CHAPTER 7. AMPHIBIANS OF THE INDOMALAYAN REALM

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.

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.

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**

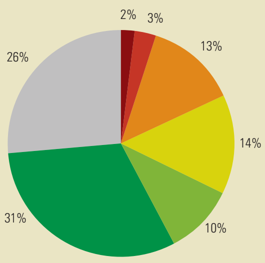


Table 1. *The Extinct amphibians of the Indomalayan Realm.*

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

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.

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*

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 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).

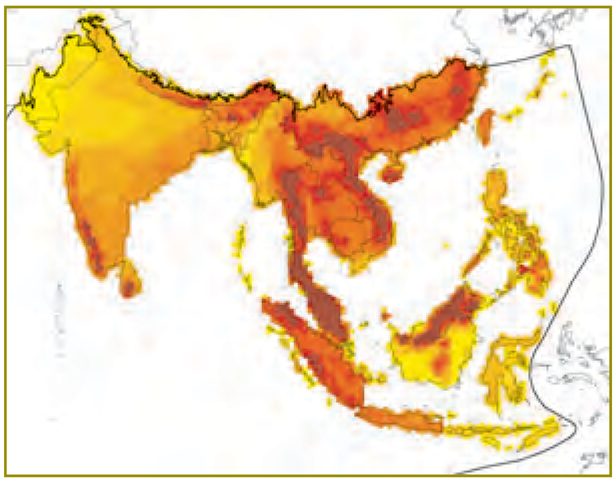


Figure 2. *The species richness of amphibians in the Indomalayan Realm, with darker colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes; maximum richness equals 84 species.*

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**

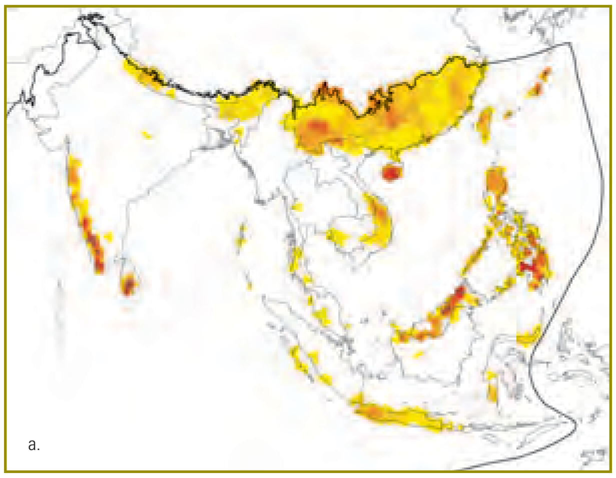
Table 2. *The number of Indomalayan amphibians in each taxonomic Family present in the region.*

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**



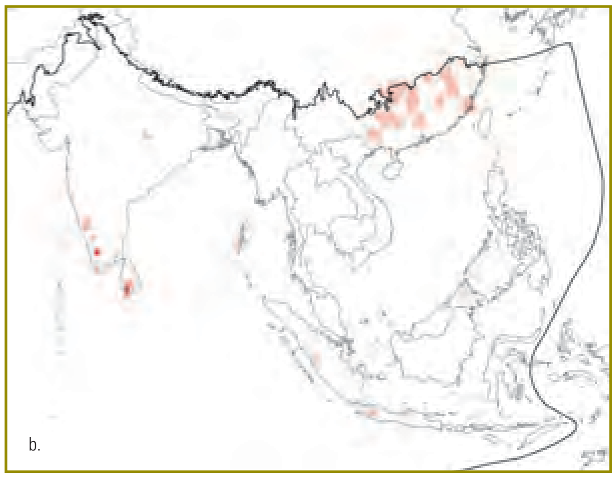


Figure 3. *a) The richness of threatened amphibians in the Indomalayan Realm, with darker colours corresponding to regions of higher richness. Colour scale based on 10 quantile classes; maximum richness equals 29 species. b) The richness of CR amphibians in the Indomalayan Realm, with darker colours 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

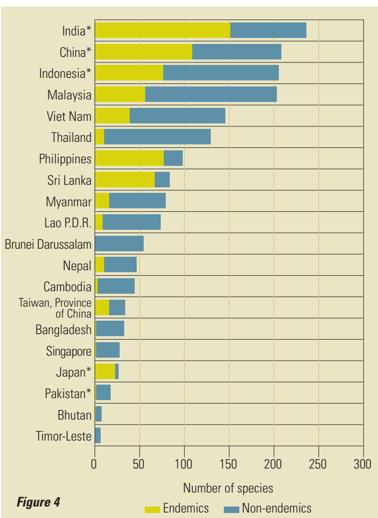


Figure 4. *The number of extant amphibians present in and endemic to each Indomalayan country. *denotes countries not entirely within the Indomalayan Realm, hence only the species whose ranges fall within the region are included. Note that 102 described species are known from Sri Lanka, but because 19 of these are extinct, only 83 are included in this figure.*

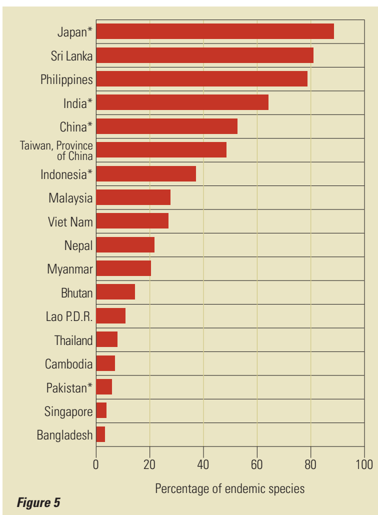


Figure 5. *Percentage of species endemic to each Indomalayan country. Countries with no endemic species are not included. *denotes countries not entirely within the Indomalayan Realm, hence only the species whose ranges fall within the region are included.*

