Near Threatened is two category deteriorations. A movement of one species from Near Threatened to Critically Endangered (as is the case with* Andrias davidianus*) is three category deteriorations.*

** If the disputed area with India is included, 84 species in China are adversely impacted by utilization.*

defined in the footnote to Table 1). In short, although utilization impacts many fewer species than habitat loss, it is the major threat driving species into rapid decline in China. Ranid species in particular are threatened by over-harvesting for food, most notably the genus *Paa*, which has seven *rapidly declining* species (accounting for 14 *category deteriorations*), all as a result of utilization. *Paa* are large, economically valuable frogs, and according to Ye *et al.* (1993), 75% of the species in China are used as human food at the sub-national or national level. The Chinese Giant Salamander is probably the species that has declined most seriously as a result of over-harvesting.

Xie *et al.* (2007) have provided the basic outline of a conservation strategy for China's amphibians. The key elements are: 1) conservation of important sites and habitats for amphibians; 2) managing for sustainable harvests; 3) scientific research (on taxonomy, threatening processes, and basic species biology); 4) planning for chytridiomycosis (not yet recorded from China); and 5) rationalizing governmental responsibility for amphibians (at present, responsibility for frogs falls under the State Forestry Administration, whereas that for salamanders is under the Ministry of Agriculture, thus making a coherent approach to amphibian conservation difficult). It is now a high priority for China to develop and implement a nationwide strategy to save its remarkable amphibian fauna.

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[1] Since the completion of data collection for the analysis in this book, eleven new amphibian species have been described from China, making a total of 357 species in the country. However, if the disputed area controlled by India is included, then there are 365 species in China, rising to 376 with the new species descriptions. Note that for the purposes of this essay, Taiwan, Province of China, is included, although statistics for this island are presented separately elsewhere in the book.

ESSAY 10.3. THE STATUS AND DISTRIBUTION OF AMPHIBIANS IN THE MEDITERRANEAN BASIN

The Mediterranean Basin, Eurasia and Africa lies at the meeting point of two major landmasses. During the mid-Tertiary, a collision between these two continental plates – the northward moving African-Arabian continent and the stationary Eurasian plate – produced an unusual geographical and topographical diversity, with high mountain ranges (more than 4,500m in elevation), peninsulas, and one of the largest island archipelagos in the world, with almost 5,000 islands and islets. Biogeographically, the Mediterranean Basin is usually taken as that portion of land around the Mediterranean Sea that has a Mediterranean climate, but for the purposes of this essay we take a relatively loose definition of the Mediterranean Basin, combining a geographic focus on states with a pragmatic cut-off point to the north and west in Europe and Turkey, and in the Sahara Desert to the south. Despite this broader definition, the region is still characterized first and foremost by its climate, where mild wet winters alternate with long hot dry summers. In some parts of the Mediterranean (such as the coastal areas of Libya and Egypt), annual rainfall can be as low as 50mm per year, whereas in the wetter regions, such as the Adriatic coast of the Balkan countries, annual rainfall can exceed 1,000mm.

As with other Mediterranean-type landscapes across the world, including for instance the Cape Fynbos region of South Africa and south-western Australia, the defining characteristic of the region, at least in terms of biodiversity, is the richness of plant species. The flora of the Mediterranean Basin is estimated to include around 25,000 species of vascular plants, 13,000 of which are endemic (Médail and Myers 2004). This remarkable floristic diversity, combined with a concomitant high level of threat, has led to the region being designated as a global biodiversity hotspot. However, as with other Mediterranean-climate regions, diversity and endemism among vertebrates are much lower than that for plants, particularly for birds and mammals. The mammal fauna is largely derived from Eurasian and African elements (even the North African mammal fauna has closer affinities with tropical Africa than with the Mediterranean Basin), whereas the avifauna is dominated by Eurasian elements. Diversity among vertebrates is highest among reptiles, with approximately 355 species present in the region, of which 170 are endemic (Cox *et al.* 2006).

Amphibian diversity in the Mediterranean Basin is much lower than reptile diversity, this being largely a reflection of the extent to which arid and semi-arid habitats predominate within the region. However, at 64%, regional endemism among the Mediterranean amphibian species is relatively very high. The family Discoglossidae (painted frogs and midwife toads) is almost endemic to the Mediterranean region, and two of the three species of Pelodytidae (parsley frogs) are fully endemic. All four members of the Pelobatidae (Eurasian spadefoots) occur in the region, two of them being wholly restricted to the Mediterranean. Among the newts and salamanders, 49% of the world's 70 Salamandridae species occur in the region, with five endemic genera (*Chioglossa*, *Euproctus*, *Lyciasalamandra*, *Pleurodeles* and *Salamandrina*[1]). The region is also noteworthy for its seven endemic cave salamander species of the genus *Speleomantes* (family Plethodontidae). Until the recent discovery of a species in Korea (Min *et al.* 2005), these were thought to be the only Old World members of a family that has around 350 species in the Americas. The single Old World member of the Proteidae, the Olm *Proteus anguinus*, is found only in a small part of north-eastern Italy and otherwise Slovenia, Croatia and a few localities in Bosnia-Herzegovina; the other five members of the family occur in eastern North America.

The richness of amphibian species in the Mediterranean basin is highest in Europe (Figure 1), especially in areas of higher rainfall. Diversity is much lower in the eastern and southern parts of the region. Amphibians clearly avoid arid areas, and are absent from most of the arid Sahara. According to the results of the Global Amphibian Assessment, 25.5% of the Mediterranean amphibian species are considered to be threatened, with 1% Critically Endangered, 12% Endangered and 12% Vulnerable. The most notable concentration of threatened species is Sardinia (Italy), with four threatened species present on this island (Figure 2). One species is listed as Extinct, the painted frog from Israel, *Discoglossus nigriventer*. Recent surveys conducted in Lebanon following reports that the species may survive in the Aammiq marsh in south-east Lebanon unfortunately failed to find any individuals of this species (Tron 2005).

The human population of the Mediterranean-rim countries currently is around 400 million people, with most people concentrated along the coast. A steady historical and continuing migration towards coastal areas, and specifically in the south and east of the Mediterranean, has resulted in growing pressure on the coastal environment and, more importantly, on its biodiversity. After several millennia of human impact, most of the region's deciduous forests have been converted to agricultural lands, evergreen woodlands, and maquis, many wetlands have been lost through drainage and diversion often to irrigate crops, and increasing aridity combined with unsustainable farming and range management practices have led to continuing desertification and land degradation in many areas. Interestingly, amphibian families that have a higher percentage of threatened species are also those considered to be more primitive phylogenetically, and coincidentally those that have large tadpoles making them more dependent on the temporal availability of water, as well as on the presence of available resources in this water to grow to reach maturity.

More recently, tourism has had a serious impact on the environment, particularly in western and southern Turkey, and in Cyprus, Tunisia, and Morocco, as well as the Mediterranean islands of the Balearics (Spain), Sardinia and Sicily (Italy), and the Cyclades Archipelago and Crete (Greece). Not surprisingly, then, habitat loss and degradation, mainly due to agriculture and infrastructure development, has had the largest impact on the region's amphibian fauna, currently affecting 19 of the 27 threatened species. However, pollution also has been a major threat, followed by invasive alien species (e.g., Ficetola *et al.* 2007) not to mention predation by domestic and commensal mammal species. Finally, there is also the risk that the fungal amphibian disease chytridiomycosis could become a more serious threat to amphibians in the Mediterranean basin in the future. Chytridiomycosis was first recorded in the Mediterranean Basin in Spain in 1997, and has since been implicated in declines of the Mediterranean populations of the common midwife toad *Alytes obstetricans* (Bosch *et al.* 2001) as well as the fire salamander *Salamandra salamandra* and common toad *Bufo bufo* (Bosch and Martínez-Solano 2006). If this fungal disease starts to become as pathogenic to Mediterranean amphibians as it has done to species elsewhere in the world, then it could rapidly become a much more serious threat in the region. In particular, other species of midwife toad (i.e., *Alytes cisternasii, A. dickhilleni, A. maurus* and *A. muletensis*) may be susceptible to the disease. If this is the case, species infected with the disease, and especially those with small insular ranges, could quickly move into a higher category of threat.

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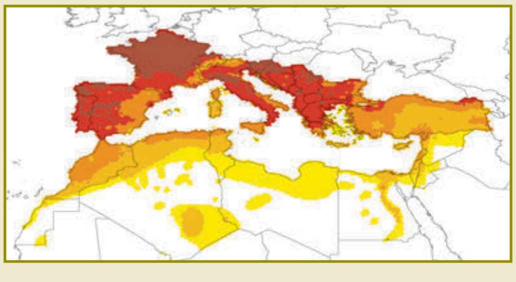

Figure 1. *Richness map of all amphibians in the Mediterranean basin, with dark red colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes. Maximum richness equals 18 species.*

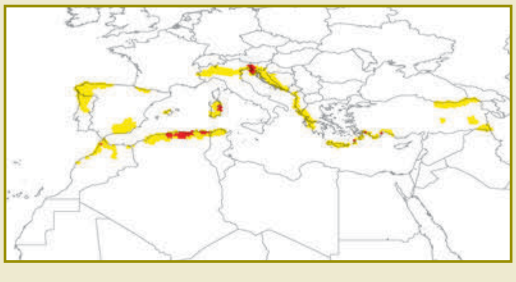

Figure 2. *Richness map of all threatened amphibians in the Mediterranean basin, with dark red colours corresponding to regions of higher richness. Colour scale based on five quantile classes. Maximum richness equals 3 species.*

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[1] At the time of writing, the genus *Calotriton*, represented by two species, had been removed from the synonymy of *Euproctus* (Carranza and Amat 2006).

CHAPTER 11. AMPHIBIAN CONSERVATION – RESPONDING TO THE GLOBAL DECLINE OF AMPHIBIANS

Michael Hoffmann, Don Church, James P. Collins, Neil Cox, Claude Gascon, Joseph H. Mendelson III, Robin D. Moore, Simon N. Stuart and Kevin C. Zippel

> *Modern amphibians have been on this planet for well over 100 million years; they are survivors, and their decline is puzzling. Scientific study of amphibians holds promise for a deeper understanding of the resilience as well as the limits of environments. This is an era of increased concern about issues in biodiversity and its maintenance in the face of environmental changes that many believe arise directly from human activities. Amphibians may serve usefully as bioindicators, organisms that convey information on the state of health of environments. How to read the message, and what to do about it, are timely challenges to scientists and to the public.* David Wake, 1991

A foray through the scientific literature of the late 1980s and early 1990s reveals a sense of alarm, and controversy, about amphibian population declines (e.g., Barinaga 1990; Blaustein and Wake 1990; Pechmann *et al.* 1991; Pechmann and Wilbur 1994). Reports of decreasing amphibian populations, particularly in seemingly undisturbed environments, made it clear that the cause was not just habitat loss (Pounds and Crump 1994). Care was also called for in reporting declines, because many observations may reflect only short-term natural fluctuations (Pechmann *et al.* 1991; Pechmann and Wilbur 1994). The issue was nonetheless of sufficient concern that IUCN's Species Survival Commission established a Declining Amphibian Populations Task Force (DAPTF) in 1991, to determine the reality, nature, extent and causes of declines of amphibians throughout the world (Heyer and Murphy 2005; and see Essay 11.1).

A little over a decade later, controversy has given way to the widely held conclusion that the world's amphibians are indeed declining and a resulting plea for a unified front to save them (Mendelson *et al.* 2006; Gascon *et al.* 2007). Much of the evidence presented both in the preceding pages and those that follow indicates that global amphibian declines are not only real, but driven by agents familiar and understood (habitat loss, commercial use, exotic species) as well as novel and insidious (disease, climate change, toxins, and the synergistic effects thereof). The remaining controversy is how best to arrest an extinction episode that is already in progress.

In September of 2005, less than a year after the initial release of the results of the Global Amphibian Assessment, more than 80 of the world's leading herpetologists and conservationists convened at a three-day Amphibian Conservation Summit in Washington, D.C., to write a consolidated action plan to halt further global losses of amphibian populations. The assumption was that it is irresponsible to document amphibian declines and extinctions without also designing and promoting an appropriate response. The resulting Amphibian Conservation Action Plan (ACAP; see Gascon *et al.* 2007) outlines the need for four types of intervention to conserve amphibians: 1) Expanded understanding of the causes of declines and extinctions; 2) Ongoing documentation of amphibian diversity, and how it is changing; 3) Development and implementation of long-term conservation programmes; and 4) Emergency responses to immediate crises (see Appendix VI). An initial five-year budget to implement this Action Plan requires at least US$400 million.

Given the existence of a consensus conservation framework among those present at the Amphibian Conservation Summit, this chapter is not a new vision for conservation action. Nor is it a detailed review of amphibian conservation efforts, a topic covered in detail elsewhere (e.g., Semlitsch 2003, Heatwole and Wilkinson in press). Rather, this chapter is intended to summarize the key action items of the ACAP, measured against our knowledge of threats to amphibians – and biodiversity more broadly – accompanied by conservation recommendations for immediate uptake by governments, corporations, civil society, biodiversity conservation organizations, and the scientific community.

Colostethus ruthveni *(Critically Endangered) is one of seven species of Critically Endangered or Endangered amphibians that are known to be confined entirely to the Sierra Nevada de Santa Marta massif in northern Colombia. The area is partly protected by the Parque Nacional Sierra Nevada de Santa Marta and the recently proclaimed El Dorado Nature Reserve. © Fundación ProAves / www.proaves.org*

THE CORE RESPONSE: DESIGNING AND IMPLEMENTING AN IMPROVED PROTECTED AREAS NETWORK FOR AMPHIBIANS

In the preceding pages, we have already established that for nine out of every 10 amphibian species classified as threatened, habitat loss and degradation is a major threat. In such cases, area- or site-based action, which usually takes the form of the establishing protected areas, is the most effective conservation response for safeguarding biodiversity in the long term (Bruner *et al.* 2001). The Programme of Work on Protected Areas of the Convention on Biological Diversity (CBD) states that protected areas are "…essential components in national and global biodiversity conservation strategies." However, habitat protection is not necessarily sufficient to ensure long-term viability in the face of threats such as emerging infectious disease (Lips *et al.* 2006) or climate change (Pounds *et al.* 2006), and often needs to be complemented by other actions, such as environmental education and targeted *ex-situ* interventions (see later), as well as by actions at the landscape scale that aim to respond to threats operating at a broader scale (Boyd *et al.* 2008).

Unfortunately, although protected areas cover 11.5% of the world's land surface, the existing network of protected areas is incomplete and does not adequately capture global biodiversity. Indeed, assessments conducted at differing scales (e.g., Rodrigues *et al.* 2004a; Rondinini *et al.* 2005), consistently reveal large gaps in the network, this being particularly evident in the tropics (Brooks *et al.* 2004), leaving many threatened species unprotected. According to the Global Amphibian Assessment, around 40% of all threatened amphibians are not represented in any protected area. An evaluation of the protection afforded to threatened amphibians through the current protected areas network suggests that amphibians are markedly less well covered than other taxa (mammals, threatened birds, and turtles and tortoises; Rodrigues *et al.* 2004a,b; Essay 11.2). Many of the amphibians that do not occur within a protected area are also found only at a single site thereby increasing the risk of extinction above that of generally more widespread bird and mammal species (Ricketts *et al.* 2005). Furthermore, protected areas vary in legal status and management type, resulting in variable levels of effectiveness, and enforcing area protection and related laws is often logistically difficult in many countries.

The last two decades saw an explosion of literature on the subject of systematic conservation planning, a field of conservation biology that aims to identify comprehensive networks of sites or protected areas that together will contribute to the overall goal of minimizing biodiversity loss (Pressey *et al.* 1993; Margules and Pressey 2000). This is necessary because, as is evident from Chapter 4, neither biodiversity nor threats to it are distributed evenly, with the result that investments must be made in some places with greater urgency than others. The significant advances made in the field of systematic conservation planning (Kirkpatrick 1983; Margules and Pressey 2000) have seen the science move beyond theory to on-the-ground application (e.g., Cowling *et al.* 2003; BirdLife International 2004).

Strategic decision-making of this order requires information on both the spatial and temporal options available for inclusion in the conservation planning framework. These two variables are commonly referred to as irreplaceability and vulnerability, respectively, in the conservation planning literature (Pressey and Taffs 2001). Irreplaceability estimates the degree to which spatial options available for conservation of unique biodiversity features are lost if a particular site is lost. At its most extreme, for example, a site with the entire population of a species is wholly irreplaceable – there are no other sites available (i.e., spatial options) for conserving the species (Pressey *et al.* 1994). Vulnerability is a measure of our temporal options available. Just as threatened species are more likely to be lost before non-threatened species, our options for conserving those sites facing high levels of vulnerability or threat are more limited in time, with places of higher threat likely to lose their biodiversity value sooner (Rodrigues *et al.* 2004b). Vulnerability and irreplaceability interact in complex ways to define conservation priorities. For example, sites of simultaneously high threat and high irreplaceability are the highest-order priorities as they correspond to places where the loss of unique biodiversity is imminent. By contrast, conservation in low irreplaceability regions can afford to be opportunity-driven, as there are plenty of spatial options.

Based on these two concepts, Rodrigues *et al.* (2004b) expanded their earlier analysis and provided a first-ever attempt at a global framework for the next step of strategically expanding the global protected area network to ensure appropriate coverage of mammals, amphibians, freshwater turtles and tortoises, and globally threatened birds. They identified several urgent priorities for expanding the network (Figure 1), which fall overwhelmingly in the tropics, especially in tropical and subtropical moist forests. Not surprisingly, the results of this study, in terms of geography, show remarkable congruence with areas already known to represent consensus priorities for reactive conservation action (Brooks *et al.* 2006).

However, just as any broad-based global priority setting exercise (see Brooks *et al.* 2006 for review of these) is useful for guiding the allocation of resources on a broad scale, the regions identified as urgent priorities for the expansion of the global network by Rodrigues *et al.* (2004b) are not useful for determining the location of the boundaries of new protected areas. Consequently, given the coarse scale of their analysis, the key recommendation from their study is that the highlighted areas become urgent priorities for finer-scale assessments to identify manageable units of global conservation significance.

The Amphibian Conservation Action Plan adopted the Key Biodiversity Areas approach (KBAs; Eken *et al.* 2004; Langhammer *et al.* 2007) as a tool for identifying globally important sites for amphibian conservation. Key Biodiversity Areas, which hinge on the concepts of threat and irreplaceability, build on nearly a quarter century of work by BirdLife International in relying on a set of criteria for identifying globally significant sites for bird conservation (Important Bird Areas; see, for example, Fishpool and Evans 2001), but extend this concept to create a taxon-neutral umbrella to incorporate all taxa (see Essay 11.3). The focus of KBAs is on species most vulnerable to extinction: globally threatened species and geographically

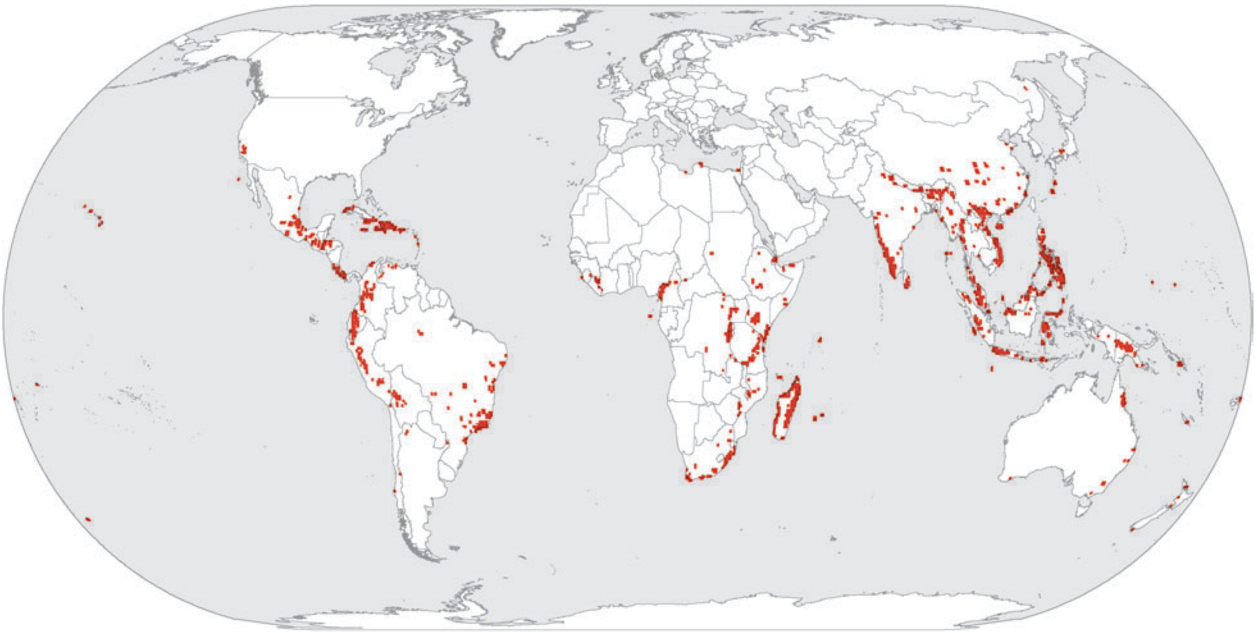

Figure 1. *Global distribution of priority sites for the expansion of the global protected-area network, based on data for all mammals, amphibians, turtles, and threatened birds. Adapted from Rodrigues* et al. *(2004b).*

concentrated species. KBA identification for amphibians is already advanced in several regions of the world, thanks to data collated through the Global Amphibian Assessment (Langhammer *et al.* 2007), and will provide a ready basis for directing valuable conservation resources to sites of known global biodiversity importance.

However, while all KBAs represent global priorities for site-scale conservation, there will be a subset of sites where conservation action is most urgent. The Amphibian Conservation Action Plan itself calls for the identification and safeguarding of the 120 KBAs where unique amphibian biodiversity is most at risk. Fortunately, there has already been considerable effort aimed at locating such places through the work of the Alliance for Zero Extinction[1], a joint initiative of more than 65 biodiversity conservation organizations around the world that aims to prevent imminent extinctions by pinpointing and safeguarding sites that represent the last refuges of highly threatened species. Such sites, termed Alliance for Zero Extinction (or AZE) sites, are discrete areas containing ~95% or more of the global population of one or more species listed as Critically Endangered or Endangered on the IUCN Red List (Ricketts *et al.* 2005)[2]. The Alliance has identified 546 sites holding 758 Critically Endangered (CR) or Endangered (EN) species of amphibians, reptiles (crocodiles, iguanas, and turtles and tortoises), mammals, birds, and conifers. At least half of these sites (263) have been identified for 381 amphibians (Figure 2). Of the sites identified so far, 125 have no formal protection and 27 only partial protection[3], yet again emphasizing that a large proportion of the world's most threatened biodiversity is not adequately represented in protected areas.

All AZE sites/species are important and top priorities in the sense that they represent known places where conservation action is needed now. However, establishing protected areas may not be the most appropriate response in all cases, but will depend on the nature of the threat. Indeed, in the context of site-scale conservation, one set of immediate priorities will be sites for which the overwhelming threat driving species declines is loss or degradation of natural habitat and for which the most obvious conservation action involves habitat protection, maintenance, or restoration. This will be particularly urgent for sites with no formal protection, or at least only partial protection. For example, the Massif de la Hotte in Haiti is the only known site for 13 Critically Endangered or Endangered amphibians, and the overwhelming threat at this site is habitat loss and degradation. Even though part of the site is protected as the Parc Natural Macaya, there is little active protection of the area and habitat loss continues even within park boundaries. Such sites (i.e., those where site-based threat and habitat loss are high) are priorities for safeguarding, and indeed several, such as the Parque Nacional Sierra Nevada de Santa Marta in the Colombian Andes, have benefited from collaborative efforts to safeguard remaining habitat[4]. At the time of going to press, efforts were underway to transform a priority cloud forest site in Sri Lanka, Morningside[5], into a Biodiversity Reserve managed by the Forest Department of Sri Lanka in collaboration with local civil society organizations.

Establishing protected areas is not normally a simple process. There are usually many competing demands for using particular parcels of land, whatever their size. For a protected area to be long-lasting, the interests of multiple stakeholders must be considered. A number of possibilities exist for building support from local stakeholders for protected areas, including: a) enabling local communities to benefit from nature reserves (such as allowing sustainable harvest of relevant products, and demonstrating the benefits of securing water catchments); b) providing local employment (for example in ecotourism, and in reserve protection, management and monitoring; and c) developing alternative livelihoods in the vicinity of reserves that enable people to enhance their standards of living in ways that are compatible with securing a sustainable future for the reserve in question. Most of the new protected areas that need to be established to conserve amphibians are in mountainous areas of the humid tropics, where both human population densities and poverty levels tend to be high. The success of these plans to establish new protected areas depends on forging alliances with development assistance agencies and community-based organizations to achieve the twin goals of biodiversity conservation and sustainable economic development. Further, establishment of protected areas is not the only way to secure areas for biodiversity, and other means that complement protected areas, including land purchase, land ownership/stewardship, and land concessions and negotiations with private landowners, may be options.

Establishing protected areas that remain resilient to the increasing threat of climate variability is another major challenge. Climate change, driven by human activity forces species to track preferred habitat conditions, but this movement may be difficult or impossible in fragmented landscapes. Further, the rate and magnitude of current climate change is such that many species may be unable to disperse quickly enough. For instance, species that inhabit high-elevation montane regions often have nowhere to disperse to as temperatures rise and other climatic conditions change. Thus, protecting species where they currently exist is only the beginning – protection is needed where species will be in the future, as well as connections in the landscape between the two. Biologists are now able to create computer models of species' range shifts that can be used to plan corridors, comprising additional parks, or multiple-use areas such as forest reserves, to limit the damage of climate change. Landscape conservation of this sort requires a large percentage of remaining natural habitats to be successful. Proactive investment in these areas will help prevent accelerating extinctions in the near future due to the 'double whammy' of climate change in a fragmented landscape. For example, numerous threatened frog species in Sri Lanka are hanging on within small fragments of the country's 5% of remaining rainforest. These species may already be affected by decreasing precipitation and warmer temperatures – conditions that increasingly wring small forest fragments dry. In these cases, restored forests around existing patches will provide water retentive buffers locally, as well as corridors to forest remnants that respond differently to a changing climate.