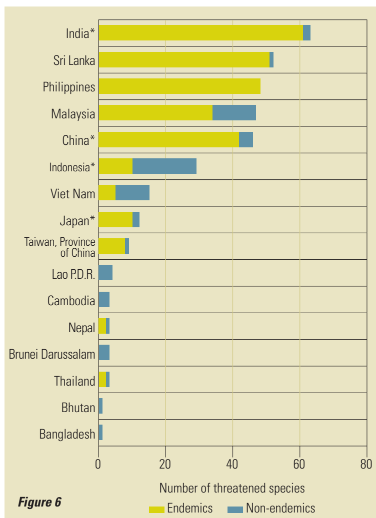


Figure 6. *The number of threatened amphibians present in and endemic to each Indomalayan country. Countries with no threatened species are not included in the diagram. *denotes countries not entirely within the Indomalayan Realm, hence only the species whose ranges fall within the region are included.*

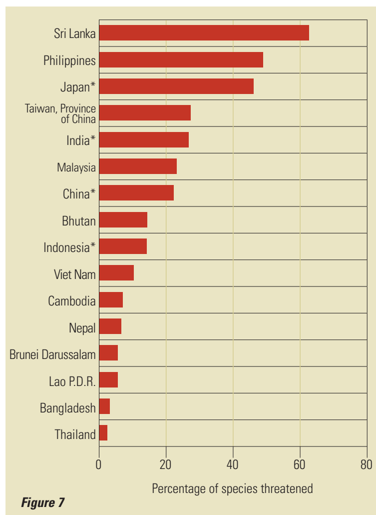


Figure 7. *Percentage of native species that are threatened. Countries with no threatened species are not included in the diagram. *denotes countries not entirely within the Indomalayan Realm, hence only the species whose ranges fall within the region are included.*

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

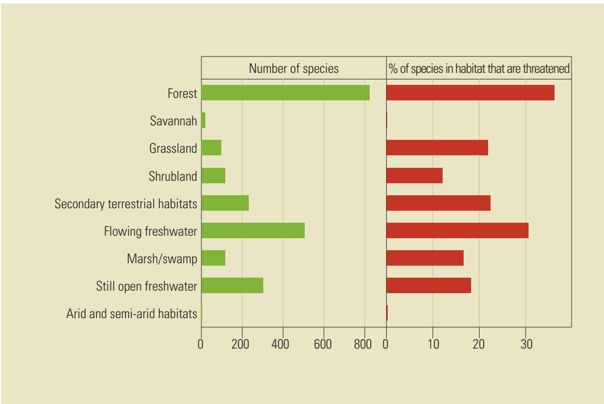


Figure 8. *The habitat preferences of Indomalayan amphibians. The plot on the left-hand side shows the number of species in the region in each habitat type. On the right-hand side, the percentage of these species which are threatened is given.*

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.*

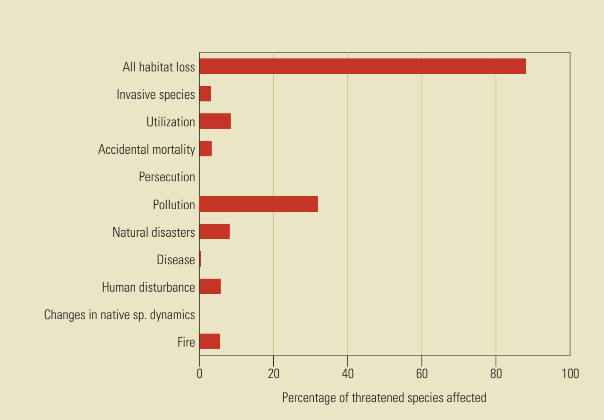


Table 7. *The purposes for which amphibians are used in the Indomalayan Realm. The numbers in brackets are the number of species within the total that are threatened species.*

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.

REFERENCES

Alcala, A.C. and Brown, W.C. 1998. *Philippine Amphibians: An Illustrated Field Guide.* Bookmark Press, Makati City, Philippines.

Bain, R.H. and Nguyen, Q.T. 2004. Herpetofaunal diversity of Ha Giang Province in northeastern Vietnam, with descriptions of two new species. *American Museum Novitates* **3453**:1-42.

Bamabaradeniya, C.N.B. and Samarasekara, V.N. (eds.) 2001. *An Overview of the Threatened Herpetofauna of South Asia.* IUCN, Colombo, Sri Lanka.
Beck, R.A., Burbank, D.W., Sercombe, W.J., Riley, G.W., Barndt, J.K. Berry, J.R., Afzal, J., Khan, A.M., Jurgen, H., Metje, J., Cheema, A., Shafique, N.A., Lawrence, R.D., and Khan, M.A. 1995. Stratigraphic evidence for an early collision between northwest India and Asia. *Nature* **373**:55-58.
Berry, P.Y. (1975) *The Amphibian Fauna of Peninsula Malaysia.* Tropical Press, Kuala Lumpur, Malaysia.
Biju, S.D. and Bossuyt, F. 2003. *New frog family from India reveals an ancient* biogeographical link with the Seychelles. *Nature* **425**:711-714.
Bourret, R. 1942. Les Batraciens de l'Indochine. *Institut Océanographique de l'Indochine* **6**:1-547
Cha-nard, T. 2003. *A Photographic Guide of Amphibians in Thailand.* Darnsutha Press Co. Ltd, Bangkok, Thailand.
Chan-ard, T., Grossmann, W., Gumprecht, A. and Schulz, K.-D. 1999. *Amphibians and Reptiles of Peninsular Malaysia and Thailand - An Illustrated Checklist.* Bushmaster Publications, Wuerselen, Germany.
Curran, L.M., Trigg, S.N., McDonald, A.K, Astiani, D., Hardiono, Y.M., Siregar, P., Caniago, I. and Kasischke, E. 2004. Lowland forest loss in protected areas of Indonesian Borneo. *Science* **303**:1000-1003.
Daniel, J.C. 2002. *The Book of Indian Reptiles and Amphibians.* Bombay Natural History Society and Oxford University Press, Mumbai, India.
Daniels, R.J.R. 2005. *Amphibians of Peninsular India.* Universities Press, Hyderabad, India.
Das, I. 1999. Biogeography of the amphibians and reptiles of the Andaman and Nicobar Islands. In: H. Ota (ed.), *Tropical Island Herpetofauna. Origin, Current Diversity and Conservation*, pp. 43-77. Elsevier Science B.V., Amsterdam, The Netherlands.
Das, I. 2002. *An Introduction to the Amphibians and Reptiles of Tropical Asia.* Natural History Publications (Borneo), Sabah, Malaysia.
Diamond, J. 1997. *Guns, Germs and Steel – a Short History of Everybody for the Last 13,000 Years.* Chatto & Windus, UK.
Dutta, S.K. 1997. *Amphibians of India and Sri Lanka.* Odyssey Publishing House, Bhubaneswar, India.
Dutta, S.K. and Manamendra-Arachchi, K. 1996. *The Amphibian Fauna of Sri Lanka.* Wildlife Heritage Trust of Sri Lanka, Colombo, Sri Lanka.
Fei, L., Ye, C.-Y., Huang, Y.-A. and Liu, M.-Y. 1999. *Atlas of Amphibians of China.* Henan Science and Technical Press, Zhengzhou, China
Fei, L., Ye, C.-Y., Jiang, J.-P., Xie, F. and Huang, Y. 2005. *An Illustrated Key to Chinese Amphibians.* Sichuan Publishing House of Science and Technology, Chengdu, China.
Frost, D.R., Grant, T., Faivovich, J.N., Bain, R.H., Haas, A., Haddad, C.F.B., de Sá, R.O., Channing, A., Wilkinson, M., Donnellan, S.C., Raxworthy, C.J., Campbell, J.A., Blotto, B.L., Moler, P., Drewes, R.C., Nussbaum, R.A., Lynch, J.D., Green, D.M. and Wheeler, W.C. 2006. The amphibian tree of life. *Bulletin of the American Museum of Natural History* **297**:1-370.
Goris, R.C. and Maeda, N. 2004. *Guide to the Amphibians and Reptiles of Japan.* Krieger, Malabar, Florida, USA.
Gower, D.J. and Wilkinson, M. 2005. Conservation biology of caecilian amphibians. *Conservation Biology* **19**:45-55.
Inger, R.F. 1966. The systematics and zoogeography of the Amphibia of Borneo. *Fieldiana: Zoology* **52**:1-402.
Inger, R.F. 1999. Distribution of amphibians in southern Asia and adjacent islands,. In: W.E. Duellman (ed.), *Patterns of Distribution of Amphibians: A Global Perspective*, pp. 445-482. Johns Hopkins University Press, Baltimore, Maryland, USA.
Inger, R.F. and Stuebing, R.B. 1997 (and 2005 update). *A Field Guide to the Frogs of Borneo.* Borneo Natural History Publishers, Kota Kinabalu, Malaysia.
Inger, R.F., Orlov, N. and Darevsky, I.S. 1999. Frogs of Vietnam: A report on new collections. *Fieldiana: Zoology* **92**:1-46.