It is necessary to emphasize that while there is little doubt that habitat protection must remain the cornerstone of any conservation action, the ecological requirements of some species means that conservation action is required at scales larger than that of protected areas. Among mammals and birds, for example, this is particularly the case for area-demanding species that have very low population densities or are migratory. Further, the nature of many threats to biodiversity is such that habitat protection alone, or other site-based interventions, is not necessarily sufficient to preserve the integrity of the broad-scale ecological and evolutionary processes necessary to ensure the persistence of species within individual sites (Lens *et al.* 2002).

A recent study provides a unique perspective on the appropriate scale for conservation action for threatened amphibians, using data collated to support IUCN Red List assessments. Boyd *et al.* (2008) found that while most species can be conserved through individual sites, or networks of sites, more than one-fifth (21%, or 353 species) of globally threatened amphibians cannot be conserved at the site scale alone in the medium-term (cf. 13% for mammals and 19% for birds). For amphibians, this is entirely due to alterations in hydrological processes, such as changes in flow regimes (including various aspects of seasonality and flow rate), which is deemed necessary for 115 species, and water quality (e.g., temperature, pH, and sediment loads), which is considered an issue for 278 species (Boyd *et al.* 2008) (Appendix VIIa and VIIb)[6].

Several initiatives and organizations are incorporating broad-scale ecological processes into conservation planning (e.g., Pressey *et al.* 2003). However, the task remains challenging due to problems with setting priorities for ecological processes, and developing targets for their conservation (Boyd *et al.* 2008). Encouragingly, the recovery plans for several threatened species, including the California Red-legged frog *Rana aurora*[7], Corroboree Frog *Pseudophryne corroboree*[8] and stream-dwelling rainforest frogs of the Wet Tropics region in North-east Queensland[9] incorporate components relating specifically to the development and implementation of guidelines for maintaining adequate water flow regimes. For example, the recovery plan for the California Red-legged Frog, the only species in the United States for which a recovery plan has been developed, includes allocating water budgets to county planners and water districts, particularly those in the San Simeon Creek and Santa Rosa Creek in San Luis Obispo County, and managing dams and reservoirs that affect populations of the species. Another example is the recovery efforts for the Kihansi Spray Toad *Nectophrynoides asperginis*, which included the construction of a gravity-fed artificial spray system to create a fine spray in an attempt to maintain the spray-zone microhabitat in the Kihansi Gorge, following the construction of a dam upstream on the Kihansi River (Lee *et al.* 2006; Krajick *et al.* 2006).

EX-SITU MANAGEMENT AND REINTRODUCTION PROGRAMMES

While immediate habitat protection must be considered an emergency measure for several amphibians (see above), even with timely and effective protection from direct anthropogenic threats, such as habitat destruction and over-collection, there are some species for which we cannot readily safeguard wild populations from uncontrollable indirect threats, such as climate change, and direct threats, such as emerging infectious diseases. Reference is often made to the Golden Toad *Bufo periglenes* as the model case of an amphibian that disappeared in pristine and well-protected habitat (Pounds and Crump 1994), but in the current era it is one of many species that have declined under similar circumstances. In cases involving threats of such a nature, conservation action *in situ* must be complemented by immediate interventions that may be invasive, but unavoidable.

Indeed, with the realization that in the absence of any clear understanding on how to combat the spread of the chytrid pathogen, the current lack of any management technique to prevent wild populations succumbing to the disease, and no real understanding on the

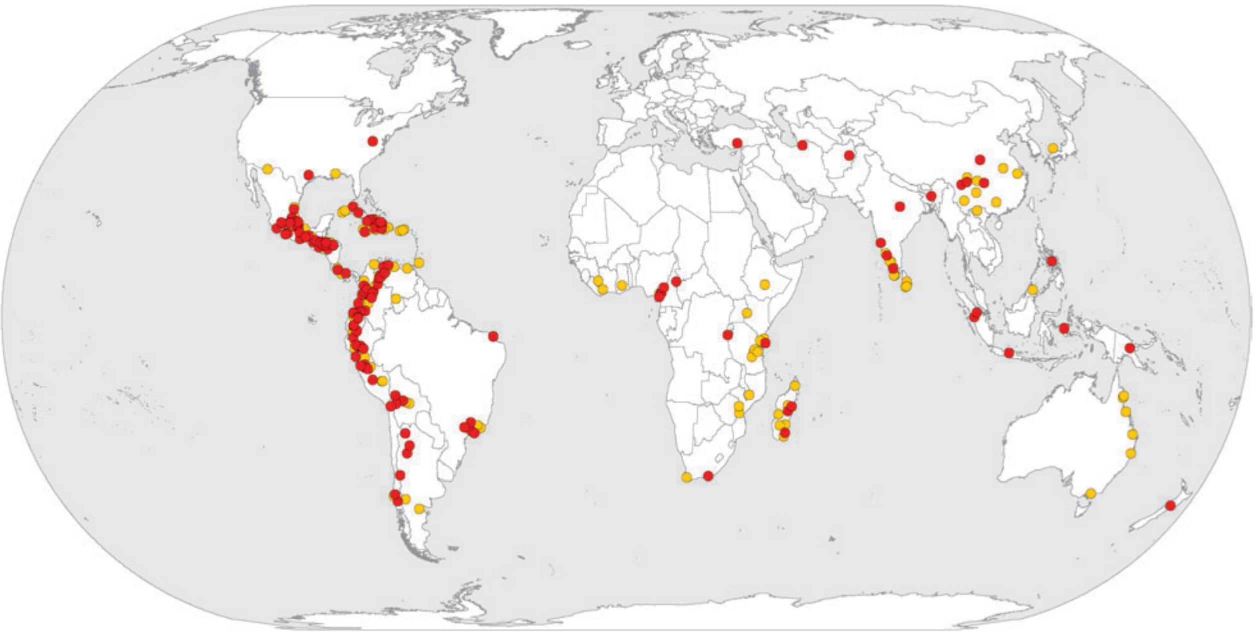

Figure 2. *Map of Alliance for Zero Extinction sites (n=263) triggered by the presence of a Critically Endangered or Endangered amphibian (381 species). Yellow sites are either fully or partially contained within declared protected areas (n=122), and red sites are completely unprotected or have unknown protection status (n=141). In areas of overlap, unprotected (red) sites are mapped above protected (green) sites to highlight the more urgent conservation priorities. Modified from Ricketts* et al. *(2005); AZE data version 2.1.*

disease's origins or mechanisms of spread, one strategy is establishing emergency *ex-situ* survival-assurance colonies where infected animals can be treated[10], and as yet unaffected but susceptible species may be safeguarded. Indeed, this may well be one of the most important roles for the *ex-situ* conservation community at this time, as through extensive field research and predictive modelling, we can, in some cases, anticipate when and where certain species will be impacted (see Essay 11.4; and Essay 9.7), thereby creating a narrow window of opportunity for proactive intervention.

Ex-situ survival-assurance colonies may provide the only option for the eventual return of some species or populations to safeguarded natural habitat. Now, more than ever, there is a need for the *ex-situ* conservation community to play an active role in averting species extinctions, not just in terms of providing the much-needed facilities and husbandry expertise, but in supporting disease-related research, education and conservation efforts on the ground. *Ex-situ* programmes cannot replace *in-situ* conservation activities, but they have the potential to provide the means for species survival while complementary research and conservation programmes proceed. The role of *ex-situ* management as a conservation measure is controversial for several reasons: 1) gaps in our knowledge of the biology and breeding behaviour of most species; 2) the removal of individuals with potentially higher fitness from populations perhaps already severely decimated; 3) uncertainty regarding the number of individuals required to maintain a viable population; 4) absence of resources for long-term maintenance of captive populations; 5) the low success rates of several previous *ex-situ* conservation efforts (see later); 6) the number of species for which such survival-assurance colonies may be needed, and 7) the degree to which such efforts may avert or misdirect funding from active conservation on the ground.

Various authors have discussed the candidacy of amphibians for *ex-situ* management programmes (Wiese and Hutchins 1994; Bloxam and Tonge 1995) and the role of *ex-situ* management in amphibian conservation has been detailed in several works (e.g., Zippel 2005; Griffiths and Kuzmin 2006; Mendelson and Rabb 2006). The valuable role of *ex-situ* management, particularly as part of a coordinated recovery programme (see Essay 11.5) has been recognized as a useful conservation tool by IUCN, which states that it should be initiated "*…to help support the conservation of a threatened taxon, its genetic diversity, and its habitat*", while noting that "*Ex situ programmes should give added value to other complementary programmes for conservation.*"[11] Consequently, just as others have made previous calls for *ex-situ* conservation action as part of a broader set of conservation priorities in declining amphibian communities (e.g., Young *et al.* 2001), the Amphibian Conservation Action Plan has incorporated *ex-situ* management as an explicit component of the overall strategy, with the proviso that dedicated infrastructure of staff members and facilities will require long-term commitments of reliable financial support.

The Massif de la Hotte in Haiti is home to the last remaining populations of 13 Critically Endangered and Endangered amphibians, more than any other single AZE site. © Robin D. Moore

However, in the face of estimates that the global *ex-situ* conservation community can currently manage viable populations of only approximately 50 amphibian species (see Essay 11.5), we need a reference point for assessing the magnitude of task. In Appendix VIII, we list 247 species for which *ex-situ* survival-assurance colonies are proposed as an urgent conservation measure to ensure the persistence of species in the face of the threat of chytridiomycosis (either because the chytrid fungus has already been documented in the species, or because the species has undergone declines and chytridiomycosis is deemed likely to be the cause[12]). Mapping the distributions of these species (Figure 3), we see that most of the species for which this is deemed necessary are concentrated in the Neotropics, mainly due to the susceptibility of montane, stream-dwelling species in the genera *Atelopus*, *Craugastor*, *Telmatobius*, and *Colostethus* to chytridiomycosis, although there are also concentrations in the Eastern Arc Mountains and in Australia.

An important caveat is that these figures exclude species flagged as Critically Endangered (Possibly Extinct), since such species represent the most urgent priorities for immediate survey work to determine whether they persist in the wild (see later). In such cases, any surviving individuals may need to form the basis for the establishment of an *ex-situ* survival-assurance colony, although this depends on the nature of any threat to the species. In addition, there are other cases where *ex-situ* survival-assurance colonies are needed because of the impact of invasive species (for example, Cape Platanna *Xenopus gilli*, EN), or to mitigate against severe overexploitation (e.g., several *Ambystoma* species), or because habitat loss has been so severe that *ex-situ* management is deemed necessary pending the initiation of habitat restoration efforts (for example, Puerto Rican Toad *Bufo lemur*). Such a list of priority species is not complete, but serves as a useful starting point for the global conservation community to initiate targeted management programmes.

While we draw attention to the need for any *ex-situ* management programme to adhere to the best available husbandry techniques, we also stress several important considerations. First, while funding opportunities are more likely to be available for such programmes in developed countries, there is often reluctance on behalf of developing countries to surrender their biodiversity to foreign institutions. This reaction is based on historical and commercial/trade precedents[14]. One solution involves transferring technology and capacity to developing nations by means of establishing *ex-situ* management facilities with sustainable funding sources, and backed by appropriate guidance in husbandry techniques for the species in question. One example of such a programme in development (it is neither complete in construction nor does it have sustainable funding), is the El Valle Amphibian Conservation Center (EVACC) at the El Nispero Zoo in Panama, an effort spear-headed by the Houston Zoo in collaboration with several zoo and non-governmental organizations. This project aims to serve as a biological repository for threatened Panamanian amphibian species and to use these populations as a possible source for reintroductions, but has a second objective which is to foster appreciation and raise awareness of amphibians among the public, through programs of education and research. Indeed, half of the allotted 220-m² space at EVACC is dedicated to public exhibits and the rest to behind-the-scenes space for managing survival-assurance populations and research projects. It had been hoped that EVACC would be operational before the arrival of chytrid in the region, but in April 2006 the first amphibian deaths due to chytridiomycosis were reported from frogs inhabiting waters of the Rio de Jesús (collected a few months before). Consequently, the emergency collection of amphibians was initiated in advance of the facility being completely constructed, and a temporary quarantine and treatment area was established in a nearby hotel. As of end July 2006, collecting teams of 50 volunteers representing 26 institutions had collected 10 of the 12 priority species[15]. The goal is for current project leaders to leave the programmes and turn over responsibility for conservation initiatives to Panamanian colleagues.

Another possibility involves negotiating ownership rights such that source countries may retain ownership over frogs and their genetic material sent to foreign zoos to form the basis for *ex-situ* survival-assurance colonies. This has already been achieved for the Kihansi Spray Toad *Nectophrynoides asperginis*, which is being bred in the Toledo and Bronx Zoos. These toads are being managed under an agreement with the Government of Tanzania, which retains ownership of the animals (see Lee *et al.* 2006; Krajick 2006).

Second, any *ex-situ* programme must be accompanied by appropriate actions directed at the long-term conservation of the species *in situ*. This could include, but may not be limited to, habitat protection, public education and awareness, research (e.g., breeding biology), population monitoring, targeted species-specific actions (such as control of invasives), and so forth.

Since the over-riding conservation role for *ex-situ* management programmes is the eventual reintroduction/translocation of species back into the wild, it is worth noting that

Figure 3. *The global distribution of Critically Endangered and Endangered amphibians (n=247) requiring ex-situ intervention (in combination with complementary in-situ and research-based actions).[13] No fewer than 59 of these species have their entire distributions confined to single sites (i.e., AZE species; see Figure 2).*

achieving the first has usually proved much easier than the latter, with much consequent debate surrounding the value of these techniques (Dodd and Seigel 1991; Seigel and Dodd 2002; Trenham and Marsh 2002; Dodd 2005). Indeed, even considering conservation success stories, such as the Mallorcan Midwife Toad *Alytes muletensis* (see Essay 11.6), a number of long-running projects have yet to demonstrate similar success, even in developed countries such as the United States. For example, Wyoming Toads *Bufo baxteri*, now Extinct in the Wild, have been part of an active breeding programme since 1993 and yet despite repeated introductions of toadlets and tadpoles to Mortenson Lake, the population is still not self-sustaining (Dreitz 2006; and see Essay 11.7). The causes for the failure of successful reintroduction are not always clear, although disease and other factors are often implicated. In any case, there are several examples of species that would be extinct at this time if they had not been included in captive programmes (such as the Wyoming Toad). In such cases, extinction has been deferred, giving researchers time to solve the *in-situ* problems.

Fortunately, other long-running conservation breeding programmes are finally showing some signs of success, such as that for the Puerto Rican Toad *Bufo lemur*. This species was believed extinct until its rediscovery in 1967, when a small breeding population of toads was found in north-west Puerto Rico (near Quebradillas) and subsequently in the Guanica Forest Preserve in the south-west of the island. No toads have been seen at the north-western site since 1992, and the Guanica Forest Preserve has become the last locality known to hold a wild population of this species. An *ex-situ* programme for the Puerto Rican Toad began in 1980 at the Mayaguez Zoo, with offspring from this programme later sent to zoos in North America, including Buffalo Zoo in New York and the Toronto Zoo in Canada. A Species Survival Plan (SSP)[16] was formed in 1983, with the goal of assisting the recovery of this species. To date, the Puerto Rican Crested Toad SSP programme includes some 23 zoos and aquaria; its efforts include education and habitat restoration, and the SSP members are supporting high school students who look for toads and study ponds in the northern part of Puerto Rico and have a special biology club with the toad as their logo. The SSP members (the zoos and aquaria in the SSP, along with Puerto Rican partners, including teachers, students, the Guanica Forest Manager, the Puerto Rican DNR and USFWS) construct new ponds for toads; install gates and signs to protect the breeding beach; print conservation booklets, bumper stickers and decals for students and interpretive centres; work with the local Juan Rivero Zoo in Mayaguez to help in their conservation programmes for Puerto Rican wildlife, including the toad; and support research on toad habitats and diseases by Puerto Rican graduate students and veterinarians. In zoos, the toads are managed genetically to ensure a diverse assurance population in the event of the unexpected loss of the small Guanica population. Tadpoles produced in the *ex-situ* programme have been sent back to Puerto Rico for release into the wild, and two artificial release ponds have been constructed to receive the tadpoles. Releases began in 1983 with 75 toadlets, and about 100,000 tadpoles have been released over the last 10 years. Eventually, in 2003, the first adult toads released as tadpoles returned to breed in the constructed ponds, evidence of the first signs of success (Zippel 2005).

While it is not possible to identify here a specific unbiased set of species for which reintroduction may be an appropriate conservation tool, it is essential that species are carefully appraised for their suitability for reintroduction, as they should also be appraised for their suitability for captive breeding, and in accordance with the IUCN/SSC Guidelines for Reintroductions[17]. Priorities for reintroduction clearly should focus on globally threatened species, and since the most successful animal reintroductions have usually involved those species that have reversible threats (Griffith *et al.* 1989; Wilson and Stanley Price 1994), it may well be necessary to give preference to those species for which actions are already underway to mitigate threats such as direct persecution, pollution, and introductions of fish or other predators. Reintroducing Axolotls *Ambystoma mexicanum* to Lake Xochimilco, for example, is complicated by the fact that existing threats need to be neutralized and potential disease and genetic risks addressed before animals from *ex-situ* populations are reintroduced into the wild (and see Essay 11.8).

This also seems the most appropriate place to mention the occasional need for translocation of threatened species to new sites as a result of impending habitat loss. An example is *Chirixalus romeri*, an endemic to Hong Kong that lost part of it natural habitat when the new Hong Kong International Airport was constructed. With funding from the Hong Kong Jockey Club, the University of Hong Kong undertook a study of the ecology and population genetics of this species to identify suitable sites for relocation of this threatened population. More than 200 individuals were rescued from Chek Lap Kok in 1992 before full-scale construction took place. A collaborative partnership was also formed with Melbourne Zoo to breed this species *ex-situ*, which was successful and over 2,800 frogs and tadpoles were released into eight sites in Hong Kong Island and the New Territories where they have been monitored every year. Breeding populations have established in seven of them.

Finally, *ex-situ* rearing of animals can also form part of an important conservation strategy aimed at promoting reasonable and sustainable use of wildlife, although only if the supply from farmed animals is such that it replaces that from the wild (see Essay 11.9). In Mexico, for example, despite the wide availability of Axolotls produced in *ex-situ* populations, wild animals are still captured and sold illegally in local markets (McKay 2003; and see Essay 2.3), while in China, even the existence of more than 100 apparently legal Chinese Giant Salamander farms to supply the ever-growing food market is insufficient to meet market demands (Essay 4.7). Furthermore, an important complication of some of these commercial enterprises is that they often farm non-native species, such as the American Bullfrog *Rana catesbeiana*, which escape and become invasive (see Essay 4.8). This could have serious implications for conservation, because the rearing of bullfrogs is a growing industry in parts of the world such as China and South America, particularly Brazil, Uruguay, and Argentina, and this species may carry chytridiomycosis (see Mazzoni *et al.* 2003).

Nonetheless, sustainable community-operated farms and commercial breeding farms can have benefits, but it is recommended that they use local species instead of exotic ones to reduce the risk of disease spread and establishment of exotic species. It is also necessary to monitor commercial breeding farms for highly valuable species to prevent wild-caught individuals from entering into the trade. Finally, a percentage of the profits generated from such breeding farms should be channelled back to amphibian conservation whenever possible (Carpenter *et al.* 2007).

In conclusion, while there is disagreement about the interplay between *in-situ* and *ex-situ* conservation action, it is preferable not to have one undermining the other. In practice, if we are to prevent amphibian extinctions, there can be no doubt of the importance of stemming rampant environmental degradation (Pounds *et al.* 2006). Other amphibian-specific conservation actions, such as those *ex-situ*, should continue, but their effectiveness will likely be reduced or compromised in the face of growing environmental deterioration. Yet, the two are compatible, complementary actions, insofar as their relative contributions and limitations are understood, accepted, and explicitly stated: *ex-situ* action is vital for a finite set of highly threatened species (but clearly not urgent for all), yet requires parallel *in-situ* efforts. Our ability to respond depends largely on the priorities of the global *ex-situ* conservation community.

TARGETED *IN-SITU* ACTIONS

Habitat protection and the establishment of *ex-situ* survival-assurance colonies represent the two most urgent *in-situ* and *ex-situ* conservation actions required, respectively, if we are to have any immediate impact on amphibian declines globally. But, as already discussed above, even though they complement one another, they will not suffice on their own. Indeed, even Ricketts *et al.* (2005) note that in the case of sites identified using their methodology to pinpoint species having their last remaining populations confined to single sites, measures

The El Valle Amphibian Conservation Center (EVACC) at the El Nispero Zoo in Panama is an effort spear-headed by the Houston Zoo in collaboration with several zoo and non-governmental organizations. Half of the allotted 220-m² space at EVACC is dedicated to public exhibits and the rest to behind-the-scenes space for managing survival-assurance populations and research projects. © Sara Riger

A mascot, highlighting the unique characteristics of the endemic Puerto Rican Crested Toad Bufo lemur *(Critically Endangered), contributes to island-wide conservation programmes at schools, fiestas, and zoo education and outreach events. © Toronto Zoo*

of habitat protection will need to be complemented by other actions, such as the control of invasive alien predators/competitors or disease.

Invasive species

The Amphibian Conservation Action Plan does not deal specifically with the issue of the impact of invasive species, which could have detrimental effects on populations as competitors, predators, and interbreeding to create hybrids. Studies show that alien predators, particularly introduced fish species (e.g., Trout *Oncorhynchus* spp., *Salmo* spp., centrarchids like bass and sunfish, and Mosquitofish *Gambusia* spp.), American Bullfrogs, and crayfish (*Procambrus clarkia*) have contributed to amphibian population declines (see Kats and Ferrer 2003). Some of these studies documented declines among amphibian communities within protected areas (e.g., Knapp and Matthews 2000). Although introduced predators may be ubiquitous in watersheds within the range of the threatened species, areas of high concentrations should be identified and the numbers of non-native predators reduced, particularly within protected areas. For example, the recovery plan for the California Red-legged Frog *Rana aurora draytonii* identifies a number of sites as areas that may benefit from non-native predator removal, including Yosemite National Park.[18]

While the most important conservation measure is prevention by means of more effective quarantine measures and enforced legislation (see Policy below), more aggressive action invariably is required for combating alien predators (e.g., Knapp and Matthews 1998)[19]. Control and removal of invasive predators is not always feasible or possible in those cases, where, for example, these species have commercial or recreational value (e.g., alien game fish), or where the species exhibit particular traits that characterize successful invaders (e.g. high reproductive rate), thereby making removal difficult. Control methods generally involve pond drainage, physical removal, poisoning (e.g., rotenone[20]), and eliminating breeding habitat of non-native predators. On the island of Mallorca in the Mediterranean Sea, for example, considerable effort was expended to control introduced snakes (*Natrix maura*), but these labour-intensive efforts mostly involved removing snakes by hand from breeding sites (Guicking *et al.* 2006). Although relatively large numbers of snakes were removed from breeding sites, there have been no studies to assess the effectiveness of this technique in controlling snake numbers. Most importantly, toads continue to survive and breed in these pools. One recent study found that large-scale removal of introduced non-native fish could result in at least partial reversal of the decline of Mountain Yellow-legged Frog *Rana muscosa* (CR), once a common inhabitant of the Sierra Nevada (California, USA). At three lakes where fish were removed, amphibian population densities increased significantly following removal of predaceous fish. Following these population increases, frogs dispersed to adjacent suitable (but unoccupied) sites, moving between 200 and 900m along streams or across dry land (Knapp *et al.* 2007). On the other hand, the afore-mentioned California Red-legged Frog recovery plan notes that filling in stock ponds known to have non-native species may be more cost effective and productive over the long-term than removing individuals. In Venezuela, the transportation of *Rana catesbeiana* to other regions outside of Mérida has been legally prohibited, and recommendations for its control and removal were passed (Resolution #64 of 15 July 2002). Furthermore, the national government, via its National Office for Biological Diversity, Ministry of the Environment, and the State Environmental Authority of Mérida, actively engage in collection and removal of individuals of all stages of the species (e.g., collection of eggs, use of dragnets, nets, air rifles and traps).

New studies involving age-structured population models provide interesting insights into the control and management of invasive species for the benefit of threatened amphibians. Doubledee *et al.* (2003), in discussing the impacts of American Bullfrogs on the California Red-legged Frog, assessed the effectiveness of different management strategies used to control bullfrog populations (such as shooting of adults and pond draining). Their results found that efforts taken to eradicate bullfrog populations by increasing adult mortality through shooting are likely to be ineffective in promoting coexistence, first because a large amount of effort – equivalent to a mortality of 65% or greater every two years – is required to make shooting adults beneficial for Red-legged Frog persistence, and second because such effort can create fluctuations in bullfrog population dynamics, which in turn may cause large fluctuations in the Red-legged Frog population. Their results suggest that a combination of shooting adults and draining livestock grazing ponds is the most successful bullfrog management strategy. Even low shooting efforts significantly decreased adult bullfrog densities by 80% when coupled with pond draining.

The recent emergence of *Batrachochytrium dendrobatidis*, the chytrid fungus that causes chytridiomycosis, may itself be the result of unintentional introductions of a pathogen as an invasive alien species. One suggestion is that the spread of the pathogen started with the export of the *African Clawed Frog Xenopus laevis from Africa* for use in pregnancy testing during the 1930s onwards. But more research is needed to test this hypothesis. Regardless of the origin of the chytrid fungus, however, bullfrogs carry it and so establishment of feral populations of this species in countries is one means by which the pathogen can gain access to other hosts (Weldon *et al.* 2004; and see Essay 4.8).