Iskandar, D.T. 1998. *The Amphibians of Java and Bali.* LIPI Field Guide Series, Yayasan Hayati, Bogor, Indonesia.
Iskandar, D.T. and Colijn, E. 2000. Preliminary Checklist of Southeast Asian and New Guinean Herpetofauna I. Amphibians. *Treubia* 31(3) supplement: 1-134. Research and Development Centre for Biology, LIPI, Bogor, Indonesia.
Japan Agency of Environment 2000. *Threatened Wildlife of Japan - Red Data Book. 2nd ed. Reptilia/Amphibia* (in Japanese with English summary). Japan Wildlife Research Center, Tokyo, Japan.
Khan, M.S. 2006. *Amphibians and Reptiles of Pakistan.* Krieger Publishing Company, Malabar, Florida, USA.
Lim, K.P. and Lim, F.L.K. 1992. *A Guide to the Amphibians and Reptiles of Singapore.* Singapore Science Centre, Singapore.
Lips, K.R., Brem, F., Brenes, R., Reeve, J.D., Alford, R.A., Voyles, J., Carey, C., Livo, L., Pessier, A.P. and Collins, J.P. 2006. Emerging infectious disease and the loss of biodiversity in a Neotropical amphibian community. *Proceedings of the National Academy of Sciences* **103**:3165-3170.
Maeda, N. and Matsui, M. 1999. *Frogs and Toads of Japan.* Bun-ichi Sogo, Shuppan, Japan.
Malkmus, R., Manthey, U., Vogel, G., Hoffmann, P. and Kosuch, J. 2002. *Amphibians and Reptiles of Mount Kinabalu (North Borneo).* A.R.G. Gantner Verlag Kommanditgesellschaft, Ruggell (Liechtenstein).
Manamendra-Arachchi, K. and Pethiyagoda, R. 2005. The Sri Lankan shrub-frogs of the genus *Philautus* Laurent, 1943 (Ranidae, Rhacophorinae), with description of 27 new species. *Raffles Bulletin of Zoology Supplement* **12**:163-303.
McKay, J.L. 2006. *A Field Guide to the Amphibians and Reptiles of Bali.* Krieger Publishing Company, Malabar, Florida, USA.
Molur, S. and Walker, S. 1998. Conservation assessment of the herpetofauna of India – an overview. *Hamadryad* **23**:169-178.
Morrison, J.C., Olson, D.M., Loucks, C.J., Dinerstein, E., Allnutt, T.F., Wikramanayake, E.D., Ricketts, T.H., Burgess, N.D., Kura, Y., Powell, G.V.N., Lamoreux, J.F., Underwood, E.C., Wettengel, W.W., D'Amico, J.A., Hedao, P., Itoua, I., Kassem, K.R. and Strand, H.E. 2001. Terrestrial ecoregions of the world: a new map of life on earth. *BioScience* **51**:933-938
Nabhitabhata, J. 1989. Species diversity of Thai herpetofauna. In: S. Wongsiri and S. Laolohakarn (eds.), *Biodiversity in Thailand*, pp. 169-204, The Science Society of Thailand, Bangkok, Thailand.
Ohler, A., Marquis, O., Swan, S. and Grosjean, S. 2000. Amphibian biodiversity of Hoang Lien Nature Reserve (Lao Cai Province, northern Vietnam) with description of two new species. *Herpetozoa* **13**:71-87.
Ohler, A., Swan, S.R. and Daltry, J.C. 2002. A recent survey of the amphibian fauna of the Cardamom Mountains, southwest Cambodia with descriptions of three new species. *Raffles Bulletin of Zoology* **50**:465-481.
Orlov, N.L., Ananjeva, N.B. and Ho, T.C. 2006. A new cascade frog (Amphibia: Ranidae) from Central Vietnam. *Russian Journal of Herpetology* **13**:155-163.
Orlov, N.L., Murphy, R.W., Ananjeva, N.B., Ryabov, S.A. and Ho, C.T., 2002. Herpetofauna of Vietnam, a checklist. Part I. Amphibia. *Russian Journal of Herpetology* **9**:81-104.
Ota, H. 2000. Current status of the threatened amphibians and reptiles of Japan. *Population Ecology* **42**:5-9.
Pawar, S., Koo, M.S, Kelley, C., M. Ahmed, M.F., Chaudhuri, S., Sarkar, S. 2007. Conservation assessment and prioritization of areas in Northeast India: priorities for amphibians and reptiles. *Biological Conservation* **136**:346-361.
Pounds, J.A., Bustamante, M.R., Coloma, L.A., Consuegra, J.A., Fogden, M.P.L., Foster, P.N., La Marca, E., Masters, K.L., Merino-Viteri, A., Puschendorf, R., Ron, S.R., Sánchez-Azofeifa, G.A., Still, C.J. and Young, B.E. 2006. Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature* **439**:161-167.

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*

Redford, K.H. 1992. The empty forest. *BioScience* **42**:412–422.
Schleich, H.H. and Kästle, W. (eds.). 2002. *Amphibians and Reptiles of Nepal.* A.R.G. Gantner Verlag K.G., Ruggell.
Stuart, B.L. 1999. Amphibians and reptiles. In: W. Duckworth, R. Salter and Khounboline (eds.), *Wildlife in Lao PDR: 1999 Status Report*, pp. 43-67. IUCN/WCS/CPAWM, Vientiane.
Stuart, B.L. 2005. New frog records from Laos. *Herpetological Review* **36**:473-479.
Stuart, B.L. and Emmett, D.A. in press. A collection of amphibians and reptiles from the Cardamom Mountains, southwestern Cambodia. *Fieldiana: Zoology.*
Stuart, B.L., Sok, K. and Neang, T. 2006. A collection of amphibians and reptiles from hilly Eastern Cambodia. *Raffles Bulletin of Zoology* **54**:129-155.
Stuart, S.N., Chanson, J.S., Cox, N.A., Young, B.E., Rodrigues, A.S.L., Fischman, D.L. and Waller, R.W. 2004. Status and trends of amphibian declines and extinctions worldwide. *Science* **306**:1783-1786.
Teynie, A., David, P., Ohler, A. and Luanglath, K. 2004. Notes on a collection of amphibians and reptiles from southern Laos, with a discussion of the occurrence of Indo-Malayan species. *Hamadryad* **29**:33-62.
Tiwari, S.K. 1991. *Zoogeography of Indian Amphibians.* Today and Tomorrow's Printers and Publishers, New Delhi, India.
Tyler, M.J. 1999. Distribution patterns of amphibians in the Australo-Papuan region. In: W.E. Duellman (ed.), *Patterns of Distribution of Amphibians. A Global Perspective*, pp. 541-556. The Johns Hopkins University Press, Baltimore, Maryland, USA.
Uchiyama, R., Maeda, N., Numata, K. and Seki, S. 2002. *A Photographic Guide: Amphibians and Reptiles in Japan.* Heibonsha, Tokyo, Japan.
Whitten, T., van Dijk, P.P., Curran, L., Meijaard, E., Supriatna, J. and Ellis, S. 2005. Sundaland. In: R.A. Mittermeier, P. Robles-Gil, M. Hoffmann, J.D. Pilgrim, T.M. Brooks, C.G. Mittermeier, J.L. Lamoreux and G. Fonseca (eds.), *Hotspots Revisited: earth's biologically richest and most threatened ecoregions*, pp. 164-172. CEMEX, Mexico City, Mexico.
Wildlife Conservation Society of the Philippines. 1997. *Philippine Red Data Book.* Bookmark, Manila, Philippines. 262 pp.
Xie, Y. and Wang, S. 2004. *China Species Red List, Vol. 1 Red List*, Higher Education Press, Beijing, China.
Ye, C.-Y, Fei, L. and Hu, S.Q. 1993. *Rare and Economic Amphibians of China.* Sichuan Publishing House of Science and Technology, Chengdu, China.
Zhao, E.M. 1998. *China Red Data Book of Endangered Animals – Amphibia.* Science Press, Beijing, China.
Zhao, E.M. 1999. Distribution patterns of amphibians in temperate East Asia. In: W.E. Duellman, W.E., *Patterns of Distribution of Amphibians: A Global Perspective*, pp. 421-443, Johns Hopkins University Press, Baltimore, Maryland, USA.
Zhao, E.M. and Adler, K. 1993. *Herpetology of China.* Society for the Study of Amphibians and Reptiles, Lawrence, Kansas, USA.
Zhao, E.M., Chang, H.W., Zhao, H. and Adler, K. 2000. Revised checklist of Chinese Amphibia and Reptilia. *Sichuan Journal of Zoology* **19**:196-207.
Ziegler, T. 2002. *Die Amphibien und Reptilien eines Tieflandfeuchtwald-Schutzgebietes in Vietnam.* NTV Wissenschaft, Münster.

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*, *Occidozyga*, *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

References

Brown, R.M. and Iskandar, D.T. 2000. Nest Site Selection, Larval Hatching and Advertisement Calls of *Limnonectes arathooni* from southwestern Sulawesi (Celebes) Island, Indonesia. *Journal of Herpetology* **34.3**:404-413.

Evans, B.J., Brown, R.M., McGuire, J.A., Supriatna, J., Andayani, N., Diesmos, A., Iskandar, D., Melnick, D.J., Canatella, D.C. 2003. Phylogenetics of Fanged Frogs: Testing Biogeographical Hypotheses at the Interface of the Asian and Australian Faunal Zone. *Systemic Biology* **52**:794-819.

Günther, R. 2006. Derived reproductive modes in New Guinean anuran amphibians and description of a new species with paternal care in the genus *Callulops* (Microhylidae). *Journal of Zoology* **268**:153-170

Inger, R.F. 1966. The systematics and zoogeography of the Amphibia of Borneo. *Fieldiana Zoology* **52**:1-402.

Inger, R.F. and Iskandar, D.T. 2005. A collection of Amphibians from West Sumatra, with description of a new species of *Megophrys* (amphibia: Anura) *Raffles Bulletin of Zoology* **53**:133-142.

Inger, R.F. and Voris, H.K. 1988. Taxonomic status and reproductive biology of Bornean tadpole-carrying frogs. *Copeia* **1988**:1060-1062.

Inger, R.F. and Voris, H.K. 2001. The biogeographical relations of the frogs and snakes of Sundaland. *Journal of Biogeography* **28**:863-891.

Inger, R.F. and Stuebing, R.B. A Field Guide to the Frogs of Borneo. Natural History Publications, Kota Kinabalu, Borneo.

Iskandar, D.T. and Tjan, K.N. 1996. The Amphibians and Reptiles of Sulawesi, with notes on the distribution and chromosomal number of frogs. In: D.J. Kitchener and A. Suyanto (eds.), *Proc. of the First International Conference on Eastern Indonesian-Australian Vertebrates*, pp.39-46. Western Australian Museum for Lembaga Ilmu Pengetahuan Indonesia, Perth, Western Australia, Australia.

Mittermeier, R.A., Gil, P.R. and Mittermeier, C.G. 1997. *Megadiversity. Earth's Biologically Wealthiest Nations.* CEMEX, Mexico City, Mexico.

Richards, S.R. and Iskandar, D.T. 2000. A new tiny species of frog of the genus *Oreophryne* (Anura, Microhylidae) from the mountains of Irian Jaya, Indonesia *Raffles Bulletin of Zoology* **48**:257-262.

Whitten, T., van Dijk, P.P., Curran, L., Meijaard, E., Wood, P., Supriatna, J. and Ellis, S. 2004. Sundaland. In: R.A. Mittermeier, P. Robles-Gil, M. Hoffmann, J.D. Pilgrim, T.M. Brooks, C.G. Mittermeier, J.L. Lamoreux and G. Fonseca (eds.), *Hotspots Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*, pp. 164-172. CEMEX, Mexico City, Mexico.