Diseases

To date, there have been few direct intervention efforts to prevent the spread of disease in wild populations of animals. Relatively successful examples include African Wild Dogs *Lycaon pictus* in Tanzania's Serengeti National Park for rabies (Woodroffe 2001) and Ethiopian Wolves *Canis simensis* in the Bale Mountains National Park of Ethiopia (Haydon *et al.* 2006). There is still no vaccine for chytridiomycosis, and development would, in any event, probably take many years. Furthermore, direct treatment of amphibians in the wild with anti-fungal agents is not without problems: release of anti-fungal agents in a way that would target the frog population significantly enough to deal with infections would have unknown effects on the fungal component of the ecosystem (Daszak *et al.* 2008). Therefore, population management strategies involving capture of wild individuals and *ex situ* treatment, combined with selection for resistant individuals that could ultimately form the basis of lineages that could be released back into the wild, are the only viable options at present (see earlier). It may be possible to collect animals for survival-assurance colonies by making use of predictive modelling and thereby move ahead of the planned spread of the disease, as was conducted by Project Golden Frog (PGF) (see Essay 11.5) and attempted with EVACC. Other preventative measures in the interim include the disinfection of vehicles and footwear with 10% chlorine bleach solution to reduce the risk of pathogen dispersal[21], and distributing signs to make people aware of the disease, the risk of spread, and means to sterilize potentially affected items. The best way to prevent unwanted diseases is to block their entry to a region. Australia affords an example of such a strategy. In July 2002, the Australian Government Minister for the Environment and Heritage decided that a threat abatement plan (TAP) "was a feasible, effective and efficient way to abate the infection process, and directed a nationally coordinated threat abatement plan be prepared to guide management of the impact of the amphibian chytrid fungus on Australian amphibians." A TAP was adopted in 2006 and one goal was to prevent amphibian populations or regions that are currently chytridiomycosis-free from becoming infected by blocking further spread of the amphibian chytrid within Australia.

Water quality

Earlier we discussed evidence that changes in water quality and water flow regimes are often a significant threat to amphibian species globally. Changes in water quality may include changes in sediment load as a result of upstream logging, but often are also due to the influence of environmental contaminants or pollutants (including pesticides, pharmaceuticals, and heavy metals). In much of the Neotropics, for example, lowland agricultural regions are subject to extensive agricultural spraying (e.g., Castillo *et al.* 1997). Furthermore, abiotic factors (temperature, salinity, pH, and ultraviolet-B radiation) may also pose a threat when normal values are exceeded and can, in turn, influence the toxicity of other contaminants. Most work to date has focused on the detrimental effects of contaminants on the aquatic life-stage of amphibians, although recent studies have also demonstrated that contaminants can have negative effects in the terrestrial environment (e.g., Hayes *et al.* 2002).

As already discussed, actions targeted at contending with changes in hydrological processes are already incorporated into the recovery plans of several species, and generally involve actions that may not be directed explicitly at actual sites where declines of amphibians are occurring (such as protected areas). However, there are instances in which such intervention may be required. Boone *et al.* (2007) propose that sites where amphibian declines are taking place should be evaluated for environmental contamination that may be present, either as a result of direct application or movement through air or water, based on which emergency clean-up action may be necessary. Here again, the recovery plan for the California Red-legged Frog *Rana aurora draytonii*[22] exemplifies a management plan that identifies several contaminated areas (e.g., Vandenberg Air Force Base in Santa Barbara County) where the species may be exposed to toxins, and proposes that contaminants should be removed and other measures that decrease exposure of the frog should be undertaken at these sites. In such cases, animals should be removed from the site while clean up occurs and either relocated or allowed to disperse back into ponds once water quality is improved.

Over-harvesting

Finally, species-targeted responses may be necessary to deal with the threat of over-harvesting, either for species in use for medicinal or food purposes (e.g., *Telmatobius* spp. or *Ambystoma* spp.; and see Essay 11.8) or for the pet trade (e.g., dendrobatid frogs, *Mantella* spp., salamanders, and newts of the genera *Tylototriton*, *Paramesotriton*, and *Cynops*). The collecting of animals and plants usually is not permitted within protected areas, or at least not within particular zones. However, the resources available to ensure collecting only in assigned areas and management are often inadequate, and illegal collecting often takes place even within nature reserves (as in the case of the Chinese Giant Salamander; see Wang *et al.* 2004; Essay 4.7).

In-situ sustainable harvesting has real potential as a management option providing that the biological requirements of the species concerned are understood and proper management is in place (see Essay 11.9). Determining sustainable harvest quotas is complex and demands information on the abundance, behaviour, and life-history characteristics of the species in question, as well as an understanding of a host of socio-economic factors. In a recent survey of levels of exploitation of species in the genus *Mantella* in Madagascar, Rabemananjara *et al.* (in press) note that because of the apparent high density of many populations, and their restricted and patchy distributions, these frogs may be well suited for a controlled system of sustainable harvesting. Most *Mantella* species are characterized by a rather high reproductive output, with up to 150 eggs per clutch, and the capacity to produce several clutches per season. Despite the high to very high numbers of several *Mantella* species that have been continuously exported from Madagascar over the past 15 years, most species appear not to have been directly impacted as a result of over-harvesting. Rabemananjara *et al.* (in press) visited populations of *Mantella aurantiaca* and *M. milotympanum* that local collectors claimed to have heavily exploited during past years (e.g., Vieites *et al.* 2005), and found *Mantella* to be very common at these sites. Rabemananjara *et al.* (in press) propose transferring the focus of the trade regulation more to the sites of collection that are usually in non-protected areas threatened by habitat destruction.

Even where the capture of wild specimens does not yet constitute a threat to a species, the development of *in-situ* harvesting practices could provide an incentive motivating local land owners and entire communities to protect native habitat instead of clearing it, with resultant conservation benefits. A local, sustainable, production programme for species of relatively high worth (e.g. *Mantella* frogs or dendrobatid frogs) could also have the additional benefit of playing a significant role in poverty reduction strategies in some of the poorest parts of the world. For example, the Global Environment Facility contributed financial support to a project in Peru aiming to promote sustainable cultivation of poison dart frogs of the genera *Epipedobates* and *Dendrobates*[23] for export. These frogs fetch US$40-120 in hobbyist markets in the United States, Europe and Japan. The Peru project established a business that exports the frogs to hobbyists in these countries. This business – with expected annual revenues of about US$300,000 in Year 3 – in turn provides supplemental livelihoods to more than 250 farmers, an incentive for preserving over 15,000ha of tropical forest, and the sustainable breeding methods conserve the populations of more than 60 species of frogs.[24]

THE NEED FOR POLICY-LEVEL INTERVENTION

Policy-based actions are essential for providing the institutional support, human and financial resources, and legal framework to ensure effective biodiversity conservation. Frequently, such actions occur by developing and implementing legislation at the national or sub-national levels, or through international agreements (e.g., Table 1).

Legislation is typically regarded as being directed at the protection of particular species, such as by regulating the harvesting of individuals (e.g., Convention for the Regulation of Whaling[25]), their trade (e.g., Convention on International Trade in Endangered Species of Wild Fauna and Flora; CITES[26]), or alterations in their habitat (e.g., the Ramsar Convention[27]). In the United States, for example, species listed under the United States Endangered Species Act (1973)[28] are protected from exploitation and disturbance, and their habitats are subject to legal protection. As of October 2006, more than 30 amphibian species were listed on the ESA (Table 2) – with a few additional species proposed as candidates for listing (such as Mountain Yellow-legged Frog *Rana muscosa,* CR) – including several species not native to the US[29].

Legislation can also promote habitat protection, with perhaps the most well known being the Convention Concerning the Protection of the World Cultural and Natural Heritage, better known as the World Heritage Convention (1972)[30]. Legislation also has the potential to protect habitat by regulating land use patterns at a broader scale (e.g., Brazil's Forestry Law). Finally, legislation can also regulate anthropogenic activities that are frequently the most pervasive causes of species declines (e.g., pollution generated by industry, transport leading to the introduction of invasive species, consumption of fossil fuels leading to climate change).

There are now more than 500 international treaties that concern the environment[31], and most countries have ratified key international treaties, although several remain unratified by key governments; for example, several countries in Asia and the Middle East, where significant commercial trade in species occurs, have yet to join CITES. Such international treaties give conservation agencies a stronger mandate domestically (Steiner *et al.* 2003), which is important given that most conservation action takes place at the national level. Of course, any legislation is only useful if it is adequately implemented, and such implementation is lacking in many cases.

Species-targeted legislation

In terms of international legislation specifically targeting species, the most relevant for amphibians is CITES, instituted in 1975 (and see Table 3). Effectively, CITES is an agreement between governments designed to ensure that international trade in wild animals and plants does not threaten their survival. Currently, CITES attempts to regulate the trade of some 30,000 different species around the world, both plants (25,000) and animals (5,000), whether dead or alive, whole animals, parts or products (e.g., carved ivory). Membership to the Convention is voluntary, and member countries, known as Parties, act jointly by agreeing to restrict international trade in a particular species that might be threatened with extinction.

In effect, CITES restricts and regulates trade in wildlife species. All forms of import and export are regulated by means of appendices, which have varying degrees of flexibility according to the required protection. Appendix I includes species threatened with extinction, and trade in specimens of these species is permitted only if the purpose of the import is non-commercial (e.g., scientific study). Appendix II includes species that are not necessarily threatened with extinction, but in which trade must be controlled to avoid levels of use that would be incompatible with their survival. All trade in Appendix I and Appendix II species is supposed to be on the basis of a "non-detriment finding" indicating that the trade in question will not harm the conservation status of the species. Appendix III contains species that are protected in at least one country, and which has then asked other CITES Parties for assistance in controlling the trade. At the request of any Party, a species can be included on Appendix III. The Secretariat and Parties to the Convention meet every two years to revise the Appendices, and species may be downgraded or upgraded depending on their status (for an amendment to be made, there must be a two-thirds majority of Parties present), and to debate the benefits of opening trade. For this reason, every Party to the Convention designates a Scientific Authority for advice on the benefits or detriments of trade, and as to the current status of species. Parties are also required to submit annual reports detailing exports and imports of CITES-listed species (although some countries have never submitted a single report). A Party that does not agree with a species listing may enter a reservation[32] and is then considered a non-Party with respect to the species in question, until the reservation is withdrawn.

Since its inception, CITES has proved to be a successful agreement, and remains one of the largest of its kind in the world. International bans implemented by means of the CITES Appendices have done much to slow the trade in wildlife products across borders, and it is perhaps a measure of CITES success, that since its inception, no species listed on one of its Appendices has been declared formally Extinct because of international trade. Nonetheless, several species known to be threatened by international trade are not currently listed on any CITES Appendix. According to the Global Amphibian Assessment, 47 amphibian species that are listed as threatened are adversely impacted by exploitation for the international trade; currently, only 20 of these species are listed on Appendix I or II of CITES, leaving several species as priorities for inclusion on a CITES Appendix (Table 4).

CITES has some drawbacks, largely because of which trade has been able to continue in many parts of the globe unchecked. First, as already noted, not all countries are Parties to the convention (currently, there are 169 signatories). Since membership is voluntary, any country not Party to the convention need not report to CITES, and so trade between these countries goes largely undocumented. These countries are, in effect, loopholes through which species can be illegally traded. Secondly, CITES, while legally binding, is an international body, and as such governs only international trade. The Convention does not replace domestic legislation, and its effectiveness is hamstrung by the degree to which countries implement and enforce their own domestic wildlife trade policies. In China, for example, the Chinese Giant Salamander *Andrias davidianus*, several *Tylototriton* spp. and *Hoplobatrachus rugulosa* are listed as Class II State Key Protected Animals whose collection, transport, cultivation, and sale requires permission from provincial authorities. Regardless, law enforcement is inadequate and illegal collecting is widespread (Wang *et al.* 2004). Further, while some Parties to CITES have domestic legislation with trade controls stricter than those required by the Convention, the effectiveness with which CITES is implemented varies between countries. At the time of writing, an Amphibian Identification Guide from Environment Canada containing all CITES protected species, is in the final stages of preparation. The guide is designed specifically for customs officers, to aid in the identification of protected species. It includes a colour key and a descriptive page for each species with full colour illustrations. Texts are in three languages: English, French and Spanish. Also, while CITES is intended to protect species threatened by international trade, it can sometimes hinder conservation, for example, blocking or delaying international movement of entire animals for *ex-situ* management programmes or parts thereof (material for genetic analysis).

Habitat-based legislation

Several international treaties are concerned with site or habitat protection, including the Ramsar Convention on Wetlands that has designated 1,429 Wetlands of International Importance for conservation and wise use and the World Heritage Convention that has designated 830 properties as part of its World Heritage List. However, the most powerful convention related to protected areas is the Convention on Biological Diversity (CBD)[33], signed by 150 government leaders at the 1992 Rio Earth Summit, and dedicated to: a) conserving biological diversity; b) sustainable use of its components; and c) fair and equitable sharing of the benefits arising from the use of genetic resources. The CBD is currently focused on the 2010 Biodiversity Target: to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on earth. To achieve this ambitious target, the CBD has employed a number of strategies, including the development and implementation of national biodiversity strategies and action plans (NBSAPs), thematic programmes (e.g., on forests, inland waters, mountains, etc), and cross-cutting issues (e.g., on plants, taxonomy, invasive alien species, and protected areas).

Protected areas are a central part of the CBD since the Parties themselves have consistently identified efforts to develop and maintain their national protected area systems as the central element of their strategy to implement the Convention. Since the 1960s, the IUCN World Congress in National Parks and Protected Areas has fundamentally influenced the protected areas agenda. The Congress, which meets every 10 years, provides a forum for discussion on all ecological, social, economic, political, and practical matters related to protected areas. The establishment of a 10% target for protected areas stemmed from the Fourth World Parks Congress in Caracas, Venezuela, in 1992, where it was recommended "*that protected areas cover at least 10 percent of each biome by the year 2000*" (IUCN 1993). Subsequently, the 10% target for protected areas became deeply entrenched in the thinking of many conservationists and incorporated into the national legislation of many countries for establishing protected areas. It was, and still is, generalized to apply

	National legislation	International agreements
Species	*United States Endangered Species Act* (1973): the species listed are protected from exploitation and disturbance, and their habitats are subject to legal protection.	*Convention on International Trade in Endangered Species of Wild Fauna and Flora* (CITES; 1975; global): regulates international trade of the species listed on its appendices. *The Bern Convention on the Conservation of European Wildlife and Natural Habitats* (1979; regional): ensures the conservation of European wildlife and natural habitats via cooperation between member States.
Sites and habitats	*Brazil's Forestry Law* (1965): establishes that each rural property in the Amazonian basin must preserve at least 80% of its forest cover. *Thailand's Wild Animals Reservation and Protection Act* (1960) and *National Park Act* (1961): legal basis for the creation of conservation areas or protected areas, including national parks (144 sites), wildlife sanctuaries (53 sites), forest parks (42 sites), wildlife non–hunting areas (52 sites), biosphere reserves (1 sites), World Heritage Natural sites (1 sites), watershed class 1 and conservation of mangroves.	*EC Habitats Directive (EC Council Directive on the Conservation of Natural Habitats of Wild Fauna and Flora*; 1992; regional): the natural habitat listed must be maintained at a favourable status, particularly by creating a network of protected sites (Natura 2000 network). *Ramsar Convention on Wetlands* (1975; global): provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources, in particular through the designation of sites under the Ramsar List of Wetlands of International Importance. *World Heritage Convention* (1972; global): encourages the identification, protection and preservation of cultural and natural heritage (including habitats of threatened species) around the world considered to be of outstanding value to humanity. Countries submit places for designation under the World Heritage List.
Activities	*China's Law on Environmental Impact Assessment* (2003): requires that governmental and non-governmental planning on land use, urban engineering, communication, and natural resource exploration goes through the process of an environmental impact assessment. *Australian quarantine regulations*: strict control measures aimed at preventing the introduction of pests and diseases (mainly established to protect the agricultural sector, but also human health and the native flora and fauna). *The Federal Constitution of the United States of Mexico (Constitución Federal de Los Estados Unidos Mexicanos)* Article 27: states that all natural resources are property of the nation, therefore all species of flora and fauna are protected. To use, collect, kill, transport or trade any amphibians, either living specimens or their parts, requires a collection permit, issued by the Mexican environmental authority (SEMARNAT).	*United Nations Framework Convention on Climate Change* (1994) and *Kyoto Protocol* (adopted in 1997, not yet into force; global): caps greenhouse gas emissions in participating industrialized nations from 2008 to 2012 and establishes an international market in emissions credits that will allow these nations to seek out the most cost-effective means to reduce atmospheric concentrations of greenhouse gases.

***Table 1.** Examples of national legislation and international agreements relevant to amphibian conservation, for the conservation of particular species, for the protection of sites or habitats, and for the regulation of activities that can pose threats to biodiversity. Dates correspond to when the agreement entered into force. For international agreements, there is an indication of whether their scope is global (any country can ratify it) or regional. Note: many of these laws/agreements could be listed under two or more categories (e.g., the EC Habitats Directive simultaneously provides for the protection of species and sites/habitats, and for the regulation of activities). Many national biodiversity acts, such as South Africa's Biodiversity Act of 2004, also fall in multiple categories. Adapted, with permission, from Baillie* et al. *(2004).*

Scientific Name	Where Listed	Listing Status	IUCN Category
Eleutherodactylus jasperi	entire	T	CR
Rana aurora draytonii	subspecies range clarified	T	NT
Rana chiricahuensis	entire	T	VU
Conraua goliath	entire	T	EN
Discoglossus nigriventer	entire	E	EX
Rana capito sevosa	Wherever found west of Mobile and Tombigbee Rivers in AL, MS, and LA	E	CR[1]
Rana muscosa	southern California DPS	E	CR
Atelopus varius zeteki	entire	E	CR[2]
Leiopelma hamiltoni	entire	E	EN
Eleutherodactylus cooki	entire	T	EN
Eurycea sosorum	entire	E	VU
Ambystoma californiense	U.S.A. (CA - Santa Barbara County)	E	VU
Ambystoma californiense	U.S.A. (CA - Sonoma County)	E	VU
Ambystoma californiense	Central CA DPS	T	VU
Plethodon nettingi	entire	T	NT
Andrias davidianus (=davidianus d.)	entire	E	CR
Batrachoseps aridus	entire	E	[3]
Ambystoma cingulatum	entire	T	VU
Andrias japonicus (=davidianus j.)	entire	E	NT
Phaeognathus hubrichti	entire	T	EN
Eurycea nana	entire	T	VU
Ambystoma macrodactylum croceum	entire	E	LC
Plethodon shenandoah	entire	E	VU
Ambystoma tigrinum stebbinsi	entire	E	LC
Typhlomolge rathbuni	entire	E	VU[4]
Bufo californicus (=microscaphus)	entire	E	EN
Bufo superciliaris	entire	E	LC
Bufo houstonensis	entire	E	EN
Bufo periglenes	entire	E	EX
Peltophryne lemur	entire	T	CR[5]
Bufo baxteri (=hemiophrys)	entire	E	EW
Nectophrynoides spp.	entire	E	[6]

***Table 2.** Amphibians listed on the United States Endangered Species Act as of October 2006. E = Endangered; T = Threatened. Endangered species are those in danger of extinction throughout all or a significant portion of their range; Threatened species are those that are likely to become Endangered in the foreseeable future. Note that these categories are independent of the IUCN Categories of Threat (final column), but species appearing on the US Endangered Species list are an under-representation of species known to be threatened with extinction. [1]considered a distinct species; [2]considered a distinct species; [3]considered a subspecies of* Batrachoseps major *(LC); [4]included in the genus* Eurycea*; [5]as* Bufo lemur*; [6]11 species recognized (8 threatened, 2 DD, 1 LC).*

Table 3. *Amphibians listed on CITES Appendices I and II. No amphibians are listed on Appendix III. Many of the amphibians listed are traded internationally as pets (e.g.,* Phyllobates, Dendrobates, Epipedobates, Mantella, Dyscophus antongilii, Scaphiophryne gottlebei, Ambystoma*).* Euphlyctis hexadactylus *and* Hoplobatrachus tigerinus *are in the frog-leg trade.* Andrias davidianus *is exploited for food, but is not generally in international trade. Other CITES-listed species (e.g., some of the African toad genera such as* Nectophrynoides*) have never been the subject of international trade, and so the utility of their listing is doubtful. The genus* Rheobatrachus *is Extinct, but not because of international trade.*

Appendix I	Appendix II	Appendix III
ANURA		
Bufonidae Toads		
Altiphrynoides spp.		
Atelopus zeteki		
Bufo periglenes		
Bufo superciliaris		
Nectophrynoides spp.		
Nimbaphrynoides spp.		
Spinophrynoides spp.		
Dendrobatidae Poison frogs		
	Allobates femoralis	
	Allobates zaparo	
	Dendrobates spp.	
	Epipedobates spp.	
	Phyllobates spp.	
Mantellidae Mantellas		
	Mantella spp.	
Microhylidae Red rain frog, tomato frog		
Dyscophus antongilii		
	Scaphiophryne gottlebei	
Myobatrachidae Gastric-brooding frogs		
	Rheobatrachus spp.	
Ranidae Frogs		
	Euphlyctis hexadactylus	
	Hoplobatrachus tigerinus	
CAUDATA		
Ambystomidae Axolotls		
	Ambystoma dumerilii	
	Ambystoma mexicanum	
Cryptobranchidae Giant salamanders		
Andrias spp.		

Table 4. *Species threatened by international trade according to the results of the Global Amphibian Assessment, indicating those species already listed on a CITES Appendix, and those for which legislation is required.*

Order	Family	Name	Appendix I	Appendix II	Not listed
Anura	Bufonidae	*Atelopus cruciger*			y
Anura	Bufonidae	*Atelopus zeteki*	y		
Anura	Bufonidae	*Melanophryniscus cambaraensis*			y
Anura	Dendrobatidae	*Dendrobates altobueyensis*		y	
Anura	Dendrobatidae	*Dendrobates bombetes*		y	
Anura	Dendrobatidae	*Dendrobates granuliferus*		y	
Anura	Dendrobatidae	*Dendrobates lehmanni*		y	
Anura	Dendrobatidae	*Dendrobates opisthomelas*		y	
Anura	Dendrobatidae	*Dendrobates speciosus*		y	
Anura	Dendrobatidae	*Dendrobates steyermarki*		y	
Anura	Dendrobatidae	*Dendrobates virolensis*		y	
Anura	Dendrobatidae	*Phyllobates terribilis*		y	
Anura	Hylidae	*Agalychnis annae*			y
Anura	Hylidae	*Phyllodytes auratus*			y
Anura	Leptodactylidae	*Caudiverbera caudiverbera*			y
Anura	Mantellidae	*Mantella aurantiaca*		y	
Anura	Mantellidae	*Mantella bernhardi*		y	
Anura	Mantellidae	*Mantella cowanii*		y	
Anura	Mantellidae	*Mantella crocea*		y	
Anura	Mantellidae	*Mantella expectata*		y	
Anura	Mantellidae	*Mantella madagascariensis*		y	
Anura	Mantellidae	*Mantella milotympanum*		y	
Anura	Mantellidae	*Mantella pulchra*		y	
Anura	Mantellidae	*Mantella viridis*		y	
Anura	Microhylidae	*Platypelis milloti*			y
Anura	Microhylidae	*Scaphiophryne boribory*			y
Anura	Microhylidae	*Scaphiophryne gottlebei*		y	
Anura	Microhylidae	*Scaphiophryne marmorata*			y
Anura	Ranidae	*Conraua goliath*			y
Anura	Ranidae	*Limnonectes macrodon*			y
Anura	Ranidae	*Rana shqiperica*			y
Caudata	Hynobiidae	*Hynobius tokyoensis*			y
Caudata	Hynobiidae	*Ranodon sibiricus*			y
Caudata	Plethodontidae	*Plethodon petraeus*			y
Caudata	Salamandridae	*Cynops ensicauda*			y
Caudata	Salamandridae	*Echinotriton andersoni*			y
Caudata	Salamandridae	*Lyciasalamandra antalyana*			y
Caudata	Salamandridae	*Lyciasalamandra atifi*			y
Caudata	Salamandridae	*Lyciasalamandra billae*			y
Caudata	Salamandridae	*Lyciasalamandra fazilae*			y
Caudata	Salamandridae	*Lyciasalamandra flavimembris*			y
Caudata	Salamandridae	*Lyciasalamandra luschani*			y
Caudata	Salamandridae	*Neurergus kaiseri*			y
Caudata	Salamandridae	*Neurergus microspilotus*			y
Caudata	Salamandridae	*Paramesotriton fuzhongensis*			y
Caudata	Salamandridae	*Salamandra algira*			y
Caudata	Salamandridae	*Tylototriton kweichowensis*			y

to individual countries and to the entire planet, despite its proven shortcomings (Soulé and Sanjayan 1998; Rodrigues *et al.* 2004a).

At the Fifth Congress held in South Africa in 2003, a workshop on "Building Comprehensive Protected Area Systems" demonstrated that despite substantial gains, global protected area systems are still far from comprehensive, and reiterated that percentage-based targets are not sufficient for protecting our biodiversity. Results from the Global Amphibian Assessment were key to building the case (see Essay 11.2). The Congress report to the CBD stated that "the global system of protected areas needs to safeguard all globally and nationally important areas for biodiversity", and in the Durban Accord asked the global community for a "commitment to expand and strengthen worldwide systems of protected areas, prioritized on the basis of imminent threat to biodiversity". Several countries responded immediately, with the President of Madagascar and the Governors of the Brazilian states of Amazonas and Amapá announcing at the Congress itself that they would significantly expand their protected area systems.

Building on these commitments, the Seventh Conference of the Parties (the governing body of the CBD) adopted a Programme of Work on Protected Areas (Decision VII/28[34]) with "*the objective of the establishment and maintenance by 2010 for terrestrial and by 2012 for marine areas of comprehensive, effectively managed, and ecologically representative national and regional systems of protected areas*". This Programme of Work has four elements (implementation, governance and equity, enabling activities, and monitoring) each with several goals. The first goal of the first element –"*to establish and strengthen national and regional systems of protected areas integrated into a global network as a contribution to globally agreed goals,*" bears mentioning since it requires the identification of sites of global biodiversity significance in each country to determine which sites are currently not represented in protected area systems, and sets priorities for new actions among these sites (and therefore links directly back to the need to identify sites requiring urgent habitat protection).