1 The Irian Jaya Biodiversity Conservation Priority-Setting Workshop. Conservation International. Biak 7-11 January 1997 ■

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**

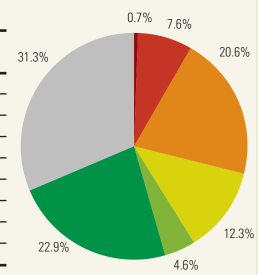


Figure 1. *Summary of the Red List status for amphibians in the Western Ghats, based on the results of the Global Amphibian Assessment.*

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.

S D Biju, Rachunliu G Kamei, Bhatta, G., Varad Giri, Neil Cox, Indraneil Das and Franky Bossuyt

References

Bhatta, G., Dinesh, K.P., Prashanth, P. and Kulkarni, N.U. 2007. A new species of *Gegeneophis* Peters (Amphibia: Gymnophiona: Caeciliidae) from Goa, India. *Zootaxa* **1409**:51-59.

Bickford, D., Lohman, D.J., Sodhi, N.S., Ng, P.K.L., Meier, R., Winker, K., Ingram, K. and Das, I. 2007. Cryptic species as a window on diversity and conservation. *Trends in Ecology and Evolution* **22**(3):148-155.

Biju, S.D. 2001. A Synopsis to the Frog Fauna of the Western Ghats, India. *Occasional Papers of the Indian Society for Conservation Biology* **1**:1-24.

Biju, S.D and Bossuyt, F. 2003. New frog family from India reveals an ancient biogeographical link with the Seychelles. *Nature* **425**:283-284.

Bossuyt, F., Meegaskumbara, M., Beenaerts, N., Gower, D., Pethiyagoda, R., Roelants, K., Mannaert, A., Wilkinson, M., Bahir, M.M., Manamendra-Arachchi, K., Ng, P.K.L., Schneider, C.J., Oommen, O.V. and Milinkovitch, M.C. 2004. Local endemism within the Western Ghats-Sri Lanka biodiversity hotspot. *Science* **306**:479-481.

Collins, D. 1990. *The Last Rain Forests.* Mitchell Beazley and IUCN, London.

Daniels, R.J. 1992. Geographical distribution patterns of amphibians in the Western Ghats, India. *Journal of Biogeography* **19**:521-529.

Das, I. 2000. Updates in amphibian systematics and nomenclature for the Indian region. *Biodiversity India, ISCB Newsletter* **8-12**:3-5.

Das, I. and Dutta, S.K. 2006. New species of *Polypedates* (Anura: Rhacophoridae) from the Western Ghats, southwest India. *Journal of Herpetology*. **40**(2):214-220.

Dutta, S.K. 1997. *Amphibians of India and Sri Lanka (Checklist and bibliography).* Odessy Publishing House, Bhubaneswar. 342 pp.

Frost, D.R. 2007. Amphibian Species of the World: an online reference. Version 5.0 (12 July 2007). Electronic Database accessible at http://research.amnh.org/herpetology/amphibia/index.html. American Museum of Natural History, New York, USA.

Frost, D.R., Grant, T., Faivovich, J.N., Bain, R.H., Haas, A., Haddad, C.F.B., de Sá, R.O., Channing, A., Wilkinson, M., Donnellan, S.C., Raxworthy, C.J., Campbell, J.A., Blotto, B.L., Moler, P., Drewes, R.C., Nussbaum, R.A., Lynch, J.D., Green, D.M. and Wheeler, W.C. 2006. The amphibian tree of life. *Bulletin of the American Museum of Natural History* **297**:1-370.

Inger, R.F. and Dutta, S.K. 1986. An overview of the amphibian fauna of India. *Journal of the Bombay Natural History Society* **83**:135-146.

Inger, R.F., Shaffer, H.B., Koshy, M. and Bakde, R. 1987. Ecological structure of a herpetological assemblage in South India. *Amphibia-Reptilia* **8**:189-202.

Kothari, A., Pratibha, P., Shekhar, S. and Dilnavaz, V. 1989. *Management of National Parks and Sanctuaries in India: A Status Report.* Ministry of Environment and Forests, Government of Kerala, New Delhi.

Pillai, R.S. and Ravichandran, M.S. 1999. Gymnophiona (Amphibia) of India, a taxonomic study. *Records of the Zoological Survey of India, Occasional Paper* No. 172. 117 pp.

Rodgers, W.A. and Panwar, H.S. 1988. *Planning a Wildlife Protected Area, Network India.* Wildlife Institute of India, Dehra Dun.

Roelants, K., Jiang, J. and Bossuyt, F. 2004. Endemic ranid (Amphibia: Anura) genera in southern mountain ranges of the Indian subcontinent represent ancient frog lineages: evidence from molecular data. *Molecular Phylogenetics and Evolution* **31**:730-740.

Roelants, K., Gower, D.J., Wilkinson, M., Loader, S.P., Biju, S.D., Guillaume, K., Moriau, L. and Bossuyt, F. 2007. Global patterns of diversification in the history of modern amphibians. *Proceedings of the National Academy of Sciences, USA* **104**:887-892.

Van Bocxlaer, I., Roelants, K., Biju, S.D., Nagaraju, J. and Bossuyt, F. 2006. Late Cretaceous Vicariance in Gondwanan Amphibians. *PLoS ONE* **1**(1):e74.