In 2002, the CBD adopted the Global Strategy for Plant Conservation, which includes 16 targets under five general headings: a) understanding and documenting plant diversity; b) conserving plant diversity; c) using plant diversity sustainably; d) promoting education and awareness about plant diversity; and e) building capacity for the conservation of plant diversity. In view of the amphibian crisis documented in this book, a multifaceted CBD global strategy on amphibians, building on the ACAP, should now be considered, and at the time of going to press, discussions were ongoing regarding the incorporation of a global strategy on amphibians into the CBD.

Environment Canada have produced an Amphibian Identification Guide containing all CITES listed species, specifically to aid customs officers in the identification of protected species. Image courtesy of Tamara Maliepaard.

Legislation aimed at regulation of activities

Among international legislative agreements regulating activities that can pose threats to biodiversity, arguably the most important is the United Nations Framework Convention on Climate Change[35] and the Kyoto Protocol. The UNFCCC, which entered into force in 1994, is an international treaty that sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. The Convention has near universal membership, with the ratification of 189 countries[36]. Recently, a number of nations have approved an addition to the treaty: the Kyoto Protocol[37], an international and legally binding agreement to reduce greenhouse gas emissions world wide, which came into effect on 16 February 2005. The Kyoto Protocol significantly strengthens the Convention by committing Annex I Parties to individual, legally binding targets to limit or reduce their greenhouse gas emissions. However, only Parties to the Convention that have also become Parties to the Kyoto Protocol (i.e., by ratifying, accepting, approving, or acceding to it) are bound by the Protocol's commitments. 165 countries have ratified the Protocol to date, with the most notable exceptions being the United States and Australia.

Under the Kyoto Protocol, developed countries (termed Annex 1 countries) have committed themselves to reducing their collective emissions of six key greenhouse gases by at least 5.2%, with a reduced emissions target of 2008-2012 (calculated as an average over the five years)[38]. Although these caps are national-level commitments, most countries will devolve their emissions targets to individual industrial entities. The complicating factor is that actual emission reductions will need to be much larger than 5%, because for some wealthy industrialized countries reduction targets will need to be as much as 15% lower than their expected emissions in 2008. To provide countries with the flexibility to meet their emission targets, the Kyoto Protocol has established three market-based mechanisms:

- Emissions Trading: the option to buy and sell emissions credits among developed countries. If one country exceeds its emissions target for one year, while another's falls below its targets, the first is permitted to purchase the second country's unused emission credits to meet its emission target.
- Joint Implementation: a country can receive emissions credits for a specific project undertaken in another country.
- Clean Development Mechanism: developed countries can receive emissions credit for financing projects that reduce emissions in developing countries

CO$_2$ emissions from deforestation are another type of emission that can be profitably reduced if allowed into a market. At present, avoided deforestation (AD) carbon trading is restricted to particular voluntary markets in the US. The much larger Kyoto Protocol-based European markets do not currently trade in avoided deforestation, largely due to political concerns of the past. Developing countries took the position that developed countries should take the first step toward tackling climate change. Now that a European carbon market is in place, developing countries see a financial opportunity to sell emissions reductions from AD. Credits for AD would be related only to the amount of deforestation avoided, not the total amount of forest. This would be true for either a project-level or country-level scheme. Imagine a country that has one million hectares of forest, and an annual forest loss baseline of ten thousand hectares per year[39]. If this loss is reduced to 5,000ha per year, the country would be credited for a 5,000ha/year reduction, not their entire million hectare carbon stock. A proposal to bring AD into the Kyoto Protocol was introduced in November 2005 by the Coalition for Rainforest Nations (CRN), a group of tropical developing countries led by Papua New Guinea and Costa Rica. This concept was originally proposed by Santilli *et al.* (2005) under the name "compensated reduction." The CRN proposal has been endorsed to date by the African Union, European Union, Pacific Island Forum, British Commonwealth, Association of Small Island States, and most recently, Indonesia. Several years of international negotiations will need to take place before an agreement can be finalized.

In the absence of an international treaty specifically designed to reduce greenhouse gases, the Intergovernmental Panel on Climate Change[40] estimates that global mean temperatures will rise by between 1.4°C and 5.8°C, with resulting catastrophic consequences for weather patterns, biodiversity, and sea levels. However, limiting climate change requires major changes beyond simply signing the Kyoto Protocol; it involves the evolution of a society that becomes carbon neutral on a global scale in this century (Lovejoy and Hannah 2005).

RESEARCH AS A CONSERVATION ACTION

Conservation action is more effective when supported by knowledge, not just on species themselves, but on the threats affecting species and the most effective measures needed for addressing those threats. Furthermore, research that is integrated with the implementation of conservation can allow for adaptive management of projects, thereby building on successes and learning from failures in a manner that best serves the species at risk. The results of

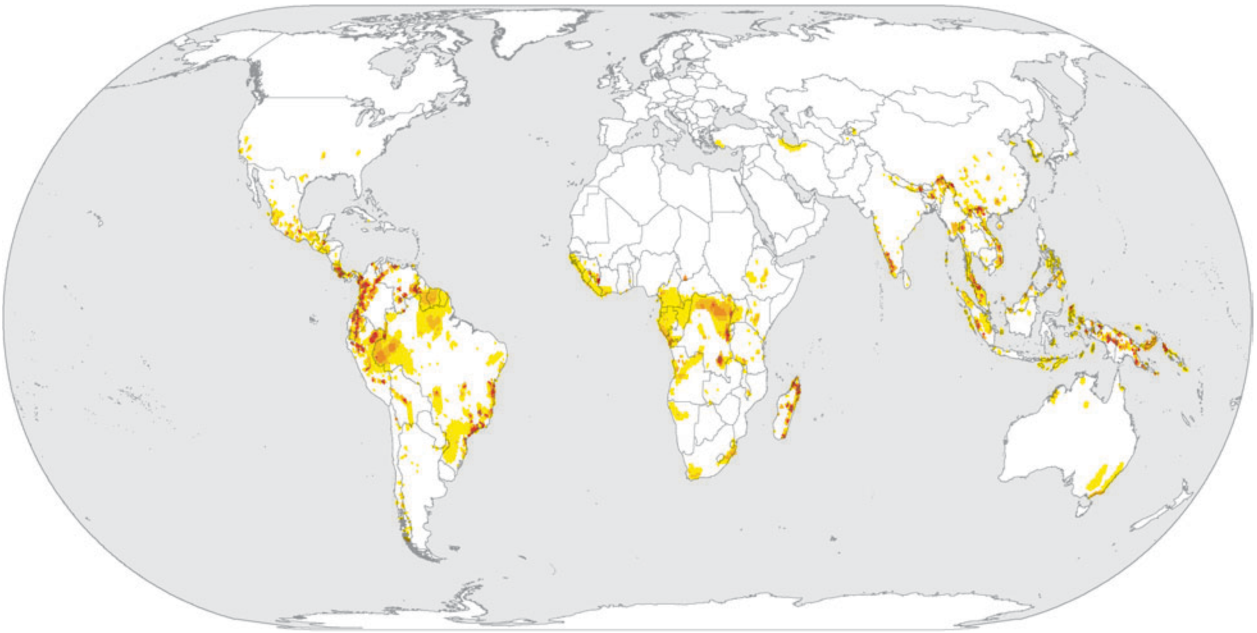

Figure 4. *Richness map of Data Deficient amphibian species, with darker reds corresponding to regions of higher richness. Colour scale based on five quantile classes. Maximum richness equals 18 species. Note: this map is only an approximation, since for most Data Deficient species the extent of occurrence is poorly known.*

the Global Amphibian Assessment provided a much-needed context for the well-publicized phenomenon of amphibian declines, but they also provide us with directions and priorities for research needs, not only on a taxon basis, but also on a thematic basis.

Among the species that emerge as priorities for research are those flagged as Data Deficient. The Red List category Data Deficient is assigned to species for which there is inadequate information available to make a direct, or indirect, assessment of its risk of extinction based on distribution or population status. As we have already seen, nearly one-quarter of all amphibians are classified as Data Deficient for one of three reasons: unknown provenance; taxonomic uncertainty; and/or inadequate data. Data Deficient species tend to be concentrated in regions with high biodiversity, but are poorly surveyed (Figure 4). There are also noticeable concentrations in regions where recent taxonomic investigations are revealing unexpected complexities in terms of species limits, such as in the Western Ghats of India (see Essay 7.2).

It is necessary to preface a discussion of research priorities and needs with a note that classification in the Data Deficient category does not imply lack of threat. Indeed, IUCN's (2006) user guidelines explicitly note "*it may be appropriate . . . to give them the same degree of attention as threatened taxa until their status can be assessed.*" The pessimistic listing of actual Data Deficient species as threatened during the Red Listing process can lead to a muddling of conservation priorities with research priorities. This stems from concerns that species listed as Data Deficient are seldom beneficiaries of conservation investment, because they are not listed as threatened (e.g. see Garnett *et al.* 2003). However, Data Deficient species should not be the immediate targets for conservation action *per se*: by definition, they are priorities for research action, be it in the form of taxonomic investigation or field-based survey work, which in turn may reveal the need to conserve these species.^{41}

Taxonomy

Although it is not yet possible to provide a reliable figure on which species are in need of further taxonomic investigation (i.e., those Data Deficient species so categorized because of taxonomic uncertainty), there are particular taxa that repeatedly emerge as in need of taxonomic work, including confused genera such as *Arthroleptis* (14 of 34 species Data Deficient), *Caecilia* (23 of 35), and *Ichthyophis* (27 of 34).

The taxonomic impediment is by no means restricted to those known species categorized as Data Deficient based on issues surrounding their actual taxonomic status. Just as species description rates continue to increase (Köhler *et al.* 2005), new studies that use complementary diagnostic characters, such as genetic sequences and acoustic features, are revealing unexpected and cryptic diversity within wide-ranging taxa, with the implication that single, widespread 'species' may actually represent multiple species having smaller geographic ranges, and, consequently, greater vulnerability to extinction (Stuart *et al.* 2006a). In the last mentioned study, the authors found that torrent frogs that have been identified to date on the basis of morphology as *Rana livida* and *Rana chalconota* represent at least 14 different species. Indeed, it is becoming increasingly apparent that morphology alone will not suffice for the purposes of biodiversity inventory work, and that new and complementary techniques are required to help identify species that warrant recognition and protection (see Essay 11.10 and Essay 11.11). In this regard, there is clearly a need to expedite the application of these techniques to known or suspected species complexes (e.g., Angulo *et al.* 2003; Fu *et al.* 2005).

The implications of such taxonomic investigations for conservation planners are as yet to be fully revealed, but may be far-reaching. It is to be expected that many Data Deficient species will really emerge as threatened species in their own right. Likewise, unravelling the complexities of current wide-ranging species complexes will likely result in a marked increase in the numbers of species currently considered threatened, and probably will see many species move from a lower category of threat to a higher category of threat. This is as a result of the influence of splitting formerly wide-ranging species on overall population size and geographic range size, which are key factors in the IUCN Red List criteria (Collar 1996). In turn, a surge in threatened species will have implications for those initiatives incorporating threatened species listings, of which the Red List is the most commonly used, into priority setting exercises. For example, studies that have investigated how the influence of differing species concepts will affect the identification of important areas for conservation have shown conflicting results (e.g., Peterson and Navarro-Sigüenza 1999; Dillon and Fjeldså 2005).

One possible side-effect of the windfall of species descriptions is that in the race to describe new species in the face of a biodiversity crisis, the publication of new descriptions of rare species might inadvertently facilitate their extinctions if the species in question turn out to have commercial value (Courchamp *et al.* 2006). Most modern species descriptions provide very detailed information on the locality and habitat where the new species occurs, turning "*. . . a scientific article into a treasure map for commercial collectors*" (Stuart *et al.* 2006b). The latter authors cite the example of the salamander *Paramesotriton laoensis* from northern Laos, which was not known in the international pet trade prior to its recent description as a new species (Stuart and Papenfuss 2002). Over the past year, Japanese and German collectors used the published description to find these salamanders, and they are now being sold to hobbyists in those countries for US$170 to US$250 each. In the face of recognition that withholding such locality information hampers conservation and science as much as it does those seeking to profit from it, Stuart *et al.* (2006b) propose that taxonomists should work closely with relevant governmental agencies to coordinate publication of the description with legislation or management plans that thwart overexploitation of the new species and that while this might lengthen publication time, alternative solutions that allow taxonomists to continue their work without contributing to species decline are wanting.

Surveys and Monitoring

Clear descriptions of species by taxonomists go hand in hand with survey work. Several large regions, such as Indonesian Papua, Indonesian Borneo, central Africa and the Albertine Rift, and parts of the Andean countries, remain very poorly surveyed, and further surveys very likely will reveal impressive levels of diversity. To cite just one recent study, Stuart *et al.* (2006c) undertook the first ever collection of amphibians in hilly eastern Cambodia since Henri Mouhout's work in 1859. Their collection comprised 30 species of amphibians, including two new species *Leptobrachium mouhoti* and *Ophryophryne synoria*, not to mention 11 new country records for Cambodia!

While such herpetological collections have great value in terms of improving knowledge on a country's national biodiversity assets, and in turn have immediate implications for national conservation strategies, there is also a need for targeted species surveys. Among those species urgently in need of survey work – indeed, representing the top priorities for field-based survey work – are species considered Critically Endangered, and flagged as Possibly Extinct (PE). This marker was designed specifically to avoid the Romeo Error (Collar 1998) – scenarios in which we might give up on a species as being extinct before it truly disappears (Butchart *et al.* 2006a). The term was first applied to the case of a bird, the Cebu Flowerpecker *Dicaeum quadricolor* from the Philippines, which was rediscovered in 1992 after 86 years without a record (Dutson *et al.* 1993), having been written off as extinct at least 40 years earlier on the presumption that no forest remained on the island of Cebu (Magsalay *et al.* 1995). Such remarkable rediscoveries are by no means unique, with several species having been rediscovered, sometimes as long as a century after their date of last record. Among amphibians, recent rediscoveries include a surviving population of *Atelopus cruciger* in Venezuela, and the rediscovery of *Atelopus nahumae* and *A. laetissimus,* both believed to have gone extinct in the Colombian Andes. On the other hand, survey work conducted in Lebanon to search for Hula Painted Frog *Discoglossus nigriventer*, a species known only from the eastern shore of Lake Huleh in Israel and last recorded in 1955, failed to record the species following tantalizing reports that it might survive in the Aammiq marsh in south-east Lebanon (although the surveys did result in a new country record for *Pelobates syriacus*) (Tron 2005).

Among those amphibians flagged here as CR(PE) (Appendix IX), one recent interesting rediscovery published at the time of writing is that of *Conraua derooi*, which has not only been rediscovered in the Togo Hills (Leaché *et al.* 2006), but has since been found outside its former range in the Atewa mountains (M.-O. Rödel, pers. comm.). Habitat loss and degradation is the major threat to this species (including increased sedimentation in breeding streams), with the result that the most immediate conservation action required is effective maintenance of natural habitat within the species' limited range.

Besides survey work, population monitoring is a required conservation action for most threatened species, especially for those where chytridiomycosis is believed to be a potential threat but has not yet resulted in population declines. Another set of species for which monitoring is important are those categorized as Vulnerable under the D2 criterion (Appendix X). These species usually have stable populations, but typically have very small distributions. As such, they are especially prone to the effects of human activities or stochastic events that could result in the species becoming Critically Endangered or even Extinct in a very short time period.

Threats

As we have already seen, while many declines are due to habitat loss and over-harvesting, other factors are also operating, some of which are rapidly driving species to extinction.

Some salamander species, such as Neurergus kaiseri *(Critically Endangered) from the southern Zagros Mountains of Iran, are increasingly threatened by the growing international pet trade, but have yet to be officially proposed for listing on a CITES appendix. © Twan Leenders*

Many of the reasons for amphibian declines have been acknowledged for decades (see Collins and Storfer 2003); others are only now beginning to be better understood (Beebee and Griffiths 2005). Stuart *et al.* (2004) coined the term "enigmatic decline species" for those species that have shown dramatic declines (see Chapter 4), even where suitable habitat remains, for reasons that are not fully explained. We now know that one of the primary reasons for these enigmatic declines is likely the emerging infectious disease chytridiomycosis (spread by its causal agent, the pathogenic fungus *Batrachochytrium dendrobatidis*) (Lips *et al.* 2006), perhaps acting in deadly synergy with other factors, particularly climate change (Pounds *et al.* 2006).

The most important research needs in terms of threats, include better understanding of the impacts of climate change, the role of environmental contaminants in declines, the spread and treatment of disease (specifically chytridiomycosis, but other emerging infectious diseases, too), and, perhaps most important of all, the context-dependency of these and other factors (Blaustein and Kiesecker 2002), particularly when compounded with land use change.

In the past decade, a great deal has been learned about the ecology, biology and impact of the chytrid pathogen (see Essay 4.5). This knowledge has included the development of advanced molecular diagnostic tests (Annis *et al.* 2004; Boyle *et al.* 2004); analysis of biochemical defences of amphibians against the pathogen (Rollins-Smith *et al.* 2002; and see Essay 2.2); and the use of ecological niche modelling to predict the spread of the disease (Ron 2005; and see Essay 11.4) and phylogenetic-based predictive models (Lips *et al.* 2006). Nonetheless, there remain several unanswered questions concerning this disease, and these offer important and urgent opportunities for targeted research (Daszak *et al.* 2007):

- Studies on the ecology of *B. dendrobatidis*, including basic and critical aspects of its natural history, such as how and where it survives, and how long it can persist in the environment. Initial studies suggest it can survive for up to 8 weeks as a saprobe, an organism that derives its nutrition from the dead remains of other organisms, in sterile pond water (Johnson and Speare 2003).
- Understanding how amphibians respond to infection. Do any amphibians become immune when first infected? We know, for example, that a number of species become susceptible again even after they have cleared an initial infection. Do amphibians respond to infection by changing behaviour, e.g., basking, to eliminate infections?
- How does the chytrid fungus spread? And is there any relationship between its spread and trade in amphibians? Despite the availability of advanced modelling techniques to predict the spread of disease, one of the highest priorities is to determine the means by which *B. dendrobatidis* moves among sites, species, and individuals over varying scales.
- Why does *B. dendrobatidis* cause declines in some amphibian populations, while others are unaffected (e.g., Retallick *et al.* 2004; Lips *et al.* 2006). Studies are needed of how immune responses, antimicrobial peptide responses (Woodhams *et al.* 2006; Harris *et al.* 2006), or the genetics of species (or populations) that appear to be tolerant of the disease (e.g., American Bullfrogs), or completely resistant to infection, differ from susceptible species.
- How does chytridiomycosis cause death? Does it affect the ability of frogs to respire or osmoregulate through their skin, or does the pathogen release toxins that ultimately cause death?
- What caused the emergence of *B. dendrobatidis*? This includes surveying museum collections (e.g., Puschendorf *et al.* 2006) and conducting molecular phylogenetic studies to determine when and where chytrid first emerged, or whether it has always been widespread and local environmental conditions cause emergence and spread (Rachowicz *et al.* 2005).
- Can lineages resistant to chytridiomycosis be selected for in captivity and reintroduced to native habitats?

Research needs on the effects of environmental contaminants on amphibians are presented by Boone *et al.* (2007), who emphasize again that there is a primary need to examine the interactive effects of either multiple contaminants or contaminants with other threats (such as disease, pathogens, climate change, and habitat alteration), to help plan mitigation measures to thwart declines. Other important directions for research into the threats posed by contaminants include:

- Improved understanding of the impact of contaminants on both aquatic and terrestrial life stages (currently, there are limited data focusing on the terrestrial life-stage or interactions between aquatic and terrestrial stages);
- Studies to investigate how contaminants affect populations over long time periods (e.g., Semlitsch *et al.* 1996), and how adaptation to a chemical stressor may influence population persistence or make individuals vulnerable to other factors (e.g. Semlitsch *et al.* 2000).
- Investigating the effects of other common pollutants on amphibians (recent studies have focused heavily on carbaryl, atrazine, and coal combustion wastes), particularly herbicides and insecticides. For example, the herbicide atrazine disrupts the endocrine system (e.g., Hayes *et al.* 2002), and herbicides can reduce the food base of the community (Diana *et al.* 2000; Boone and James 2003). Other groups of contamination resulting from industry by-products, mining activities and oil and gas prospecting leakages, as well as human and other animal waste products (pharmaceuticals, sewage by-products), also pose potential threats that require study (Brooks *et al.* 2003).
- The types of contaminants and combinations of contaminants that amphibians are exposed to in nature.

Finally, research related to climate change is needed. Recent climate change is causing some species to breed earlier (e.g., Beebee 1995; Gibbs and Breisch 2001; Corn 2003), and recent warming episodes may play some causal role in declines in some areas (Pounds *et al.* 1999, 2006). However, there remains a need for further research to understand how climate change affects amphibians, and given the loss of amphibians from pristine habitat, the possible synergies between disease dynamics and climate change.

AMPHIBIAN CONSERVATION – CODA

Amphibian declines were open to debate only 15 years ago, but increasing evidence reveals that many amphibians are undergoing cataclysmic declines, some to extinction, and that a suite of causes is responsible. How we respond, and in what way, will depend on whether the conservation community at large can focus attention on known priorities and use the tools and knowledge available to act.

Some have argued that hope is already lost, the resources do not exist, and that the best conservation scientists can do is act as scribes documenting the declines of a once diverse fauna. We contend that to do so, in the face of explicit existing conservation options, would be not unlike the fire trucks standing by while the Sistine Chapel burns. History has shown that targeted conservation efforts can help the recovery of even the most threatened species, including species that have declined to low numbers, such as the Rodrigues Fody *Foudia flavicans* (Impey *et al.* 2002), Black Robin *Petroica traverse* (Aikman *et al.* 2001), Mallorcan mid-wife toad *Alytes muletensis* (Essay 11.6), Antiguan Racer *Alsophis antiguae* (Daltry *et al.* 2001), and Black-footed Ferret *Mustela nigripes* (Dobson and Lyles 2000).

In a recent study investigating how many bird extinctions conservationists have prevented, Butchart *et al.* (2006b) used data on population sizes, population trends, threatening processes, and conservation actions, to identify at least 26 bird species surviving in the wild that would have very probably gone extinct without conservation programmes. Of course, many still require sustained conservation efforts, and a major increase in global conservation resources is necessary to extend such efforts to thousands of threatened species. Nonetheless, such case studies prove that action directed at priority species can be a path to future recovery (Rodrigues 2006).

We have demonstrated that we have the information at hand to at the very least identify which species require what type of conservation action, and which species require that action first. This, in the end, is what defines our ability to mitigate biodiversity loss – our ability to set priorities for where we should invest resources. The resources are limited, but the constraints can act as a lens that concentrates options and resources on the most urgent. We cannot expect to ensure habitat protection for the 90% of species for which habitat loss is a threat, but there are is a finite set of species for which our failure to secure the last remaining tracts of habitat *now* means, almost certainly, the loss of a country's, even the Earth's, unique biodiversity assets.

So, as we set out to put a face on the amphibian crisis in the pages that follow, we end with a challenge. A proposed action plan has been developed with many ambitious components, including some not discussed above, such as establishing national networks in priority countries to monitor trade in amphibians. These actions should form part of a unified and coordinated conservation response that must address the top priorities. To coordinate and facilitate such targeted conservation programmes for amphibians, Mendelson *et al.* (2006) called for the formation of an Amphibian Survival Alliance (ASA) – under the umbrella of the Amphibian Specialist Group (ASG) of the Species Survival Commission of IUCN (see Essay 11.12). The ASA is envisioned as a partnership-based alliance, consisting of a large and diverse set of stakeholders, and representing a global vehicle for mobilizing and coordinating stakeholders to examine, deliberate, and act on advancing the Amphibian Conservation Action Plan.

Our research designed to understand the causes and consequences of amphibian declines will require inspired thinking, and must lead to explicit practical recommendations for actions. Our actions, in turn, will need to be methodical and exacting. Our failures will need to motivate us, while our successes will need to be promoted. The hope is that, in the end, we *can* succeed in even the most difficult of cases.

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Endnotes

1 www.zeroextinction.org

2 The cornerstones of AZE site identification, as with that for KBAs, are the IUCN Red List categories assigned to taxa that trigger the identification of a site in the first place. Thus, it is crucial that the Red Listing process is rigorous, transparent, objective and repeatable, and appropriately supported by the relevant supporting documentation, given the utility and value of these in conservation planning (see also Rodrigues *et al*. 2006).

3 Protection status is not known for 16 sites.

4 In this instance, three conservation NGOs - Fundación ProAves Colombia, Conservation International, and American Bird Conservancy - joined by the IUCN/SSC Amphibian Specialist Group, teamed up to protect a 1,600-acre site (the El Dorado Nature Reserve) on the north-west slope of the Sierra Nevada de Santa Marta massif, on the Caribbean coast of Colombia. The site provides what is believed to be a critical last refuge for several highly threatened amphibian species (including *Atelopus laetissimus*, *A. nahumae*, *Colostethus ruthveni*, and *Cryptobatrachus boulengeri*) as well as for several threatened bird species (*Pyrrhura viridicata*, *Myiotheretes pernix*, and *Campylopterus phainopeplus*).

5 Morningside is a 1,000-ha area just to the east of the Sinharaja World heritage Site, and the only known site for five highly threatened amphibians: *Microhyla karunaratnei* (CR), *Polypedates fastigo* (CR), *Philautus simba* (CR), *Philautus procax* (CR), and *Philautus decoris* (EN).

6 Although disease is a major threat factor, the current priority conservation response is research and probably captive breeding. At this stage, it's not clear what conservation action can be taken at either the site or landscape scale to reduce the threat of disease.

7 http://ecos.fws.gov/docs/recovery_plans/2002/020528.pdf

8 http://www.deh.gov.au/biodiversity/threatened/publications/recovery/corroboree-frog/index.html

9 http://www.deh.gov.au/biodiversity/threatened/publications/recovery/rainforest-frogs/index.html

10 Treatment is usually via antifungal drugs (Parker *et al.* 2002) or heat (Woodhams *et al.* 2003).

11 http://www.iucn.org/themes/ssc/publications/policy/exsituen.htm

12 In some cases, it is reasonable to predict that chytrid could be the cause of such declines where a species shares particular biological traits or habitat preferences that would render it susceptible to infection.

13 We identified any CR or EN species for which a) chytrid was already identified as a known threat (i.e., known to be a major threat resulting in declines, whether in tandem with other threats such as habitat loss or not), or b) chytrid was believed very likely to be the cause of observed declines given that the species shared certain biological traits or habitat preferences (e.g., montane, stream-breeding, congeneric) with other affected species such that it was very likely to be affected by chytrid, as those species for which the establishment of ex-situ assurance colonies is absolutely necessary.

14 http://www.planeta.com/planeta/98/0598property.html

15 *Atelopus zeteki*, *Anotheca spinosa*, *Gastrotheca cornuta*, *Hemiphractus fasciatus*, *Eleutherodactylus punctariolus*, *Eleutherodactylus bufoniformis*, *Eleutherodactylus museosus*, *Hylomantis* [*Phyllomedusa*] *lemur*, *Ecnomiohyla* [*Hyla*] *fimbiimembra*, and *Hyloscirtus* [*Hyla*] *palmeri*. Two priority species *Dendrobates vicentei* and *Hyloscirtus* [*Hyla*] *colymba* are yet to be collected.

16 The Species Survival Plan programme began in 1981 as a cooperative population management and conservation program for selected species in zoos and aquariums in North America. Each SSP manages the breeding of a species in order to maintain a healthy and self-sustaining population that is both genetically diverse and demographically stable. Beyond this, SSPs participate in a variety of other cooperative conservation activities, such as research, public education, reintroduction and field projects. Currently, 107 SSPs covering 161 individual species are administered by the Association of Zoos and Aquarium, whose membership includes accredited zoos and aquariums throughout North America. Besides the Puerto Rican Toad, the only other amphibian species for which an SSP exists is the Wyoming Toad. See http://www.aza.org/ConScience/ConScienceSSPFact/ for more information.

17 http://www.iucn.org/themes/ssc/publications/policy/reinte.htm

18 http://ecos.fws.gov/docs/recovery_plans/2002/020528.pdf

19 Comprehensive reviews of options for invasive species control and prevention are provided in McNeely *et al.* (2001), Wittenberg and Cock (2001), and Veitch and Clout (2002). IUCN has also prepared a set of guidelines to help countries, conservation agencies and concerned individuals to reduce the threats posed by invasive alien species to global biodiversity (http://www.iucn.org/themes/ssc/publications/policy/invasivesEng.htm).

20 Rotenone is a piscicide that has been used to remove unwanted fish stocks from a variety of aquatic habitats, although not without negative impacts on other aquatic fauna and amphibians. The impacts of rotenone-containing piscicides on amphibians have been reviewed by Fontenot *et al.* (1994) and McCoid and Bettoli (1996).

21 www.nwhc.usgs.gov/research/amph_dc/sop_mailing.html

22 http://ecos.fws.gov/docs/recovery_plans/2002/020528.pdf

23 These species are listed on Appendix II of CITES (see later), which means that international trade in these species is permissible if sustainably managed. CITES officials have been supportive of this project because it will alleviate pressure on poison dart frog populations.

24 http://www.gefonline.org/projectDetails.cfm?projID=1485

25 http://www.iwcoffice.org/commission/convention.htm

26 www.cites.org

27 www.ramsar.org

28 http://www.fws.gov/endangered/esa.html

29 The ESA implements US participation in CITES, and these were rolled together in the legislation when the ESA was implemented in 1973 (the same year as CITES was formed). Consequently, there is a link between ESA and CITES and some species threatened by trade have also been listed. In the late 1970s, FWS had a long list of candidate species (about 200 species), including many foreign species (many of which were unrelated to CITES issues). A Fund for Animals lawsuit pushed for the listing of most or all of the candidates, and the resultant mass listing resulted in the listing of many foreign species. As such, most of the foreign listings occurred in the first decade of the ESA and there have been very few since. FWS currently has little interest in listing new foreign species. Provisions on take do not apply in foreign jurisdictions and are unenforceable. Further, FWS has a stated policy that foreign listed species are the lowest in priority among listed species, and there are no recovery plans for listed species and no funding.

30 http://whc.unesco.org/en/conventiontext/

31 www.ecolex.org

32 A Party may enter a Reservation only at the time that it joins the Convention, or within 90 days of a change being made in the listing of a species on the Appendices.

33 www.biodiv.org

34 http://www.biodiv.org/doc/publications/pa-text-en.pdf

35 http://unfccc.int/2860.php

36 Iraq, Somalia and Timor-Leste are among those yet to ratify

37 http://unfccc.int/kyoto_protocol/items/2830.php

38 Cuts in the three most important gases – carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) – will be measured against a base year of 1990. Cuts in three long-lived industrial gases – hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) – can be measured against either a 1990 or 1995 baseline.

39 To know how much deforestation has been reduced, it is necessary to know how much deforestation would occurred otherwise. This reference level is referred to as a baseline. While there are a number of ways this baseline could be selected (e.g. modeled projections, present deforestation rate), the best baseline for a variety of reasons is an average deforestation rate over a recent historical time period.

40 http://www.ipcc.ch/

41 Conversely, listing species that are known to be genuinely threatened with extinction as Data Deficient, either because assessors demand substantial evidence that a species is threatened before making such a classification, or to side-step well intentioned but misguided government policies that restrict field research on threatened species, could result in species not receiving conservation attention before it is too late (see Pimenta *et al.* 2005; Stuart *et al.* 2005 for discussion).

Several amphibians have been rediscovered after not having been seen after extended periods in the wild, including Atelopus nahumae *(Critically Endangered) which was rediscovered in March 2006 on the north-west slope of the Sierra Nevada de Santa Marta massif in Colombia. © Conservacion Internacional-Colombia*

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ESSAY 11.1. THE DECLINING AMPHIBIAN POPULATIONS TASK FORCE: A SHORT HISTORY

The global amphibian community first became aware of the amphibian decline phenomenon at the first World Congress of Herpetology in Canterbury, UK, in 1989. Conversation outside the formal sessions was dominated by anecdotal reports, from all over the world, of once-common species that had disappeared. In the following year, a workshop set up by the US National Academy of Sciences lead to the formation of the Declining Amphibian Populations Task Force (DAPTF) in 1991, under the aegis of IUCN's Species Survival Commission. From the start, the DAPTF was formerly linked to the World Congress of Herpetology (WCH).

The first DAPTF Office was established at Oregon State University, Corvallis, under the direction of James L. Vial, assisted by Lorelei Saylor. In 1994, the DAPTF Office moved to the Open University, UK, with Tim Halliday as International Director and John Baker as International Coordinator; it remained there until the closure of the DAPTF in June, 2006. During its existence, the DAPTF has had five Chairs: David B. Wake, Robert Johnson, W. Ronald Heyer, James Hanken, and James P. Collins. It has had three International Coordinators: John Baker, John Wilkinson, and Jeanne McKay.

At a meeting in 1992, the DAPTF set itself the following goals (Heyer and Murphy 2005):

1. Catalyse, catalogue and coordinate efforts to gain an understanding of amphibian population declines.
2. Identify those target populations, species and regions that merit immediate attention.
3. Gather and critically examine evidence concerning causal factors contributing to amphibian declines and identify remedial action.
4. Promote data collection on amphibian populations on a long-term basis.
5. Enlist the support of appropriate scientific disciplines needed to address the issues.
6. Disseminate information on amphibian declines to the scientific community and promote public awareness.
7. Advise the IUCN, other conservation organizations, and appropriate governmental bodies on necessary and immediate action.

An important product of the DAPTF has been its regular, free newsletter, *Froglog*. This has been used as a means by which the DAPTF Office can communicate with the herpetological community, and as a medium through which herpetologists can report the results of their work and air their views on amphibian declines. As the DAPTF has developed and grown, *Froglog* has increased in size and frequency of publication; in 1997, it went from a quarterly to bi-monthly publication. As of June 2006, 75 issues of *Froglog* had been published. Since 2004, *Froglog* has been published electronically.

The membership of the DAPTF was informal and it is impossible to say how many people around the world considered themselves to be members. The circulation of *Froglog* reached 3,000 when it was produced only in hard copy, but many of these copies went to groups rather than individuals. The membership was organized into 90 Regional Working Groups, covering specific regions (e.g., Southeast Asia), specific countries, or specific regions within countries. The work of some of these working groups contributed to the production of major regional reports on amphibians, such as those for the Lesser Antilles (Kaiser and Henderson 1994), the former Soviet Union (Kuzmin *et al.* 1995), Canada (Green 1997), Australia (Campbell 1999), southern Africa (Minter *et al.* 2004), and the USA (Lannoo 2005). From the beginning, the DAPTF recognized the importance of developing protocols for monitoring amphibian populations and for disseminating best practice in population monitoring among its members. An issue-based DAPTF working group addressed this issue and produced an important book on the subject (Heyer *et al.* 1994).

Since its inception, the DAPTF has allocated a substantial proportion of its budget to an annual programme of Seed Grants. These are small awards (typically $500 to $2000) given to support projects that further the DAPTF's mission, with the intention that they will not only yield results that further our scientific understanding of the amphibian decline phenomenon, but will also lead to recipients setting up new lines of research that will attract further, more substantial funding from conventional sources (Halliday 2002). While the greatest number of proposals has been received from the USA, the DAPTF steadily increased its global outreach year by year. Up until June 2006, proposals had been received from over 80 different countries, and the DAPTF had funded projects in 49 countries. While most projects have been for research, some Seed Grants were awarded to particular Regional Working Groups to fund workshops and meetings. In the last few years, the budget for Seed Grants was augmented by large donations from other organizations: an anonymous donor (AD), Conservation International (CI), the Critical Ecosystem Partnership Fund (CEPF), and the Amphibian and Reptile Monitoring Initiative (ARMI). These donors specified the areas in which their funding can be used: climate change (AD), specific biodiversity hotspots (CI and CEPF), and activities within the USA (ARMI).

The decline in the number of applications for DAPTF Seed Grants from 2004 onwards (Table 1) is probably a reflection of the fact that the amphibian decline phenomenon has achieved much higher status in the wider academic community since the DAPTF was established. This has enabled amphibian researchers in many parts of the world to obtain substantial grants from conventional grant-giving bodies. The changing pattern of applications for DAPTF Seed Grants reflects the DAPTF's most important achievement: it stimulated and sustained interest in amphibian declines until such time as the academic community as a whole came to recognize its full importance. The DAPTF Seed Grant program was very successful in achieving its aim of enabling researchers to initiate innovative lines of research into amphibian declines and their causes. As of June 2006, the number of papers in refereed journals that acknowledged the DAPTF as a source of funding exceeded 100.

In addition to its Seed Grant programme, the DAPTF maintained a small Rapid Response Fund, recognizing that some aspects of amphibian declines, notably mass mortality events, require more immediate action than can be provided by an annual grant program. Between 1998 and 2006, the DAPTF received 17 bids to this fund, and funded eight of them.

The development of the DAPTF coincided with the development of the internet, enormously facilitating the capacity of organizations like the DAPTF to communicate and disseminate information globally. The DAPTF launched its own web site in 2004 and is now linked to numerous web sites, such as AmphibiaWeb (www.amphibiaweb.org), which cover various aspects of amphibian biology, status and conservation. In June 2006, the DAPTF was disbanded as an independent organization, with many of its activities being incorporated into the IUCN/SSC Amphibian Specialist Group (ASG) (see Essay 11.12).

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Table 1. *DAPTF Seed Grants submitted and awarded by year.*

Year	No. Submitted	No. Awarded	Value ($$)
1992	2	1	1,000
1993	31	5	4,975
1994	1	0	0
1995	38	9	15,517
1996	3	2	3,000
1997	49	11	22,921
1998	53	15	27,550
1999	45	14	23,828
2000/1	47	21	40,283
2002	57	37	58,217
2003	63	19	32,537
2004	65	23	43,123
2005	48	14	25,450
2006	32	12	23,133
Totals	**534**	**183**	**$321,534**

ESSAY 11.2. AMPHIBIAN GLOBAL GAP ANALYSIS: EVALUATING THE EFFECTIVENESS OF THE WORLD'S PROTECTED AREAS IN REPRESENTING AMPHIBIANS

The *in-situ* conservation of viable populations in natural ecosystems is widely recognized as a fundamental requirement for the maintenance of biodiversity (e.g., Convention on Biological Diversity). Indeed, the practical value of protected areas in shielding areas of land from destructive use has been clearly demonstrated (e.g. Bruner *et al.* 2001). Protected areas have therefore received wide recognition as core components of conservation strategies, and their designation is a requirement of several multilateral environmental agreements (e.g., the Convention on Biological Diversity and the Ramsar Convention on Wetlands), as well as national and international legislation (e.g., European Union Birds and Habitats Directives).

In 1992, the Fourth Congress on National Parks and Protected Areas (Caracas, Venezuela) called for protection of at least 10% of each major biome by the Year 2000 (IUCN 1993), an ambitious target at a time when only an estimated 3% of the planet's land area was under protection. In 2003, the Fifth World Parks Congress (Durban, South Africa) witnessed the announcement that 11.5% of the Earth's land surface is now under some form of protection (Chape *et al.* 2003). Most Governments have invested in the creation of protected areas systems, with more than 100,000 being recognized by the 2003 United Nations List of Protected Areas (Chape *et al.* 2003).

This extraordinary expansion of the global network of protected areas should be celebrated as a major conservation achievement, as they are no doubt contributing very significantly for the protection of the world's biodiversity. However, this global network is still largely incomplete. A recent global gap analysis found that at least 12% of the species of birds, mammals, amphibians and turtles analysed were not covered by any protected area in any part of their ranges (Rodrigues *et al.* 2004). Amphibians had the highest proportion of gap species. Here, we update the results of this 2004 global gap analysis for amphibians, drawing on improved species and protected area data.

A precise evaluation of how effective the world's protected areas are in safeguarding amphibians is not possible with current knowledge. On the one hand, our data on species' distributions are very coarse: all we have are generalized maps of extent of occurrence that for most species are likely to include vast expanses of unsuitable habitat. On the other hand, our data on protected areas are very limited: the database is likely to be incomplete, but also likely to include many areas in which amphibian species are poorly protected, or not protected at all. It is therefore impossible to know exactly which species are adequately conserved in which protected areas. We used a diversity of approaches to obtain a range of estimate of the degree to which amphibian species are covered by the global network of protected areas.

The first three approaches employed (Table 1) investigated the spatial overlap between the amphibian distribution maps compiled through the Global Amphibian Assessment and the 2006 World Database on Protected Areas (WDPA 2006). The WDPA includes about 57,500 protected areas mapped as polygons and about 118,000 protected areas mapped as points. Amongst the latter, the 80,500 for which area information was available were converted to circles, while the remaining protected areas were simply mapped as points.

In the most simple of the gap analysis approaches (Gap 1), we looked for species whose ranges do not overlap any of the protected areas in the WDPA. This approach considers a species to be 'covered' if any part of its mapped range overlaps any protected area; otherwise, it is a 'gap species'. Given the data limitations explained above, this is very likely to be a crude overestimate of the overall species coverage. Trying to focus on protected areas more likely to effectively protect species, in our second approach (Gap 2) we narrowed down the definition of protected area to include only those classified by IUCN as 'strictly protected', that is, under categories I to VI (IUCN 1994). The third approach (Gap 3) considered only protected areas larger than 1,000 ha (thus excluding also all of those mapped as points) which are classified under categories I to IV (Table 1). The fourth and final approach (Gap 4) did not use the WDPA data. Instead, it used information provided by the Global Amphibian Assessment experts on whether or not a species was known to occur in protected areas. A species was considered covered if protected areas were considered to be a conservation measure in place, and a gap species otherwise.

The fraction of species identified as gap species varied between 14.1% and 28.8% of all amphibians, and between 19.7% and 35.1% of threatened species (Table 1). The strong bias towards threatened species is again evident from Figure 1, which also demonstrates that species of higher levels of threat (Critically Endangered) are particularly likely to be gap species. Data Deficient species are the dominant Red List category amongst gap species (Figure 1). Less-known species tend to have poorly known distributions, so many of these species may be subsequently found to occur in protected areas. However, lack of knowledge is often associated with rarity, and thus many of these species are likely to have truly small populations and to be highly threatened.

Previous studies found that levels of coverage for amphibians are substantially lower than for other vertebrate taxa (Rodrigues *et al.* 2004). This is likely a reflection of their much smaller range sizes, as widespread species tend to be covered in protected areas even if by chance alone. Other explanations include habitat preference – amphibians tend to be associated with freshwater habitats, which are not particularly well addressed by the terrestrial network of protected areas – and taxonomic bias – few protected areas were created with any consideration of amphibian distributions. By mapping the gap species found according to each approach it is possible to obtain a map of the regions where the global protected area network is most incomplete in representing amphibian species (Figure 2).

Overall, the areas identified as having higher concentrations of gap species

Gap analysis approach	All species	Threatened species
Gap 1 (All protected areas in the WDPA)	815 (14.1%)	356 (19.7%)
Gap 2 (IUCN categories I to IV)	1,390 (24.0%)	599 (33.1%)
Gap 3 (IUCN categories I to IV AND >1,000 ha)	1,473 (25.4%)	635 (35.1%)
Gap 4 (GAA experts)	1,669 (28.8%)	618 (34.1%)
Total number of species	**5,794**	**1,810**

Table 1. *Number and percentage of gap species under each approach, for all species and for threatened species. The total number of species refers to those for which distribution maps were compiled in the Global Amphibian Assessment (i.e., it excludes 124 species of unknown distributions).*

fall overwhelmingly in the tropics, especially in tropical and subtropical moist forests. They are also disproportionately located on islands, and on regions of high topographic complexity (tropical mountains). In the Western Hemisphere, the highest concentrations of gap species are found in the tropical Andes and in the Sierra Madre mountains in Central America. The Atlantic Forest and the Caribbean are also highlighted. Although the Guayana Shield and the Amazon are noted centres of endemism (see Chapter 4), the general lack of gaps there reflects their extensive networks of protected areas and the relatively wide ranges of most of their species.

For Africa, gap species tend to concentrate almost exclusively in the mountains, including the Cameroonian highlands, the Eastern Arc Mountains, the Albertine rift, the Ethiopian Highlands, and eastern Madagascar. Most gap species found in these regions of high endemism (see Chapter 4) have very restricted ranges. Concentrations of gap species in Somalia, on the other hand, reflect this region's extremely poor protected area coverage.

In Asia, the main concentrations of gap species are found in the Western Ghats and Sri Lanka, but also in Himalayan slopes, southern China, and Japan, particularly the Nansei-Shoto (or Ryukyu) Islands. Further east, New Guinea and the Solomon Islands emerge as major priorities for the establishment of new protected areas. All of these are areas of very high endemism for amphibians (see Chapter 4).

Nearly all of the regions identified here as having major gaps in protected area coverage of amphibian species are located in low-income countries in the tropics – those that can least afford the costs of establishing and enforcing protected areas (James *et al.* 1999). This is the case even if the significant local benefits of protected areas are factored in (Balmford *et al.* 2003), because much of the benefit of the establishment of protected areas is realized at a global scale (Kremen *et al.* 2000). Thus, our recommendation for the rapid establishment of protected areas in these regions goes hand-in-hand with a recommendation that the costs of this conservation are largely borne by the global community. Donor country governments, through bilateral and multilateral institutions, as well as NGOs, foundations, and private corporations and individuals all have an important role to play in financing conservation (Balmford and Whitten 2003).

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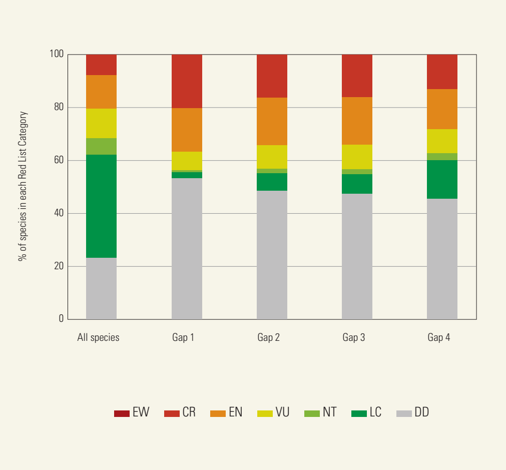

Figure 1. *Distribution of Red List categories amongst all species of amphibians and amongst those identified as gap species. Red List categories: CR – Critically Endangered; EN – Endangered; VU – Vulnerable; NT – Near Threatened; LC – Least Concern; DD – Data Deficient; EW – Extinct in the Wild.*

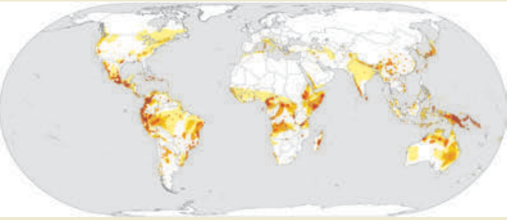

Figure 2. *Number of amphibian gap species per equal-area (3,113km^2) hexagon, averaged across the results of the four approaches to gap analysis employed. Darker cells have, on average, a larger number of gap species; colour scale based on seven quantile classes.*

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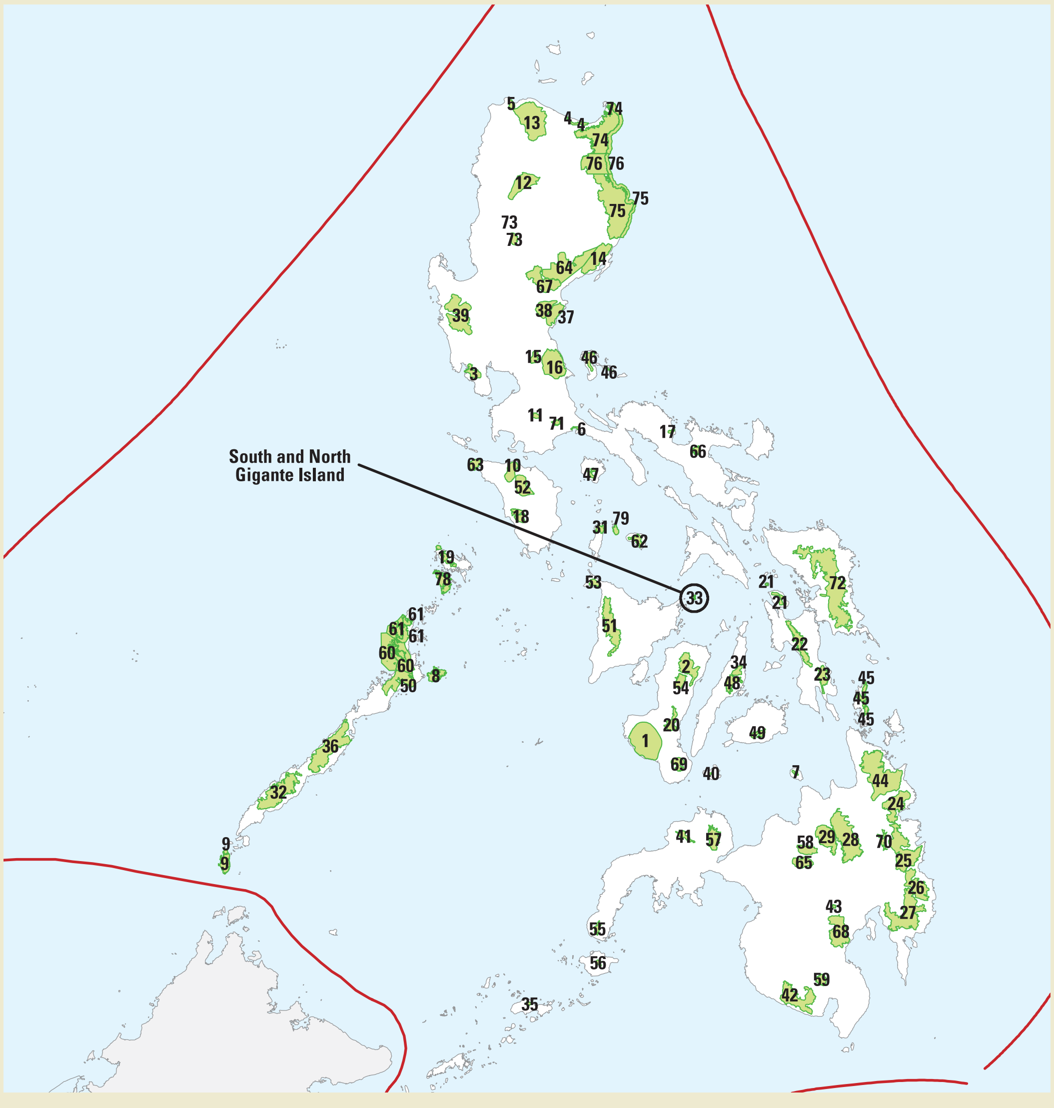
ESSAY 11.3. IDENTIFYING AND SAFEGUARDING KEY BIODIVERSITY AREAS FOR AMPHIBIAN CONSERVATION

The overwhelming threat to biodiversity worldwide is the loss of native habitat (Baillie *et al.* 2004). Nearly 90% of globally threatened amphibians are being negatively impacted by habitat loss. Thus, conserving habitat is critical for the survival of amphibian species. One of the most effective means of targeting habitat conservation efforts is through the identification of globally significant sites for biodiversity conservation, termed Key Biodiversity Areas (KBAs; Eken *et al.* 2004).