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).

Rafe Brown, Arvin Diesmos, and Angel Alcala

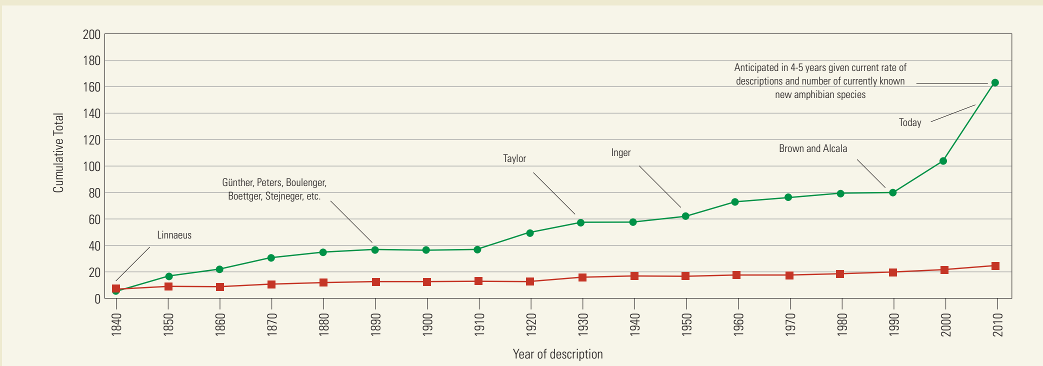


Figure 1. *Species accumulation curve for Philippine amphibians, including endemic (circles) and non-endemic (squares) species. Estimates of numbers of new species awaiting description are based on a combination of morphological, behavioural, and ecological character differences, with species' distinctiveness confirmed by bioacoustic and molecular data.*

References

Alcala, A.C. and Brown, W.C. 1999. Philippine frogs of the genus *Platymantis* (Amphibia: Ranidae). *Philippine Journal of Science* **128**:281-287.

Brown, R.M. 2004. "Evolution of ecomorphological variation and acoustic diversity in mate-recognition signals of Southeast Asian forest frogs (subfamily Platymantinae)". Ph.D. Dissertation, University of Texas, Austin, Texas, USA.

Brown, R.M., Diesmos, A.C. and Alcala, A.C. 2002 ("2001"). The state of Philippine herpetology and the challenges for the next decade. *Silliman Journal* **42**:18-87.

Brown, R.M. and Guttman, S.I. 2002. Phylogenetic systematic of the *Rana signata* complex of Philippine and Bornean stream frogs; reconsideration of Huxley's modification of Wallace's Line at the Oriental-Australian faunal zone interface. *Biological Journal of the Linnean Society* **76**:393-461.

Brown W.C., Brown, R.M. and Alcala, A.C. 1997. Species of the *hazelae* group of *Platymantis* (Amphibia: Ranidae) from the Philippines, with descriptions of two new species. *Proceedings of the California Academy of Sciences* **49**:405-421.

Catibog-Sinha, C.S. and Heaney, L.R. 2006. *Philippine biodiversity: Principles and Practice.* Haribon Foundation for Conservation of Natural Resources, Quezon City, Philippines.

Diesmos, A.C., Brown, R.M., Alcala, A.C., Sison, R.V., Afuang, L.E. and Gee, G.V.A. 2002. Philippine amphibians and reptiles. In: P.S. Ong, L.E. Afuang and R.G. Rosell-Ambal (eds.), *Philippine Biodiversity Conservation Priorities: a Second Iteration of the National Biodiversity Strategy and Action Plan*, pp.26-44. Department of the Environment and Natural Resources–Protected Areas and Wildlife Bureau, Conservation International Philippines, Biodiversity Conservation Program–University of the Philippines Center for Integrative and Developmental Studies, and Foundation for the Philippine Environment. Quezon City, Philippines.

Evans, B.J., Brown, R.M., McGuire, J.A., Supriatna, J., Andayani, N., Diesmos, A.C., Iskandar, D., Melnick, D.J. and Cannatella, D.C. 2003. Phylogenetics of fanged frogs: testing biogeographical hypotheses at the interface of the Asian and Australian faunal zones. *Systematic Biology* **52**:794-819.

Hanken, J. 1999. Why are there so many new amphibian species when amphibians are declining? *Trends in Ecology and Evolution* **14:**7-8.

Inger, R.F. 1954. Systematics and zoogeography of Philippine Amphibia. *Fieldiana* **33**:181-531.

Köhler, J., Vieites, D.R., Bonett, R.M., García, F.H., Glaw, F. Skeinke, D. and Vences, M. 2005. New amphibians and global conservation: a boost in species discoveries in a highly endangered vertebrate group. *BioScience* **55**:693–696.

Lips, K.R., Reeve, J. and Witters, L.R., 2003. Ecological factors predicting amphibian population declines in Central America. *Conservation Biology* **17**:1078-1088.

Sodhi, N.S., Koh, L.P., Brook, B.W. and Ng, P.K.L. 2004. Southeast Asian biodiversity: an impending disaster. *Trends in Ecology and Evolution* **19**:654–660.