KBAs are identified using a set of globally standard criteria and thresholds derived from those developed by BirdLife International for the identification of Important Bird Areas (IBAs; e.g., Fishpool and Evans 2001). The KBA criteria align with the two principal measures of systematic conservation

Figure 1. *Key Biodiversity Areas identified for amphibian species in the Philippines, indicating the single Alliance for Zero Extinction site (South Gigante Island. Numbers on the map correspond as follows: 1 - Southwestern Negros; 2 - Northern Negros Natural Park; 3 - Bataan Natural Park and Subic Bay Forest Reserve; 4 - Buguey Wetlands; 5 - Kalbario-Patapat National Park; 6 - Pagbilao and Tayabas Bay; 7 - Timpoong and Hibok-hibok Natural Monument; 8 - Dumaran-Araceli; 9 - Balabac Island; 10 - Puerto Galera; 11 - Mt. Makiling Forest Reserve; 12 - Balbalasang-Balbalan National Park; 13 - Apayao Lowland Forest; 14 - North Central Sierra Madre Mountains; 15 - Angat Watershed Forest Reserve; 16 - Mts. Irid-Angilo and Binuang; 17 - Mt. Kulasi; 18 - Malpalon; 19 - Busuanga Island; 20 - Ban-ban; 21 - Biliran and Maripipi Island; 22 - Anonang-Lobi Range; 23 - Mt. Nacolod; 24 - Mt. Diwata Range; 25 - Bislig; 26 - Mt. Agtuuganon and Mt. Pasian; 27 - Mt. Kampalili-Puting Bato; 28 - Mt. Kaluayan-Mt. Kinabalian Complex; 29 - Mt. Tago Range; 30 - Siburan; 31 - Balogo Watershed; 32 - Mt. Mantalingajan; 33 - South and North Gigante Island; 34 - Mt. Capayas; 35 - Mt. Dajo National Park; 36 - Victoria and Anepahan Ranges; 37 - Mt. Dingalan; 38 - Aurora Memorial National Park; 39 - Zambales Mountains; 40 - Mt. Bandila-an; 41 - Mt. Dapiak-Mt. Paraya; 42 - Mt. Busa-Kiamba; 43 - Mt. Sinaka; 44 - Mt. Hilong-hilong; 45 - Mt. Kambinlio and Mt. Redondo; 46 - Polillo Island; 47 - Marinduque Wildlife Sanctuary; 48 - Central Cebu Protected Landscape; 49 - Rajah Sikatuna Protected Landscape; 50 - San Vicente-Taytay-Roxas Forests; 51 - Central Panay Mountains; 52 - Mt. Halcon; 53 - Northwest Panay Peninsula Natural Park; 54 - Mt. Canlaon Natural Park; 55 - Pasonanca Natural Park; 56 - Basilan Natural Biotic Area; 57 - Mt. Malindang Natural Park; 58 - Mt. Kitanglad Range Natural Park; 59 - Mt. Matutum Protected Landscape; 60 - Malampaya Sound Protected Landscape and Seascape; 61 - El Nido Managed Resource Protected Area; 62 - Mt. Guiting-guiting Natural Park; 63 - Mt. Calavite Wildlife Sanctuary; 64 - Quirino Protected Landscape; 65 - Mt. Kalatungan Range Natural Park; 66 - Mt. Isarog Natural Park; 67 - Casecnan Protected Landscape; 68 - Mt. Apo Natural Park; 69 - Cuernos de Negros; 70 - Agusan Marsh Wildlife Sanctuary; 71 - Mts. Banahaw-San Cristobal Protected Landscape; 72 - Samar Island Natural Park; 73 - Mt. Pulag National Park; 74 - North Eastern Cagayan Protected Landscape and Seascape; 75 - Northern Sierra Madre Natural Park; 76 - Penablanca Protected Landscape and Seascape; 77 - Calauit Island; 78 - Culion Island; 79 - Romblon Island*



planning, vulnerability and irreplaceability (Margules and Pressey 2000), and can be applied to all taxonomic groups. Sites that hold one or more globally threatened species or that have globally significant populations of a geographically concentrated species qualify. Geographically concentrated species include those that have a limited global range size (provisionally set at 50,000km²), termed restricted-range species, as well as globally significant congregations of species.

Boundaries for KBAs are drawn to yield sites that can be managed for conservation, using data on management units, species' ecological requirements, the extent of remaining habitat, topographical features, and human settlement patterns. In identifying and delineating KBAs for amphibians, information from the Global Amphibian Assessment (GAA), including range polygons, population estimates, and information on threats, conservation measures, and habitat requirements of species, can be used in combination with more specific locality data to help identify globally important sites.

The identification of the set of KBAs within a region is typically driven from the national level. A good example of a country where this process is far advanced is the Philippines. With more than 20,000 endemic species, the Philippines is one of the world's 17 "megadiversity" countries (Mittermeier *et al.* 1997), but with less than 7% of its original forest cover remaining intact, it is also one of 34 global biodiversity hotspots (Mittermeier *et al.* 2004). As such, accurately targeting scarce conservation resources is particularly important. Several priority-setting processes have contributed to this goal, including the identification of 117 IBAs by BirdLife International and the Haribon Foundation in 2001 and of 206 conservation priority areas by the Philippine Biodiversity Conservation Priority-setting Program (PBCPP) in 2002. In 2004, Conservation International-Philippines, in collaboration with the Haribon Foundation and the Protected Areas and Wildlife Bureau of the Department of Environment and Natural Resources, built on this earlier work to identify KBAs for multiple taxonomic groups, using a systematic, data-driven process. A number of other partner NGOs, government agencies, research institutions, and individual experts were involved in contributing data and peer review.

A total of 128 KBAs were identified for threatened and endemic amphibians, mammals, birds, reptiles, and freshwater fish, with 79 sites triggered by 49 amphibian species (Figure 1). This total includes one Alliance for Zero Extinction site (see main text) identified for an amphibian species (the Endangered island forest frog, *Platymantis insulata*, which is entirely restricted to the tiny island of South Gigante).

The KBA process sometimes focuses on a regional level and involves multi-country cooperation. For example, in 2002, Nature Kenya and the Wildlife Conservation Society of Tanzania, with the support of the Critical Ecosystem Partnership Fund (CEPF), collaborated to identify globally important sites for conservation within the Eastern Arc Mountains and Coastal Forests of Tanzania and Kenya biodiversity hotspot (*sensu* Myers *et al.* 2000). Building upon the successful identification of IBAs in the region, a total of 160 KBAs were identified across five taxonomic groups (plants, gastropods, birds, mammals, and amphibians). A total of 20 KBAs were identified for 44 amphibian species. Although KBAs continue to be refined as additional species and habitat data are obtained, the process of communicating these conservation targets to partners is well underway. In East Africa, in addition to providing a geographically explicit strategy for US$7 million of CEPF investment in the hotspot, these sites have also been adopted by a number of conservation partners in Tanzania and Kenya. Most importantly, they serve as the basis for priority sites in the $62.2 million Eastern Arc Mountains Endowment Fund, supported by the Global Environment Facility (GEF). The identification of KBAs, therefore, clearly serves as a vital tool in focusing and leveraging funding for conservation.

Once identified, safeguarding KBAs can take many forms, ranging from formal governmental protection and management, to strengthened management at existing sites, to implementing community-based conservation, to strengthening and monitoring the success of existing projects on the ground. One recent example from Colombia concerns the proclamation of the El Dorado Nature Reserve, contiguous with the Parque Nacional Natural Sierra Nevada de Santa Marta, which is the only known site for seven threatened amphibians, including the Critically Endangered Santa Marta Harlequin Frog *Atelopus laetissimus* and San Lorenzo Harlequin Frog *Atelopus nahumae*. Upon learning of the impending sale of plots from the site for the construction of vacation homes, three conservation organizations, Fundación ProAves, the American Bird Conservancy, and Conservation International, stepped in to protect this 1,600-acre site on the north-west slope of the Sierra Nevada de Santa Marta massif.

In summary, site conservation is clearly critical in ensuring the long-term persistence of amphibian species, and in many cases complements and enhances the effectiveness of other important conservation techniques, such as disease mitigation, invasive species eradication, and captive breeding. However, effective conservation action is only possible if we know where such sites are – and the KBA approach provides the tools necessary to highlight sites of global conservation significance for amphibians.

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ESSAY 11.4. PREDICTING THE DISTRIBUTION AND SPREAD OF PATHOGENS TO AMPHIBIANS

Knowledge of the distribution of species is essential in order to conserve biodiversity. Conventional methods for inferring and monitoring changes in species distributions require labour- and time-intensive efforts and are realistically practical only for selected taxa and small geographic regions. Nevertheless, as human-induced pressures on biological diversity and extinctions increase worldwide, accurate predictions of species distributions are in increasingly urgent demand by both scientific and conservation communities.

Modelling ecological niches to predict the geographic distribution of species has become an indispensable tool and has been used to study a wide variety of processes in ecology, evolution, and conservation (Graham *et al.* 2004). This suite of modelling techniques use complex mathematical algorithms to quantify the environmental space, or envelope, of species by determining the association between occurrence records and a series of environmental or biotic niche dimensions (e.g., temperature, precipitation, vegetation; see Figure 1). This relationship is then used to estimate the probability of occurrence of the target species in regions where it has not yet been recorded, and to estimate the geographic extent of suitable habitat. These areas are "analogous ecologically" to areas where the species has been reported to occur. As such, they are a function of the species' ecological niche or environmental requirements, at least along the niche dimensions considered (Soberón and Peterson 2005).

More recently, ecological niche modelling has been used in epidemiological studies to predict the distributions of pathogens, pests and diseases. For example, areas of Chagas disease, Ebola haemorrhagic fever, and Sudden Oak Death outbreaks have been successfully predicted (Peterson *et al.* 2002, 2004; Guo *et al.* 2005). These studies also yielded a detailed understanding of disease occurrence and risk areas, parasite-host distributional relationships, and ecological factors contributing to outbreaks. These and other examples reveal the applicability of ecological niche modelling to better inform programmes aimed at managing wildlife infectious diseases, particularly in regions where species survival has been compromised by the arrival of emerging diseases. Nevertheless, the application of ecological niche modelling on studies of amphibians' pathogens has been surprisingly limited.

Emerging infectious diseases have been increasingly identified across the globe as a threat to wildlife and human welfare (Daszak *et al.* 2000). An emerging disease generally has two characteristics: (1) its geographical range or host range is expanding, or its prevalence has been increasing in recent years, and (2) these changes are frequently driven by some form of large-scale anthropogenic environmental change, such as climate anomalies or deforestation (Daszak *et al.* 2004). Given the link between disease occurrence and environmental conditions, ecological niche modelling should prove to be a valuable tool for examining the dynamics of emerging diseases.

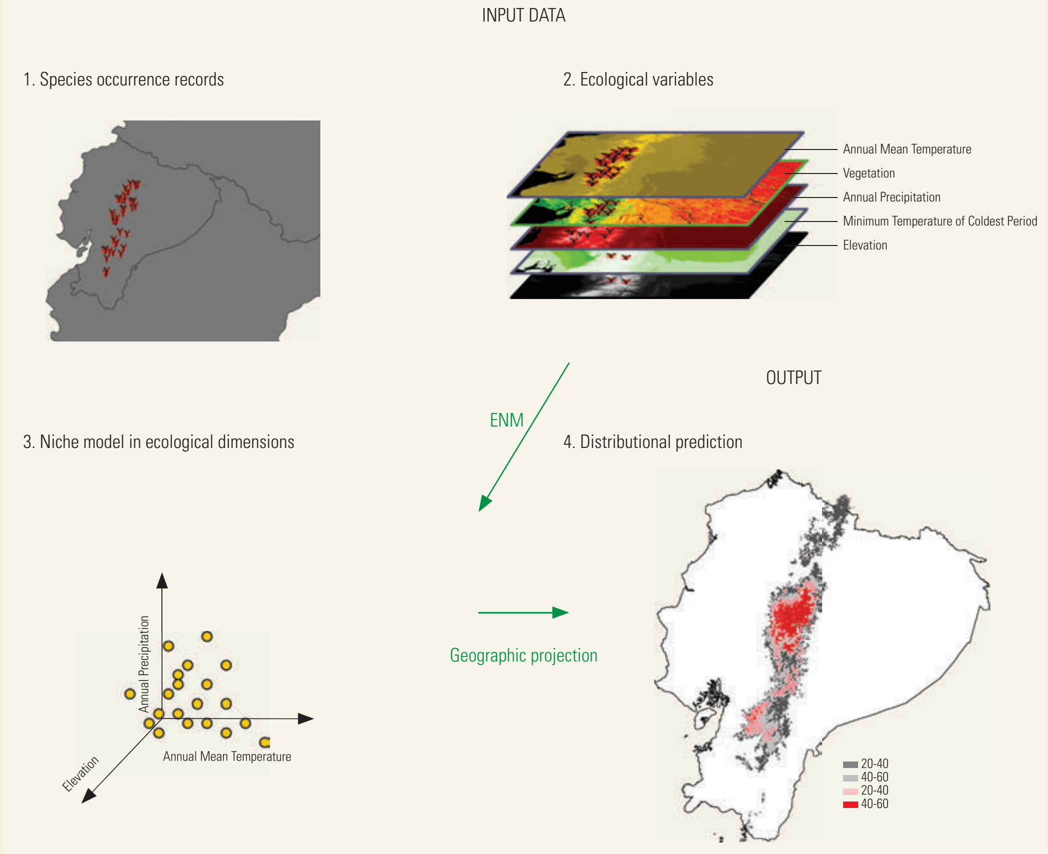
Studies have shown that habitat degradation and climate change can affect the life cycle of pathogens and can, therefore, influence the patterns of disease outbreak and transmission. As a consequence, modelling the distribution of pathogens under different scenarios of future climate change, habitat loss, and fragmentation can be an important predictive tool to facilitate disease control. Identifying areas where disease is likely to spread as a result of climate change and habitat degradation should allow prioritization of monitoring efforts into high risk and presently uninfected areas. Predictions of both current and future distributions should also be useful for management of both pathogens and infected species.

Amphibians may provide a dramatic example of the devastating impact of emerging diseases on wildlife. Over the past few years, a number of studies have implicated fungal, viral, bacterial, and parasitic diseases in population declines, and even extinctions, of amphibians (Daszak *et al.* 2003). Of particular relevance is chytridiomycosis, a disease caused by a pathogenic fungus that may be related to mass deaths and severe declines in amphibian populations around the Earth (Longcore *et al.* 1999; Daszak *et al.* 2003).

Niche modelling and disease in amphibians: an illustrative example

The first application of niche modelling as a tool to characterize the environmental envelope and potential distribution of an amphibian pathogen was

Figure 1. *Ecological niche modeling (ENM). Predictions of niche occurrence are based on: (1) Species geographic distribution in the form of primary point occurrence data, and (2) Environmental variables. Modeling (3) consists on finding the association between species occurrence records and environmental or ecological variables. The associations find "resemblances" on the environmental layers between occurrence records and other regions of the map. The output is a prediction of the distribution of regions suitable for the occurrence of the target species (4). The prediction represents the ecological niche projected back onto geography. Most of the modeling methods yield maps showing varying probabilities of the presence of suitable conditions across the region.*



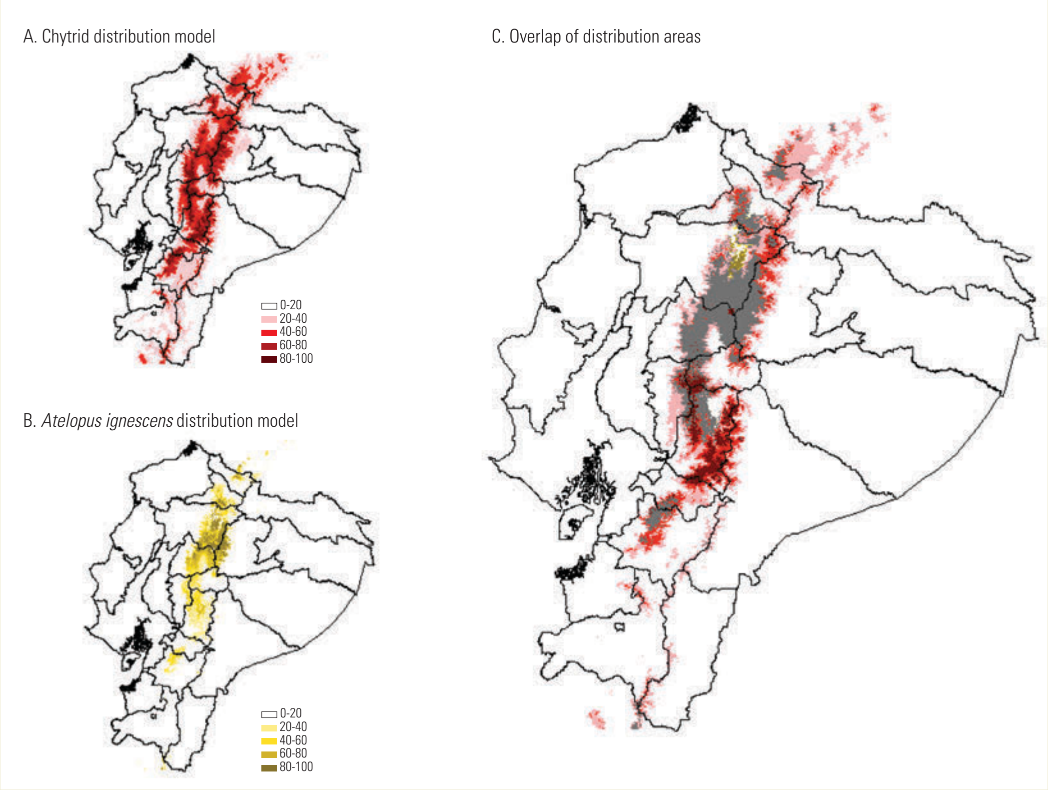


Figure 2. *Predicted distribution of the fundamental niche of (A) the chytrid fungus Batrachochytrium dendrobatidis, and (B) the Jambato toad, Atelopus ignescens, in Ecuador, South America. Darker yellow and red tones indicate a higher probability of occurrence. (C) shows areas of overlap between both species (gray areas). Red and yellow tones show areas of no overlap. Models were built from nine chytrid and 76 A. ignescens localities of known occurrence using MAXENT (Phillips* et al. *2004). A 0.5 threshold was used to transform the probability data to presence/absence data for the chytrid fungus model. The predicted areas for the pathogen and the host overlap widely.*

published by Ron (2005). Niche modelling was used to predict the distribution of the chytrid fungus *Batrachochytrium dendrobatidis*, in the New World. The predictions indicate that the regions of highest suitability for the chytrid are also the areas with the most diverse amphibian faunas worldwide. This study makes recommendations for management based on the fact that regions suitable for the establishment of the pathogen are widespread and that the pathogen has been regularly found in the pet trade. Specifically, Ron (2005) suggests the implementation of severe trade regulations for live amphibians to avoid anthropogenic spread of the pathogen.

The predicted occurrence of the chytrid fungus under a wide variety of environmental regimes and habitat types contrasts with the fact that most records for the chytrid fungus in the West Indies, Central, and South America are restricted to a somewhat limited portion of the predicted environmental niche (e.g., from montane forests and paramos). This asymmetry probably results from the inclusion of North American records in the process of model building, and highlights potential biases in the application of environmental niche modelling when the underlying locality data is not a representative sample of the pathogen's environmental niche. Ideally, the input of the model should consist of positive localities found from uniform sampling throughout the distribution range. In reality, the distribution of positive records is biased by accessibility to field sites, availability of museum collections and economic resources, and even by scientists' idiosyncrasies (e.g., *a priori* perceptions of where the pathogen *should* occur). Other sources of model error are false positive localities and the exclusion of niche dimensions that are relevant to limit the pathogen niche. Comprehensible reviews of these sources of error are provided by Guisan and Zimmerman (2000) and Guisan and Thuiller (2005).

Predicting pathogen and host overlap

To exemplify the applicability of ecological niche modelling in the study of amphibian declines, we modelled the distribution of both the chytrid fungus and the Jambato Toad, *Atelopus ignescens* (CR), in Ecuador. The Jambato Toad was once widespread and common in the northern Andes and represents a well-documented case of the disappearance of an amphibian in the Neotropics during the late 1980s. According to our predictions, the geographic distribution of chytrid in Ecuador overlaps widely with that of the Jambato Toad (Figure 2). The environmental envelope analysis shows that both have very similar environmental requirements (i.e., low temperatures during the coldest and driest seasons; Figure 3). These results suggest an ecological and geographical association between both species that is consistent with hypotheses implicating the chytrid fungus in the extinction of the Jambato Toad and other Andean amphibians (Ron *et al.* 2003; Pounds *et al.* 2006). More detailed studies to explore the overlap between the niche space of threatened species and the chytrid fungus would be valuable to help clarify the role of this pathogen in widespread amphibian population declines.

Newly available information

Several new types of information should be used to improve our understanding of the geographic and ecological distribution of the chytrid fungus and other pathogens of amphibians, as well as to predict how these distributions will change as a result of anthropogenic activities. The past several years have witnessed a tremendous increase in the availability of information that includes extensive databases on species occurrence (hosts and pathogens), high-resolution spatial data from remote-sensing platforms, comprehensive treatments of species phylogenies, and new insights on pathogen environmental physiology. Species occurrence records can be used to evaluate the spatial overlap of amphibian species and pathogens to assess extinction risks in the context of their respective evolutionary histories. Fine-grained remotely sensed information and faster computer processors should allow us to build more precise and refined predictions of amphibian disease outbreaks using ecological niche modelling. At present, the temporal resolution of climate maps is 30 years, which is too gross to predict disease driven by demographic processes. Finally, manipulative experimentation has resulted in new information about the physiology of chytrid fungus that can also be used to refine distribution models.

We expect that the combination of these diverse sources of information in the framework of ecological niche modelling will contribute significantly to understand disease epidemiology. New insights on disease distribution and spread would also help to develop and test hypotheses on disease dynamics that will improve our capacity to design effective conservation programmes for amphibians.

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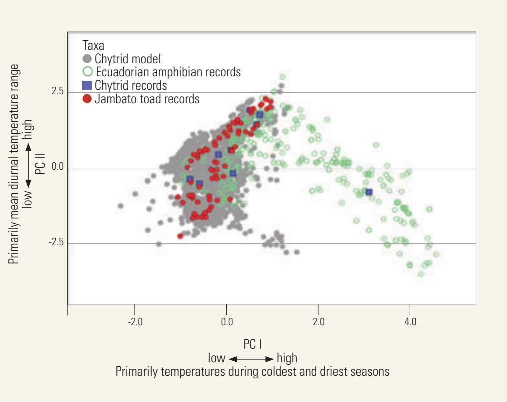

Figure 3. *Axes I and II from principal components analysis based on 19 environmental variables in Ecuador. Gray circles: 2000 random locations within the Chytrid fungus predicted niche distribution; green circles: 296 localities of known occurrence of Ecuadorian endemic species of amphibians in the genera* Colostethus *and* Atelopus*; blue squares: 9 localities of known occurrence of Chytrid fungus* Batrachochytrium dendrobatidis*; red circles: 74 localities of known occurrence of Jambato Toad* Atelopus ignescens*. So far, all examined specimens of* A. ignescens *for chytridiomycosis have tested negative (Ron* et al. *2003). However, the overlap between chytrid fungus model and Jambato toad's occurrences in the environmental space is evident. Locality data is from specimens deposited in Field Museum of Natural History, Museo de Zoología Pontificia Universidad Católica del Ecuador, Museo de Historia Natural Gustavo Orcés, Museum of Comparative Zoology Harvard University, Museum of Zoology University of Michigan, Museum of Vertebrate Zoology University of California, Natural History Museum University of Kansas, and Natural History Museum of Los Angeles County.*

ESSAY 11.5. ON THE ROLE OF *EX-SITU* MANAGEMENT IN THE CONSERVATION OF AMPHIBIANS

The best place to conserve wildlife is in the wild. However, *in-situ* threats sometimes cannot be mitigated quickly enough to prevent the extinction of a species in the immediate future, with the result that *ex-situ* intervention then becomes the only option available. However, given the magnitude of the problem versus the currently limited resources of the global *ex-situ* community, there simply is no room for most species in need of *ex-situ* management. For example, we estimate that the global zoo community can currently manage viable populations of ~50 amphibian species, which amounts to perhaps 10% of those requiring *ex-situ* intervention. Much *ex-situ* space exists in the private sector, but very little is currently utilized for conservation, with a few notable exceptions. Other limitations of *ex-situ* programmes are expense and risk of disease transmission, inbreeding and artificial selection. *Ex-situ* programmes must be placed in the broader context of integrated recovery efforts: they are one component of the global conservation response, one that cannot stand alone, and one whose success still ultimately relies upon mitigation of the *in-situ* threats.

We see five conservation roles for *ex-situ* populations, balancing their potential contributions with their inherent limitations, all of which directly or indirectly benefit wild populations:

- management for release to augment or restore wild populations
- conservation research

- conservation education
- commercial production to relieve *in-situ* collecting pressure
- fund-raising to support any of the first four activities and/or directly support *in-situ* conservation

These roles are not mutually exclusive, and with careful planning, most *ex-situ* populations can serve and benefit from multiple roles. Although these roles have been dealt with in larger monographs (e.g., Griffiths and Kuzmin 2006, Marantelli *et al.* unpubl.), management for release is a task unique to the *ex-situ* community and will therefore be the focus of this essay. Here, we submit case studies in which programmes implemented by the *ex-situ* community have helped prevent the extinction of a threatened species. We present these case studies as models show-casing a range of options for future action.

Translocations with time in *ex-situ* programme limited to that required for transport

In circumstances where threats have been identified and mitigated or are spatially limited, and where populations still exist that are demographically robust enough to sustain harvesting, the simple translocation of animals to threat-free locations may lead to the re-establishment of populations previously lost. Such programmes can be achieved cheaply and with minimum risk. Successful re-establishment of populations has been achieved by this method for the Natterjack Toad *Bufo calamita* (LC; Denton *et al.* 1997). Translocation of tadpoles from one wild site to another has established new populations of the Mallorcan Midwife Toad *Alytes muletensis* (VU; Buley and Gonzalez 2000; and see Essay 11.6) where previously more risky and expensive *ex-situ* breeding programmes were employed.

Translocations/reintroductions with time in *ex-situ* programme limited to that required for head-starting

Where threats are mitigated, but extant populations cannot sustain the harvesting levels required to establish new populations through translocation, or where reduction of mortality can help achieve a positive rate of population increase, head-starting programmes can be an effective and economical solution. Such projects utilize naturally produced individuals – usually eggs – and protectively rear them through periods of otherwise naturally high mortality. This usually results in the production of large numbers of individuals that would otherwise have perished, without the cost or risk of a captive-breeding programme. A number of projects have used head-starting to some effect (Sredl *et al.* 2002; Gibson and Freeman 1997; Sredl and Healy 1999; Krofta 2003).

Translocations/reintroductions where *ex-situ* management is required until *in-situ* threats can be mitigated

Often threats are not immediately controllable or even identified and, in such cases, species may require *ex-situ* management across generations. In cases where threats are known to be temporally limited or able to be quickly mitigated, the *ex-situ* programme may be short or comprise only a generation or two. It is always desirable to reduce *ex-situ* time to minimize risks and maximize the value of the limited available resources. Captive breeding and reintroduction of frogs have been used to relocate and re-establish populations of Romer's Treefrog (*Chirixalus romeri*, EN) following the loss of their habitat to development (Banks 1996; Dudgeon and Lau 1999). Over 100,000 zoo-produced tadpoles of the Puerto Rican Crested Toad (*Bufo lemur,* CR) have been released, over the past decade, to augment small wild populations and restore extirpated populations in areas where breeding habitat has been restored (Johnson 1999). In some cases the duration of *ex-situ* management is indeterminate. Such programmes are resource-intensive and face additional risks, including genetic loss, artificial selection, and the prospect that the species may never be repatriated. For the Kihansi Spray Toad (*Nectophrynoides asperginis*, CR), the *ex-situ* population has circumvented complete extinction, but there is currently no way to mitigate the *in-situ* threats (Krajick 2006). Project Golden Frog (PGF; Zippel 2002) and a collaborative multi-species effort in Panama by the Atlanta Botanical Garden and Zoo Atlanta (Mendelson and Rabb 2006) are other examples where the *ex-situ* component of the programme will be of indeterminate duration. PGF focused its efforts for the Panamanian Golden Frog (*Atelopus zeteki*, CR) along three main objectives: population and habitat assessments, an intensively managed *ex-situ* breeding programme, and range-country education initiatives. Through the breeding programme, hundreds of offspring have been produced and distributed among dozens of AZA-accredited zoos. In the US, the frog became a symbol of the impacts of emerging diseases), with an immediate response from educators and funding from granting agencies. The Atlanta-based initiative attempted a pre-emptive extraction of other Panamanian species at an ecosystem scale. Based on data made available by Lips *et al.* (2006), the team worked ahead of and behind the frontline of the progressing chytrid fungus. They demonstrated that it is possible to collect animals from infected areas, treat them for chytrid infection regardless of their level of infection, and establish them in *ex-situ* populations.

In conclusion, although species persistence must ultimately be achieved in the wild, it can be facilitated by effective *ex-situ* conservation programmes. However, there are several important elements that define a successful *ex-situ* programme. Firstly, where *ex-situ* intervention is warranted to avoid uncontrollable threats, it is best done in the range country due to disease risks, political considerations, limited out-of-range capacity, and expense. *Ex-situ* facilities worldwide that have adequate resources should partner with zoos or other institutions in the range country. If capacity does not exist there, it must be built. Prioritizing efforts within range countries provides renewed focus, both on capacity building to facilitate in-country accountability and on government support, for an international response to preserve national (and global) biodiversity.

Secondly, it is essential that animals removed from the wild and intended for eventual release be kept in strict isolation (Marantelli *et al.* in prep) to prevent exposing them to novel pathogens and parasites. The risk is significantly increased as animals cross more or greater biogeographic barriers from their natural range. Moreover, specimens must undergo rigorous health screening prior to return or release to test that isolation has successfully excluded known organisms. If the *ex-situ* community is to be responsible, for amphibians or any organisms they move, they should not gamble on biosecurity issues and risk becoming the vector for a new disease outbreak in the wildby transfer of foreign pathogens to the range or host country.

Third, regardless of where the population is maintained, a programme has a better chance of success if the time spent *ex-situ* is minimized (thus reducing the potential for disease exposure, inbreeding, and artificial selection). And, finally, conservation research, education, and fundraising should be simultaneous priorities for *ex-situ* populations. All of these activities must be linked to, and for the benefit of, an *in-situ* conservation programme aimed at reversing the threats and thereby making the *ex-situ* programme unnecessary.

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FROG FOLKLORE

Golden frogs have long been admired for their bright, yellow aposematic color that warns predators of their toxic skin. Early Panamanians imagined that golden frogs magically transformed into golden huacas upon death. Huacas are gold statues representing the power and fortune golden frogs would bring to their owners.

POPULATION IN PERIL!

Pollution, loss of habitat, and the exotic pet trade in Panama have thinned out the golden frog population fast! This species is also suffering from a dangerous fungal disease that is affecting amphibian populations worldwide!

HELP IS AT HAND!

Project Golden Frog is a coordinated conservation effort by zoos, universities, and government agencies focusing on field studies, captive breeding programs, and education about Golden Frogs. The Buffalo Zoo is involved with Project Golden Frog to help ensure their survival. Learn more about Project Golden Frog at www.projectgoldenfrog.org

BE A FROG WATCHER!

The National Frog Watch Program is a community based organization that relies on volunteers like you to listen to frog calls in your neck of the woods! Visit www.frogwatch.org to receive more information on how you can become a frog watcher! By monitoring frog calls we can learn about the health of our environment and help save

Educational graphics forming part of Panamanian Golden Frog Atelopus zeteki *mixed-species exhibit at the Buffalo Zoo. In addition to* A. zeteki, *the exhibit currently houses two other Panamanian species, namely* Hylomantis lemur *(Endangered) and* Colostethus pratti *(Least Concern). © John Kast*


Michael Lau returning to Hong Kong with the first batch of Romer's Treefrog Chirixalus romeri *(Endangered) bred at Melbourne Zoo. © Chris Banks*

ESSAY 11.6. A CONSERVATION SUCCESS STORY: THE MALLORCAN MIDWIFE TOAD *ALYTES MULETENSIS*

The midwife toad of the Balearic island of Mallorca, *Alytes muletensis,* gains its name from the unusual behaviour of the males, which carry fertilized eggs around their back legs until they hatch; upon hatching the emerging tadpoles are released into a pool of water to complete their development. The local Catalan name of *ferreret* means "little iron-worker" because their 'chinking' call sounds like iron being hit with a hammer.

Until the late 1970s, the Mallorcan Midwife Toad was known only from fossil evidence and was thought to be extinct. However, re-examination of a specimen originally collected in 1978 revealed that this was not, as first thought, an introduced common midwife toad (*Alytes obstetricans*), but an example of the Mallorcan Midwife Toad (Mayol and Alcover 1981). Subsequent surveys revealed the global distribution of the toad to consist of about 13 populations, all contained within the Serra de Tramuntana. Within these mountains, torrents of water flow through steep-sided karstic gorges during the winter, carving out semi-permanent plunge pools that provide breeding grounds for the toad in the spring and summer months when the rest of the torrent dries up. Although the toad remains restricted to the mountains, fossil evidence indicates that the species was once widespread across Mallorca and also inhabited lowland areas (A. Alcover pers. comm.). The increasingly reduced and fragmented distribution of the species prompted its listing as Critically Endangered in the 1996 IUCN Red List (Baillie and Groombridge 1996).

A number of theories have been proposed to explain the decline of the Mallorcan Midwife Toad. Changes in water demand and population pressure have resulted in increasingly limited availability of breeding sites for the species and this may have restricted its range to areas where suitable breeding pools persist. However, most researchers attribute the principal cause of decline to predation and competition from introduced species such


Tadpoles from a snake-free pool (upper) and a pool subject to predation from snakes (lower) showing the strikingly different morphologies. © Robin D. Moore

Male Mallorcan Midwife Toad Alytes muletensis *(Endangered) carrying fertilized eggs on its back legs. © Gerardo Garcia*

as green frogs, *Rana perezi*, and, more significantly, the viperine snake, *Natrix maura*, a semi-aquatic serpent that preys upon both tadpoles and adult toads. Archeological and, more recently, molecular evidence (Guicking *et al.* 2006) supports the idea that the viperine snake appeared in Mallorca around 2000 years ago following the arrival of the Romans. Being an island species that evolved with few natural vertebrate predators, the Mallorcan Midwife Toad was undoubtedly susceptible to the impacts of predation and competition from introduced species. The snake may have eliminated the toad from much of the island, and recent research indicates that predation from snakes continues to negatively impact some extant populations. In response to intense predation pressure, tadpoles have evolved a number of behavioural and morphological anti-predator responses. Upon detecting chemical cues from snakes in the water, tadpoles reduce activity levels and, over a matter of weeks, change shape - becoming more streamlined with a larger tail muscle - to facilitate their escape if they are detected (Moore *et al.* 2004). Such defences may have allowed the toad to cling onto survival in the face of intense predation pressure and may have facilitated its co-existence with the snake in some areas today.

In 1985, at the invitation of the Mallorcan government, the Jersey Wildlife Preservation Trust (JWPT), now known as the Durrell Wildlife Conservation Trust (DWCT), initiated a species recovery program for the toad. A captive population was initially founded at Jersey Zoo, UK, using 20 individuals collected from one site, and the species was bred in captivity for the first time in 1988. Captive populations stemming from this founder colony are now held in a number of institutions in both Spain and the UK and these have been augmented with several more bloodlines that are maintained separately to ensure genetic integrity. One of the main aims of the captive-breeding program has been to provide toads for reintroduction into their natural habitat.

The first reintroduction of 76 captive toads from JWPT occurred in 1989, at the request of the Mallorcan government, into two sites chosen by the Conselleria d'Agricultura Pesca (CDAP). Since then, releases of young toads and tadpoles have been made into numerous unoccupied sites within the known historical range of the species. Such sites have been identified after a careful assessment of potential threats, with appropriate habitat and predator management carried out in order to maximize the chances of success. Natural populations are also known to use livestock watering troughs, or cisterns, and construction of such artificial breeding sites in the traditional style has also proved successful in re-establishing populations in areas where water is otherwise in short supply. The success of the reintroduction programme is illustrated by the fact that about 25% of the current wild population stems from captive-bred stock and that 12 new breeding sites have been established since 1989 through reintroductions (Buley and Gonzalez-Villavicencio 2000). At a recovery group meeting in Jersey in November 2002, a decision was made to suspend reintroductions from *ex-situ* breeding colonies as a precaution against the transmission of diseases, such as the chytrid fungus. It was suggested that conservation efforts rather focus on translocating individuals from existing populations into new, unoccupied sites and head-starting tadpoles to increase the chances of success for such translocations.

The recovery program has proven extremely successful in reversing the decline of the toad. Nineteen breeding populations now exist within the Serra de Tramuntana and six of these have been established from successful reintroductions of captive individuals. As a result, the species was downlisted by two categories to Vulnerable during the course of the Global Amphibian Assessment. The success of this program can be attributed to a number of factors. Firstly, there has been effective collaboration among international governments, NGOs, academic institutions, and zoos. This collaboration has meant that captive breeding and reintroduction has been just one component of a wider recovery program involving threat mitigation and habitat management, health screening of wild and captive toads, ongoing monitoring of all the toad populations, and raising awareness among visitors and stakeholders. Secondly, these activities have been underpinned by targeted research on reproductive biology, survey methodologies, the impact of threats, and population genetics. Recent research, for instance, has shown that relatively high levels of heterozygosity and important fitness attributes can be retained for a few generations of captive breeding in this species, but that both may start to deteriorate in the long-term (Kraaijeveld-Smit *et al.* 2006); such findings have important implications for this, and other, recovery programmes.

Extant populations continue to be monitored and captive populations maintained as a 'safety net' and for conservation research in order to ensure the continued recovery of the Mallorcan Midwife Toad. This represents a rare conservation success story and has the potential to serve as a model for other amphibian recovery programmes throughout the world.

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The Sierra Tramuntana of northern Mallorca, Balearic Islands, Spain – home to the Mallorcan Midwife Toad Alytes muletensis *(Endangered). © Robin D. Moore*

ESSAY 11.7. WHEN HABITAT PROTECTION AND SUCCESSFUL CAPTIVE BREEDING ARE NOT ENOUGH: THE CASE OF THE WYOMING TOAD

During the last Ice Age, vast glaciers occupied most of North America's far northern latitudes, and the ranges of many northern, cold-climate plants and animals extended well to the south of their present distributions. With glacial recession and subsequent warming, the distributions of these species withdrew northward. One of these, the Canadian Toad *Bufo hemiophrys*, disappeared from most of the southern part of its range in the prairie region of the north-central United States. Until the 1940s, herpetologists believed that the Canadian Toad lived only as far south as the northern fringe of the United States, including northern Minnesota and northern North Dakota. But, in 1946, George Baxter, newly arrived at the University of Wyoming, discovered an isolated population in the Laramie Basin in south-eastern Wyoming, about 500 miles away from the nearest known population in eastern South Dakota. Since then, herpetologists have scoured the region, but all known occurrences of this population have been found only within about 50km of the town of Laramie, within an area of about 2,330km², at elevations between 2,300 and 2,500m asl.

The toad's habitat in Wyoming consists of wet meadows, marshy wetlands, and the moist low-gradient edges of open bodies of water. Baxter's initial discoveries were along the floodplains of the Big and Little Laramie rivers, but recent observations indicate that toads responded to changing irrigation practices in the basin by switching from floodplain pools and pooled irrigation water to more isolated ponds and seepage lakes. Toads survive the Laramie Basin's long, cold winters by burrowing into the deep sandy soils of old, vegetated dunes near the breeding areas, or by moving into rodent burrows.

At the time of its discovery, the toad that Baxter discovered in the Laramie Basin was regarded as a population of the Canadian Toad. In 1968, Kenneth Porter of the University of Denver carefully compared the characteristics of the Wyoming population with those of Canadian Toads in Canada and determined that the Wyoming toads warranted recognition as a new subspecies, which he named *Bufo hemiophrys baxteri*, in recognition of Baxter's discovery. It was later considered a distinct species (Smith *et al.* 1998), and the Laramie Basin population is now generally known as the Wyoming Toad (*Bufo baxteri*).

Baxter's field observations over many years indicated that the Wyoming Toad was relatively common in the 1950s and 1960s, but then underwent a substantial decline in distribution and abundance in the 1970s. In fact, by the mid-1980s, the Wyoming population appeared to be extinct. At the time, there was concern that pesticide applications for mosquito control in the Laramie Basin might be a major factor in the decline. Concerted survey efforts in the 1980s fortunately revealed tiny remnant populations but, by 1987, the known range included only a single site. Wild Wyoming Toads have since been found only at this site, initially protected by The Nature Conservancy and now included in the Mortenson Lake National Wildlife Refuge.

A "wild" Wyoming Toad Bufo baxteri *(Extinct in the Wild) from Mortensen Lake, Albany Country, Wyoming. A single population of Wyoming toads was discovered at Mortenson Lake in 1987. This location was purchased by The Nature Conservancy, and the Mortenson Lake National Wildlife Refuge was established in 1993. © Douglas A. Keinath*

In the late 1980s and early 1990s, the Mortenson Lake population persisted with an adult population in the low 100s, and then declined to just a few adults by 1993. Breeding output dropped from a few egg masses per year to zero. Fearing that the toad might disappear completely from Wyoming, biologists collected the few remaining individuals in 1993 and 1994 and began attempts to breed them in captivity. This effort, now involving several zoos and other facilities, generated good numbers of offspring for release into the wild. An effort in the early 1990s to establish additional populations through releases of captive-raised toads at Lake George and Rush Lake on the Hutton Lake National Wildlife Refuge was unsuccessful. At Mortenson Lake, releases of many thousands of toadlets and tadpoles beginning in the mid-1990s resulted in at least modest toad survival and even a renewal of reproduction in the wild in 1998-2000, generating hopes for population recovery. However, subsequent declines, poor reproduction, and observations of diseased and dead toads in the early 2000s, put the toad back into an extremely precarious status. The free-ranging population surely would be completely gone without annual releases of thousands of captive-reared toadlets. Accordingly, the species remains functionally extinct in the wild.

Several factors may have contributed to the toad's decline and current poor condition. As with most threatened species, the toad has experienced habitat loss and degradation. Irrigation practices in river floodplains, now used for hay production, probably made streamside areas less suitable for successful toad reproduction. For example, de-watering prior to hay-cutting may kill toad larvae before they metamorphose into toadlets capable of living on land. Also, some potential breeding sites have dried up as a result of prolonged drought, while drought-related increases in evaporation have made Mortenson Lake more saline and perhaps less suitable for toads.

However, recent evidence suggests that the primary threat to the Wyoming Toad is not habitat degradation, but rather the pathogenic chytrid fungus (*Batrachochytrium dendrobatidis*), now associated with amphibian declines around the world. The fungus has been discovered at Mortenson Lake and in the captive population. Retrospective analyses indicate that the chytrid fungus has been present at Mortenson Lake since 1989.

Continued survival of the Wyoming toad depends on intensive management. An important immediate concern is maintenance of the toad's genetic diversity through careful management of the captive breeding stock. Excessive inbreeding and associated loss of genetic variation potentially could compromise the toad's reproductive performance and hinder the population's ability to respond to environmental variations.

Even if the Mortenson Lake population were in better condition, the toad's long-term survival and recovery would still depend on the identification of additional reintroduction sites and the establishment of several wild populations. This is a basic conservation precaution that minimizes the probability that localized events do not eliminate the entire species. Happily, private landowners have begun to step forward and allow toads to be released into suitable habitat on their property. A recent initiative that may play an important role in facilitating this effort is known as the Safe Harbor Agreement (SHA). According to the U.S. Fish and Wildlife Service, a SHA "*encourages landowners to conduct voluntary conservation activities and assures them that they will not be subjected to increased restrictions should their beneficial stewardship efforts result in increased endangered species populations. As long as enrolled landowners allow the agreed upon habitat improvements to be completed on their property and maintain their responsibilities, they may make use of the property during the permit term, even if such use results in the take of individual Wyoming toads or harm to their habitat. This approach may be critical in establishing additional sites into which captive-reared toadlets might be released with improved chances of survival and eventual reproduction.*"

Recently, a SHA was involved in the release of captive-raised toads on a private ranch near Mortenson Lake. Well-managed cattle grazing – which is compatible with and may even facilitate toad recovery – is being continued on the ranch. Only time will tell if the toads can avoid or overcome the fungal threat and establish a viable population on this and other potential reintroduction sites. Meanwhile, the Wyoming Toad remains one of the world's most threatened species.

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ESSAY 11.8. CONSERVATION ACTION FOR THE MEXICAN AXOLOTL *AMBYSTOMA MEXICANUM*

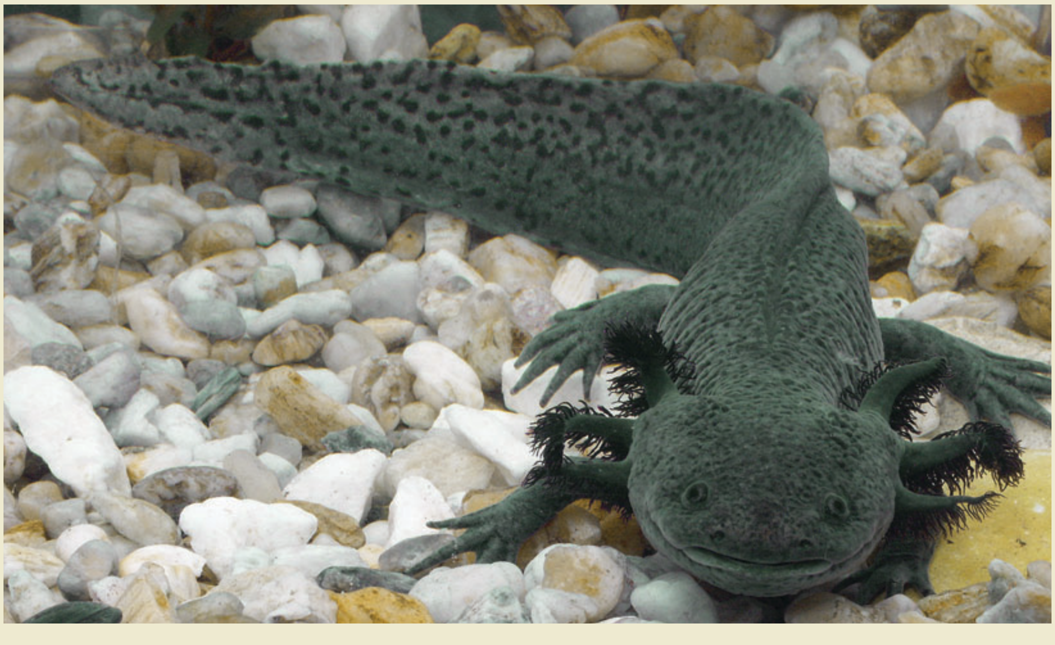
The Mexican Axolotl (*Ambystoma mexicanum*) is one of Latin America's most threatened amphibians. The vast wetland upon which Mexico City was founded – and which once provided a rich and productive habitat for the Axolotl and other endemic fauna – is now reduced to a handful of small, isolated patches surrounded by development. Of these, Lake Xochimilco is the largest, covering just over 2km² – but it is certainly no longer a lake. The development of the 'chinampas' – raised fields of mud and vegetation reclaimed from the lake – has been going on for centuries and has reduced the system to a series of canals running between islands of development. Today, the landscape is often referred to as the 'floating gardens' (a misnomer, as the chinampas are not floating at all). Habitat loss, introduced predators, pollution, and illegal collection for food and medicines have all taken their toll on the Axolotl. Consequently, the threats facing this species are complex and not easily reversible. However, its prominent position within Aztec mythology (see Essay 2.3) and the ancient lacustrine economy of the region means that the Axolotl is well known – although poorly understood – among local people. Some 2000 remeros (local boatmen) earn a living by punting visitors along the lake's canal system in gaily decorated trajineras (pleasure boats), while the chinamperos (local farmers) cultivate the adjacent land, in much the same way as their ancestors have done for centuries. Fishing is also important to the local economy, and although non-native carp and *Tilapia* may have replaced the Axolotl as the main catch, researchers have yet to improve upon the highly skilled traditional netting method used by the fishermen for finding Axolotls.

Over the last five years, a conservation programme on the Axolotl has been initiated and fostered by a partnership of British and Mexican organizations (Griffiths *et al.* 2004). This project was the brainchild of the late Dr Virginia Graue of the Universita Autonoma Metropolitana at Xochimilco (UAM-X), who contacted the Durrell Institute of Conservation and Ecology (DICE) in 1999 for assistance with the development of the project. As it was clear that addressing the many threats that the Axolotl faced would be impossible without the co-operation of local stakeholders, the project focused on embracing local people within the conservation planning process. This was done by promoting the Axolotl as a flagship species for nature tourism and conservation education within the region. Using a field station (run by UAM-X) on the shores of the lake as a base, and with funding from the IUCN/ SSC Declining Amphibian Populations Task Force (DAPTF), as well as the British Government's Darwin Initiative programme, the project partnership held training workshops on amphibian biology and conservation for local students and conservation organizations, nature guiding for local boatmen, and souvenir production for unemployed artisans.

In addition, the project has been actively engaged in ongoing studies focusing on the population status of, and threats to, the Axolotl. Despite its precarious status in the wild, the Axolotl is one of the most familiar amphibians in laboratories and aquaria throughout the world. Animals were originally collected in 1863 for the Natural History Museum in Paris, and many of today's captive animals probably stem from these founders (Smith 1989). As a result of its well-known reproductive biology, and the availability of captive populations, there is considerable interest in reintroducing Axolotls to Lake Xochimilco. However, there are several problems associated with such releases. At the very least, threats need to be neutralized and potential disease and genetic problems need to be addressed before captive animals are put back into the wild (Griffiths *et al.* 2004). Despite the wide availability of captive-bred Axolotls, wild animals are still captured and sold illegally in local markets (McKay 2003). A proposal to upgrade *Ambystoma mexicanum* from CITES Appendix II (controlled international trade) to Appendix I (species threatened with extinction and international trade permitted only in exceptional circumstances) is currently under discussion by the Mexican authorities.

As a result of a conservation workshop, held at UAM-X in December 2004, the goals for the conservation of the Axolotl and its habitat were finally distilled into eight categories: (1) biology of the species; (2) legislation; (3) social actions; (4) political actions; (5) ecological interactions; (6) local environment; (7) education; and (8) resource use and harvesting. These goals provided the framework for the Species and Habitat Action plan for the Axolotl and the Xochimilco system that was published in 2005 (DICE, UAM-X, 2005). Following the workshop, the Senate of the Congress of the Mexican government passed a motion requesting the President to instruct the Secretariat of the Commission for the Environment, Natural Resources and Fishing to initiate an urgent governmental programme to avoid the extinction of the Axolotl in Lake Xochimilco. What this decision will mean, in practice, remains to be seen, but it will certainly influence governmental actions that impact the Axolotl and Xochimilco conservation. The decision, in itself, is an indication of the leverage that such projects can achieve.

One of the most important products to emerge from the project's first phase is the partnership of diverse organizations that all have an interest in the future of the Axolotl and its habitat: the Grupo por la Investigacione del la Ajolote y Xochimilco (GIAX), which is co-ordinated by Dr Luis Zambrano of the Institute of Biology, UNAM. Despite the obvious benefits accruing as a result of raising awareness and building local capacity, initial data from this first phase of the project indicate that the status of the Axolotl has deteriorated to such an extent that the species now warrants classification as 'Critically Endangered' according to the IUCN Red List categories and criteria. This reclassification has provided a sharper focus for the implementation of the action plan. The new partnerships forged within GIAX will be instrumental in taking the plan forward during the second phase of the Darwin Initiative project. The training of remeros as nature guides has resulted in a significant increase in their income from visitors to Lake Xochimilco. Some of the remeros are currently being trained as nature guide 'trainers', with a view to the training package eventually being handed over to, and managed by, the guild of remeros. By the end of the second phase of the project, it is hoped that nature tourism will be contributing significantly to the sustainable development of the Xochimilco system, and will be independent of external funding. In parallel, research is



The Critically Endangered Mexican Axolotl Ambystoma mexicanum *is endemic to the canals of Lake Xochimilco in central Mexico, on the southern edge of Mexico City. © Ian G. Bride*

A typical Xochimilco canal scene beyond the busy urban area, showing a trajinera (pleasure boat) in the foreground. The boats in the distance are selling ornamental plants grown on the chinampas. © Ian G. Bride

being carried out on the productivity of the Xochimilco system, with a view to balancing the needs of the local fishermen with ameliorating the threats associated with introduced species and poor water quality. Ultimately, the future of the Axolotl will depend upon how successfully local stakeholders and their livelihoods engage with the protection of this unique wetland.