Stuart, S.N., Chanson, J.S., Cox, N.A., Young, B.E., Rodrigues, A.S.L., Fischman, D.L. and Waller, R.W. 2004. Status and trends of amphibian declines and extinctions worldwide. *Science* **306**:1783-1786. ■

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 (tree frogs; C); and an example of an enigmatic intermediate:* Platymantis insulata *(a terrestrial species, nested within the tree frog 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

References

Bain, R.H., Lathrop, A., Murphy, R.W., Orlov, N.L. and Ho, C.T. 2003. Cryptic species of a cascade frog from Southeast Asia: taxonomic revisions and descriptions of six new species. *American Museum Novitates* **3417**:1-60.

Bourret, R. 1937. Notes herpétologiques sur l'Indochine française. XIV. Les batraciens de la collection du Laboratoire des Sciences Naturelles de l'Université. Descriptions de quinze espèces ou variétés nouvelles. Annexe au Bulletin Général de l'Instruction Publique **4**:5-56.

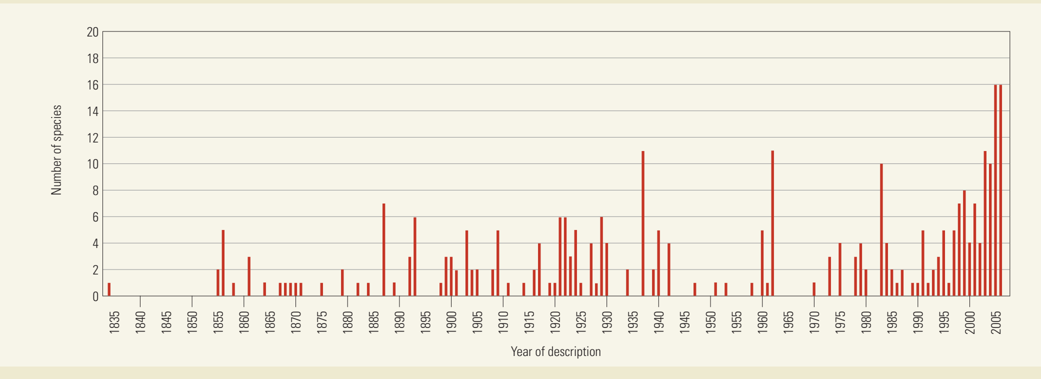


Figure 1. *Annual amphibian species descriptions (n = 299 descriptions) from mainland Southeast Asia, defined as Vietnam, Laos, Cambodia, Thailand (north of the Isthmus of Kra), Myanmar (north of the Isthmus of Kra), and southern China (Yunnan, Guangxi, Guangdong, Fujian, Hainan, Hong Kong and Taiwan). 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.*

Brown, R.M. 2007. *Introduction, Robert F. Inger's Systematics and Zoogeography of Philippine Amphibia* (Foreword to the 2007 reprint of Inger's 1954 monograph). In: Systematics and Zoogeography of Philippine Amphibia, pp. 1-17. Natural History Publications, Kota Kinabalu.

Frost, D.R. 2006. *Amphibian Species of the World: an Online Reference*. Version 4 (17 August 2006). Electronic database accessible at http://research.amnh.org/herpetology/amphibia/index.php. American Museum of Natural History, New York, USA.

Hanken, J. 1999. Why are there so many new amphibian species when amphibians are declining? *Trends in Ecology & Evolution* **14**:7-8.

Köhler, J., Vieites, D.R., Bonett, R.M., Garcia, F.H., Glaw, F., Steinke, D. and Vences, M. 2005. New Amphibians and Global Conservation: A Boost in Species Discoveries in a Highly Endangered Vertebrate Group. *BioScience* **55**:693-696.

Kuramoto, M. and Wang, C.-S. 1987. A new rhacophorid treefrog from Taiwan, with comparisons to *Chirixalus eiffingeri* (Anura, Rhacophoridae). *Copeia* **1987**:931-942.

Li, C., Ye, C.-Y. and Fei, L. 2001. Taxonomic studies of *Odorrana andersonii* in China (Anura: Ranidae). *Acta Zootaxonomica Sinica* **26**:234-238.

Liu, C.-C. and Hu, S.-Q. 1962. A herpetological report of Kwangsi. *Acta Zoologica Sinica* **14**(Suppl.):73-104.

Stuart, B.L., Inger, R.F. and Voris, H.K. 2006. High level of cryptic species diversity revealed by sympatric lineages of Southeast Asian forest frogs. *Biology Letters* **2**:470-474.

Wogan, G.O.U., Htun Win, Thin Thin, Kyi Soe Lwin, Awan Khwi Shein, Sai Wunna Kyi, and Hla Tun. 2003. A new species of *Bufo* (Anura: Bufonidae) from Myanmar (Burma), and redescription of the little-known species *Bufo stuarti* Smith 1929. *Proceedings of the California Academy of Sciences* **54**:141-153. ■

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.

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

A Bornean endemic, Ansonia spinulifer *(Near Threatened), is a characteristic species reported from lowland localities throughout Borneo from 150-750 m asl. © Djoko Iskandar*

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

References

Inger, R.F. 2005. *The systematics and zoogeography of the Amphibia of Borneo*. Natural History Publications, Kota Kinabalu (reprint), Malaysia.

Inger, R.F. and Stuebing, R.B. 2005. *A field guide to the frogs of Borneo*. 2nd edn. Natural History Publications, Kota Kinabalu, Malaysia.

Inger, R.F. and Tan, F.-L. 1996. *The natural history of amphibians and reptiles in Sabah*. Natural History Publications, Kota Kinabalu, Malaysia. ■

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*