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Some of the 50-plus participants who attended the Axolotl Species/Habitat Action Plan Workshop, held at the Universita Autonoma Metropolitana at Xochimilco in December 2004. Participants are holding up the name plate of the trajinera that the Darwin Initiative project bought for CIBAC. © Ian G. Bride

ESSAY 11.9. MANAGING PROBLEMS OF OVER-EXPLOITATION AND TRADE IN AMPHIBIANS

To many cultures, amphibians are an important and commonly available source of protein. In some places, even tadpoles can be made into a local dish. The water-holding frogs in Australia store a reservoir of water in the bladder to last through the extended dry season and are used by the aborigines when no other source of water is available (Tyler 1976). Certain amphibians are also commonly used in traditional medicine. For example, in China, nine species of amphibians are listed in "The Great Pharmacopoeia" published over four hundred years ago. Up to 32 species are now recognized to be of medicinal value in traditional Chinese medicine (Ye *et al.* 1993). Some amphibians are also exploited to provide useful materials, like the poison from the various Poison Dart frogs for hunting and the skin of the Marine Toad for the leather industry in the Americas. Many exotic frogs, such as the colourful Mantellas (genus *Mantella*) from Madagascar, and a number of salamander species, are also collected to supply the pet trade. There is also quite a demand for frogs for use in the laboratory. And, in some countries such as Mexico, certain amphibians are used in witch craft and art crafts. Amphibians also play a role in shaping the local culture. For example, the Mexican Axolotl *Ambystomma mexicanum*, which has various mythological connections – the ancient Mexicans considered it the twin brother of Quetzalcoatl – has played an important role in the local communities around lakes in the Basin of Mexico (see Essay 2.3). There is even a frog festival in a branch of the Zhuang Minority in southern China.

These species survived centuries of traditional use and the 'edible frogs' remained common and widespread until commercial trade set in leading to a much larger level of exploitation that is often unsustainable. As early as the 1930s, Bourret (1942) noted the mass commercial trade of large edible frogs from Viet Nam into China. The collapse of populations of favourite 'frog legs' species in Asia shows that even in common, fast-growing and fecund species, such levels of exploitation are not without limit. Once depleted, the ecological functions carried out by these frogs are also hampered, which contributes to the outbreak of insect pests in rice paddies. The demand for amphibians is unlikely to diminish in the near future due to continual growth in human population and the increased purchasing power that accompanies growing economies. The resulting high collecting pressure often acts together with habitat destruction and degradation and poses a substantial threat to many amphibians. In China, for example, utilization adversely affects 84 species, some 30% of the amphibian fauna (Baillie *et al.* 2004).

The species hardest hit by over-exploitation are those that are rare, restricted or highly valuable. In recent years, a number of frogs and salamanders such as the Lao Salamander *Paramesotriton laoensis* (DD) and Kaiser's Spotted Newt *Neurergus kaiseri* (CR) have been subjected to commercial collection for pet trade at levels that are believed to have removed the majority of individuals from the wild (Stuart *et al.* 2006; Leahy 2006). Another example of a species hard hit by commercial exploitation, but for food, is the Chinese Giant Salamander *Andrias davidianus* (see Essay 4.7). This species, the largest amphibian in the world (adults can weigh more than 40kg) ranges widely in central and southern China and large populations once existed in many places. However, it is regarded as a delicacy and fetches a very high price. The species is particularly susceptible to over-harvesting because it is nearly fully aquatic and utilizes specific hiding places in clear mountain streams. Juveniles are also of marketable size and are collected as well as adults. Highly destructive methods, such as liming or the use of poison, are sometimes used to collect all the individuals in the stream. Individuals are also being collected as breeding stock in commercial farms. All these factors together with the long life-cycle make the Chinese Giant Salamander especially vulnerable to over-exploitation, and this Critically Endangered species has now disappeared from many areas, and a conservation action plan is urgently needed to reverse its decline.

Frog farming has gained momentum in many places and commercial feed is now available to feed the frogs and their tadpoles. These farms can make a positive contribution towards conservation if the supply from breeding farms substitutes for that from the wild, or if part of the income generated is directed back into biodiversity conservation. However, there remain challenges, including disease control within farms and the economic cost/benefit of farming efforts as a business activity (Kusrini and Alford 2006). One negative consequence of amphibian farming is that the American Bullfrog is one of the favourite species in many parts of the world. These animals often escape and become invasive, affecting the local ecosystem and biodiversity. In Mexico, for example, this species has been introduced into 16 of the country's 32 states. Most places actually have their own 'edible' frogs that are more suited to the local environment and are much better candidates for farming than exotic species. However, regardless of species, frog farming still runs the risk of transmitting diseases from captive frogs to those in the wild anywhere from the farm surroundings and transport routes to destination markets.

An alternative to farming and its associated problems is to explore options for sustainable use of local wild populations. The short life-cycle, high fecundity and high population size of many large frogs actually renders them quite resilient to certain levels of harvesting. If the requirements of the species concerned are known, and proper management is in place, these frogs can be harvested without affecting their population. There are examples in northern China where harvest of the Chinese Brown Frog *Rana chensinensis* (LC), a species used in traditional Chinese medicine, can be increased by providing breeding ponds and raising the tadpoles (Ye *et al.* 1993). Another example of sustainable use of amphibians is the harvesting of the grass frog *Rana forreri* (LC), which is a popular laboratory animal. These animals are harvested according to an annual quota and then exported to the United States. In Thailand and Indonesia, frogs (mainly *Hoplobatrachus rugulosus*, *Fejervarya cancrivora* and *Fejervarya limnocharis*) living and breeding in rice paddies, not only feed on crop pests but also are harvested for local consumption and export (Kusrini and Alford 2006). When combined with sustainable land-use practices, such as organic farming, this increases the economic gains, reduces or eliminates the need for and use of chemicals, and can bring additional conservation benefits to many other amphibians and wildlife. It might also provide an additional incentive to conserve their natural habitats in the case of non-commensal species.

To prevent unrestricted exploitation and possible extirpation of populations and species, several countries have implemented legislation that specifically regulates or prohibits the exploitation of particular amphibian species. Legislation usually also exists to protect particular natural areas as parks or sanctuaries, and amphibian populations inside such areas may be partly or completely protected by the regulations in force for the area. For species threatened by international trade, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is quite effective in regulating levels of trade and even in banning the commercial trade in highly threatened species (see Chapter 11). Adequate local legislations and enforcement is also needed as many amphibians are consumed locally. Wildlife trade is dynamic, and monitoring and reporting are important to provide an early warning system.

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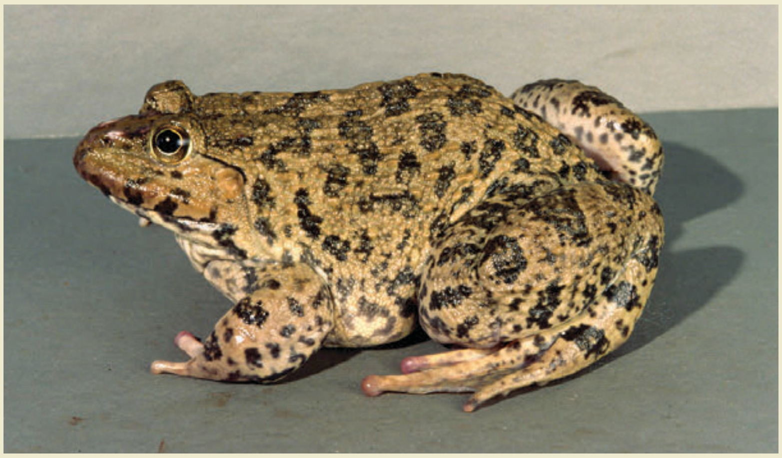
A farmed, market-bought Hoplobatrachus rugulosus *(Least Concern), the most common species used in the frog-leg trade in Asia, showing obvious signs of farm rearing, including bulbous toe-tips and transport damage behind the nostrils. © Peter Paul van Dijk, 1994-2000*

An assortment of local language frog-farming manuals for the rearing of Hoplobatrachus rugulosus *(in Chinese and Thai),* Rana catesbeiana *(Thai),* Paa *spp. (Chinese) and local ranids (Chinese). © CI/Peter Paul van Dijk, 2007*

ESSAY 11.10. FILLING THE BLACK HOLE: CHALLENGES IN TAXONOMY TO PROTECT AMPHIBIANS

Less than 10% of species on the planet have been discovered and fewer than 1% are known beyond brief anatomical descriptions (Wilson 2005). Without a doubt, our alarmingly inadequate knowledge of the Earth's diversity is one of the most significant challenges to effectively protect threatened species, all the more urgent as biologically rich regions are destroyed at unprecedented rates.

An excellent example of the significance of this problem is provided by extinction risk assessments, such as those integral to the Global Amphibian Assessment. However, Red Lists of threatened species only evaluate formally described species. Although undescribed species may well have a high risk of extinction, they are ignored by conservation initiatives that rely on information contained within the IUCN Red List. Therefore, filling this taxonomic void should be a priority for the implementation of effective conservation programmes.

Among terrestrial vertebrates, sampling of amphibians appears to be particularly incomplete. This is indicated by the large number of species described during recent decades (for example, see Figure 1) at a rate of discovery that exceeds that of every other vertebrate group (Cannatella and Hillis 2004). During the period 1992-2003, the number of species of amphibians increased by 25% with most of the additions being new discoveries rather than subspecies elevated to the species rank (Kohler *et al.* 2005; and see Essay 1.1). Recent estimates indicate that the number of amphibians awaiting formal description in Southeast Asia and the Neotropics should be well above 1,000 (see below). These figures suggest that, at a global scale, the taxonomic deficit could be a serious obstacle for the success of any comprehensive programme to protect amphibians. Thus, intensive efforts in taxonomy and systematics are indispensable to secure adequate conservation measures.

Fortunately, the increasing use of genetic markers in systematics could increase the rate at which amphibian species are discovered. These tools quantify genetic variation within and among populations, which can expose genetic clusters that correspond to separate species. These data are usually complemented with geographic distribution, and morphological, or behavioural data to corroborate species identities. The use of genetic markers allows the identification of previously unsampled species and enables us to detect cryptic species that have previously been hiding under a single morphologically identified species. The available techniques include allozymes, AFLPs, microstatellites, and, most prominently, DNA sequencing (including DNA bar-coding; see Essay 11.11).

Genetic markers have been used recently to estimate the number of species of amphibians that remain to be discovered. In a review of species-level molecular phylogenies of Neotropical amphibians, Ron *et al.* (2006) found that phylogenetic studies have lead to a 28% increase in the number of known species. The increase was higher (39%) for studies where taxon sampling has been more intensive (i.e., studies that included more than 50% of the described species). This indicates that a significant number of species have either been overlooked by morphology-based taxonomic reviews or have not been sampled at all.

Given that there are approximately 2,800 described species of amphibians in the Neotropics and assuming, conservatively, that the proportion of undescribed amphibians lies between 0.28 and 0.39, then the number of Neotropical species awaiting description should lie between 784 and 1,092. This estimate is considered conservative because the proportion of species discovered should increase with taxon sampling, which until now has been exhaustive only in a few Neotropical clades. Phylogenies with non-exhaustive sampling often include predominantly species of easy access, available in the pet trade (e.g., poison-arrow frogs of the genus *Dendrobates*) and/or distributed in habitats that, because of their relative accessibility and conspicuousness, are already described.

Applying the same logic and approach to another amphibian species-rich faunal region (Indo-China, and the island archipelagos of the Philippines, Malaysia, and Indonesia), we can provide estimates of the magnitude of the problem of underestimated biodiversity using the recent phylogenetic studies of Evans *et al.* (2003), Brown (2004), and Stuart *et al.* (2006). Our estimate of undetected species in this region lies between 271 and 364 undescribed forms. We can further examine the trends in one small oceanic island archipelago country (the Philippines) that has been the subject of recent intensive diversity assessment (see http://www.herpwatch.org) and "ground truth" these estimates with first hand knowledge of new species awaiting description. The estimated numbers for the Philippines lie somewhere between 32 and 43 undescribed species (see Essay 7.3). We also have personal knowledge of approximately 55 undescribed species awaiting description in the genera *Platymantis* and *Limnonectes* from the Philippines and Sulawesi (R. Brown, A. Diesmos, and A. Alcala, unpubl.), suggesting again that the estimation process is conservative.

Advertisement calls provide a cost-effective tool for species discovery and identification. Male Trachycephalus venulosus *(Least Concern) call by inflating large lateral vocal sacs. They occur in dry forests in western Ecuador. © Santiago R. Ron*

A potential caveat with molecular techniques is that some genetic markers are inadequate to define species boundaries because they either have evolved too slowly or to fast. In addition, the use of genetic markers is still limited in developing countries, precisely in the regions where the taxonomic void is more extensive. Thus, species identification in many circumstances will continue to rely primarily in morphological or behavioural traits.

An alternative to discover morphologically cryptic species is through analysis of advertisement calls. In anurans, males produce advertisement calls which function to attract females, defend territories, or confront competing males. Because advertisement calls also have a function in species recognition and discrimination (Gerhardt and Huber 2002), they can be excellent indicators of species boundaries, in some cases as reliable as genetic markers. In one increasingly well-studied group, the Ceratobatrachine frogs of Southeast Asia and the South-West Pacific (Alcala and Brown 1999), advertisement calls have provided a small group of modestly-funded researchers with a powerful means of species delimitation. Combined with analysis of mitochondrial gene sequences, advertisement calls have served as the primary set of characters for the recognition of more than 45 undescribed species over the past 10 years. Of approximately 60 species for which sequence data and call data are both available (Brown 2004, unpubl.), only two cases exist where sequence data and call data lead to differing conclusions with regards to the distinctiveness of a species. Both are cases in which populations of frogs possess very distinctive advertisement calls, but are genetically indistinct from sympatric congeners, and both are suspected cases of hybridization and introgression.

The overwhelming trend that results from this work is the general conclusion that genetic and call data are both very illustrative tools for identification of cryptic independent evolutionary lineages, particularly when used in complimentary fashion by field workers.

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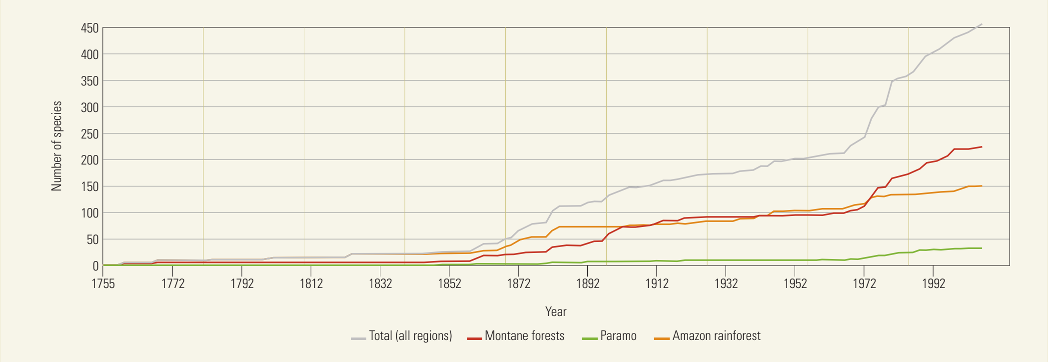
Figure 1. *An example of the large number of amphibians that remain to be described is given by the accumulated number of formally described species of amphibians in Ecuador (period 1758-2006). The number of species has almost doubled since 1970 and additions continue at a fast rate, especially from montane habitats.*



ESSAY 11.11. AMPHIBIAN CONSERVATION: NEW PERSPECTIVES THROUGH DNA BARCODING

Effective conservation requires that conservation practitioners are armed with the appropriate knowledge, specifically about what to conserve and where to conserve it. For this reason, conservation efforts on the ground rely heavily on comprehensive assessments in the field (i.e. species inventories) supported by appropriate taxonomic studies. Unfortunately, for the majority of living organisms worldwide, both have been inadequately addressed. Among amphibians, for example, we know that many tropical regions are still far from being well sampled (cf. Duellman 1999) and the recent observed increase in species numbers (over 25 per cent in 11 years; Köhler *et al.* 2005; and see Essay 1.1) is largely due to the intensified exploration of tropical areas and the application of modern techniques such as bioacoustics and molecular genetics. A major problem in both field surveys and inventory work, as well as in taxonomy, is that species are often difficult to identify. In amphibians, this is particularly problematic in species-rich genera, such as Afrotropical tree frogs (e.g., *Hyperolius*) or the Neotropical harlequin toads (*Atelopus*), which generally display little inter-specific morphological variation.

The amphibian fauna of the Kakamega Forest in western Kenya represents a case in point. This small forest fragment (240km²), long recognized as a site of global conservation importance (e.g., Fishpool and Evans 2001), is under increasing pressure, in particular due to firewood gathering and agricultural expansion. Despite the fact that it is one of the best sampled regions in Kenya, five frog species were recorded only recently (Lötters *et al.* 2006) resulting in a total of 25 species from this site. However, the taxonomic status of several species from the Kakamega Forest still remains difficult to determine due to their cryptic nature. For example, through extensive and meticulous "detective" work, we found that there are, in fact, two species of the genus *Phrynobatrachus* in the Kakamega Forest which are morphologically indistinguishable (Lötters *et al.* 2006), and at least three scientific names may be applicable to them (*P. mababiensis* from Namibia, *P. minutus* from Ethiopia and *P. scheffleri* from Kenya).

An exciting new tool to help speed the identification of known species and the discovery of new ones, is termed 'DNA barcoding', in which a short standardized fragment of DNA is sequenced and compared with reference data (e.g. Herbert *et al.* 2003). The method is easy to perform and also allows for more objectivity in species diagnosis, and only small tissue samples are required from study animals, thereby reducing time and costs. DNA barcoding is similar to the universal barcodes of products in the retail industry, and it was with the idea of making the barcode of every species on Earth available, i.e. "writing the encyclopedia of life", that the Consortium for the Barcode of Life was initiated in 2004 (http://www.barcoding.si.edu/). Although still science fiction, we may be well on our way to one day using handheld 'tricorders' to identify any life-form directly in the field, just as Mr. Spock did in the famous 1960s space drama *Star Trek*. Apart from the obvious advantages for conservation-related initiatives, barcoding's benefits include the ability to identify fragmentary specimens, and different life-stages (e.g., amphibian larvae) to the level of species (review in Savolainen *et al.* 2005).

There has been a lot of discussion about the barcoding movement, including the anxiety that classical taxonomy will be replaced by a code-based, rather than organism-focused, discipline that deals with 'black box' species (i.e., information without knowledge), far removed from actual species and hence from conservation (e.g. Ebach and Holdrege 2005). DNA barcoding can only be a supplement to classical taxonomy and consequently conservation (cf. Gregory 2005). Furthermore, the accuracy of DNA barcoding is not quite 100 per cent. In some cases, although genetic variation is low, data other than genetic information (such as advertisement calls) can also suggest species status (e.g. Lötters *et al.* 2005).

The idea of using a single universal genetic marker for all groups of organisms has been critically discussed. In contrast to a fragment of the cytochrome oxidase subunit I gene (COI) (Herbert *et al.* 2003), which has been widely used in, for example, fish and birds, Vences *et al.* (2005) advocated that in amphibians the mitochondrial 16S rRNA gene fulfills the requirements better then COI due to stronger constancy of priming sites. Currently, a debate has arisen about the use of mitochondrial versus nuclear DNA, or both combined, for barcoding (Rubinoff 2006).

But how relevant and useful is DNA barcoding for the purposes of amphibian conservation? Can we just undertake a "rapid assessment" into an unexplored region, collect amphibian samples, barcode them, and immediately obtain results? Certainly, some databases already exist with catalogued DNA barcode details, such as NCBI/GenBank in the USA, Europe's EBI/EMBL Nucleotide Sequence Database, and the DNA Database of Japan (DDBJ) – all inter-linked. However, the data are unevenly distributed with respect to taxon and geography. For example, a search of GenBank[1], the largest and most widely used of the databases, for 16S gene sequences of the Neotropical poison frogs (Dendrobatidae), a family of frogs attractive to scientists for different reasons, reveals that these are well represented (665 sequences versus ~ 240 described species). In contrast, the abovementioned Afrotropical frog genus *Phrynobatrachus* is represented by not more than 67 16S gene sequences, and 17 putative taxa out of about 69 known species. Apart from problems due to missing sequence data for many species, other criticisms include the need to rely entirely on the taxonomic identification of original voucher specimens against which sequence data is checked, the genetic purity of the sequence itself, and the possible overlap of inter- and intra-specific variation (Meyer and Paulay 2005).

In summary, DNA barcoding certainly provides new perspectives to amphibian conservation. However, at the current stage, its applicability is still limited due to lack of reference data for most species and because the taxonomy of many species (complexes) is not at the stage that allows samples from the field to be quickly sequenced and then definitively allocated to species. Nonetheless, coupled with traditional taxonomic tools, it could have important uses for disclosing hidden diversity.

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[1] http://www.ncbi.nih.gov, accessed 1 May 2006

Afrixalus osorioi (Least Concern), a banana frog only recently recorded from the Kakamega Forest, may represent a species complex. However, the DNA barcode for specimens from the type locality in Angola is not available. © Stefan Lötters

DNA barcoding is a powerful tool for linking different life stages, e.g. frog tadpoles to adults. In this case, the photograph shows a typical Xenopus *larva collected at Kakamega Forest from where only one* Xenopus *species is known. © Stefan Lötters*

ESSAY 11.12. THE AMPHIBIAN SPECIALIST GROUP: PAST, PRESENT AND FUTURE

The Global Amphibian Assessment (GAA) sharpened the scientific community's focus on both the global nature and extent of amphibian declines and extinctions (Stuart *et al.* 2004). The results of the GAA demonstrated that the amphibian crisis is complex in nature and requires a comprehensive set of solutions. While traditional approaches to conservation will continue to form the core of a global strategy, novel approaches will also be required to address threats such as emerging infectious diseases and global climate change.

Under the auspices of the World Conservation Union (IUCN) and Conservation International (CI), an International Amphibian Summit was convened in September 2005 in Washington, DC, to devise a strategic global plan of action for amphibian conservation in the form of the Amphibian Conservation Action Plan (ACAP). Prior to the Summit, the IUCN Species Survival Commission (IUCN/SSC) focused on promoting amphibian conservation through the Global Amphibian Specialist Group (GASG), on decline-related research through the Declining Amphibian Populations Task Force (DAPTF; see Essay 11.1), and on monitoring and assessments through an informal network of researchers contributing data to the GAA. These programmes have accomplish a great deal, but the magnitude of the current crisis requires a coordinated, unified approach to amphibian conservation, research and assessment that is beyond the scope of any of these individual initiatives (Mendelson *et al.* 2006). Recognizing this, a decision was made to merge the GASG, DAPTF and the GAA to form a single body committed to implementing a global strategy for amphibian conservation: the Amphibian Specialist Group (ASG).

The logo of the Amphibian Specialist Group

The ASG is a network of conservation professionals working under the IUCN/SSC framework with the mission of enabling amphibian research and conservation worldwide. The ASG envisions taking IUCN's Specialist Group model to the next level of effectiveness by establishing a Secretariat that will coordinate regional working groups and a global web of stakeholders to leverage their intellectual, institutional, and financial capacity. The Secretariat has two Co-Chairs (currently Claude Gascon and James Collins), an Executive Officer, and Conservation, Research, Assessment, Development and Communications Divisions, each headed by a director.

The Conservation Division promotes and supports the conservation of threatened amphibian species globally. By strengthening partnerships among institutions in developed and developing countries, and by forging links with groups such as other IUCN/SSC Specialist Groups, the ASG builds regional capacity to ensure that amphibians are incorporated into conservation plans. Through a collaborative partnership with Arizona State University, amphibian conservation and research projects in priority regions are supported by grants through the Critical Ecosystems Partnership Fund (CEPF), based at Conservation International. Additionally, the ASG also supports conservation and research through the allocation of Seed Grants, building upon the successful model established by DAPTF. An Amphibian Conservation Award will be presented annually to recognize an individual who has made significant contributions to amphibian conservation worldwide.

The Research Division works closely with research partners from the global network of national and regional working groups to apply a strategic and coordinated approach to research on the causes of global amphibian declines and to disseminating the results. Many amphibian declines and extinctions are caused by complex interactions of factors such as disease and climate change, and understanding these processes is vital for effective conservation action. The Research division works to narrow knowledge gaps through targeted research agendas for poorly known regions and groups, and strives to apply scientific research results to conservation. A central on-line storehouse of publications and current research results is being developed to facilitate information exchange amongst researchers and conservation practitioners. Information will also be presented in multiple languages to facilitate knowledge-sharing. The ASG will support targeted field research in poorly known regions of the world and link global expertise with local expertise in developing countries by conducting training courses for field practitioners and students. These actions will strengthen regional and country-based capacity to improve knowledge of the taxonomy, distribution, abundance, and causes of amphibian declines.

The Assessment Division – which fulfills the ASG's Red List Authority responsibilities – will regularly assesses the conservation status of every amphibian species in the world through the GAA. The ASG aims to make the GAA a more proactive process based on a "bottom up" flow of data to ensure the most up-to-date and accurate information on every amphibian species. The Assessment Division will undertake periodic analysis of the database and communicate the findings to the global network and beyond. Findings will be distributed on CDs to those regions where internet access is poor or unavailable. Information will be disseminated in paper where appropriate via working groups through workshops and meetings. The Assessment division will regularly assess the conservation status of every amphibian species and feed this information into on-the-ground identification of conservation targets and priorities.

In coordination with the directors of the Conservation, Research and Assessment divisions, regional working group heads will initiate projects in their respective regions. To aid in the outreach and fundraising aspects of the ASG network, an Advisory Board has been established comprising key stakeholders and advisor-advocates representing policymakers, the media, business, academia, conservation organizations, and government agencies. ASG communications will include a new and expanded bi-monthly newsletter (*Froglog*) that will be available free of charge on the ASG website (www.amphibians.org).

The ASG will ensure long-term sustainability of amphibian research and conservation by building on DAPTF's worldwide network of expert working groups and integrating them into IUCN's global network of Specialist Groups. The ASG will support the development and dissemination of new tools and best practices for adoption and application by a network of local, national, and regional working groups. By mainstreaming amphibian conservation best practices into the global web of international conservation programmes, national planning processes, and local practice, the ASG will ensure the sustainability of amphibian research and conservation.

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