Figure 1. *Oligodon arnensis*, a non-endemic colubrid snake species found in the lowlands throughout the island, except the dry southeastern parts. *Photo by Indraneil Das.*

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Conservation of biodiversity in a hotspot: Sri Lanka's amphibians and reptiles

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***Abstract.*—Sri Lanka is a continental tropical island that is considered a hotspot for amphibian and reptile diversity. During the last decade herpetological research has substantially improved our knowledge of species and their taxonomic status. However, additional work is needed on ecology and population viability within the framework of human impacts on natural ecosystems. These human induced activities have led to severe fragmentation of formerly continuous forest in the wet zone and central hills of Sri Lanka, where most endemic and threatened species occur. Here I discuss current development in biodiversity issues regarding the Convention on Biological Diversity and their effects on the future of herpetofaunal conservation in Sri Lanka. To better understand Sri Lanka's conservation challenges and threats I discuss the following topics: Sri Lanka's biogeography; its extant ecosystems and landscapes along with the changes resulting from patterns of human settlement; human population growth and its concomitant impact on natural ecosystems; and a brief history of herpetological studies in Sri Lanka. Further, I discuss major conservation issues related to the ecoregional and hotspot approach to biodiversity conservation, the IUCN species lists, and the institutional framework in biodiversity conservation. Finally, I propose an integrated action plan for the conservation of Sri Lanka's herpetofauna that includes cooperation between relevant institutions, future scientific studies, education, capacity development, *in situ* and *ex situ* conservation, and encouragement of increased collaborative effort in biodiversity conservation with the Western Ghats of southern India.**

Key words. Sri Lanka, biogeography, history of herpetological research, biodiversity conservation, biodiversity hotspot, amphibians, reptiles, action plan

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Introduction

The World Summit on Sustainable Development, held in Johannesburg in 2002, and the United Nations General Assembly endorsed a "2010 Target" based on a decision of the 6th Conference of the Parties to the Convention on Biological Diversity. The target was to achieve, by 2010, a significant reduction of the current rate of biodiversity loss at global, regional, and national levels as a contribution to poverty alleviation and to the benefit of all life on Earth (SCBD 2010). The 2010 target and its 21 subtargets have not been met globally despite partial local achievements (SCBD 2010). To scale up efforts to deal with continued biodiversity loss and other biodiversity issues the United Nations proclaimed 2010 the "International Year of Biodiversity." The main objectives of the Year were to (source: Secretariat of the Convention on Biological Diversity):

- Enhance public awareness of the importance of conserving biodiversity and underlying threats to biodiversity.
- Raise awareness of accomplishments to save biodiversity by communities and governments.
- Promote innovative solutions to reduce threats to biodiversity.
- Encourage individuals, organizations, and governments to take immediate steps to halt biodiversity loss.
- Initiate dialog between stake holders for steps taken in the post-2010 period.

In October 2010 the 10th meeting of the Conference of the Parties to the Convention on Biological Diversity (COP 10) took place in Nagoya, Japan. Efforts in Nagoya were

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underpinned by earlier reports on biodiversity such as the biodiversity synthesis report of the Millennium Ecosystem Assessment (MEA 2005) and Global Biodiversity Outlook 3 (SCBD 2010). The COP 10 meeting was a breakthrough in the conservation of biological diversity. Meeting participants adopted an outstanding measures package including: (1) a strategic plan for biodiversity and the Aichi biodiversity targets; (2) the Nagoya protocol on access to genetic resources and fair and equitable sharing of benefits arising from their utilization; (3) a strategy for resource mobilization; (4) a continuation of the process of establishing an intergovernmental platform on biodiversity and ecosystem services; and (5) the recommendation to the United Nations General Assembly to declare 2011-2020 the UN Decade on Biodiversity.

One key outcome of the COP 10 meeting was the recommendation to globally update the national biodiversity strategies and action plans (NBSAPs). Within the process of updating, amphibians and reptiles could get more attendance within the overall framework of preserving Sri Lanka's unique biodiversity. The relevance of an adequate consideration of Sri Lanka's herpetofauna for NBSAP is that Sri Lanka is recognized as a global amphibian hotspot (Meegaskumbura et al. 2002; Pethiyagoda and Manamendra-Arachchi 1998) as well as a mega-hotspot of reptile diversity (Somaweera and Somaweera 2009).

Moreover, especially since the release of the 4th Assessment Report of the IPCC (2007; see: www.ipcc.ch) and the so-called "Stern Review" (Stern 2006), the global political leadership and the UN have increasingly focused on discussions of global climate change and its effects on human well-being and the future of Earth's biological diversity. Collectively these most recent developments seem to set the stage for new discussions about conserving Sri Lanka's biodiversity and mitigating the impacts of—and adapting to—global climate change. The herpetofauna of Sri Lanka, being an essential component and an indicator of the overall health of Sri Lanka's ecosystems, plays a crucial role in contributing both to the sustenance of the country's wealth in life forms and ecosystem services provided to the local human population.

This paper is future-oriented and action-oriented with regard to the long term preservation of Sri Lanka's herpetofauna. Here I provide a holistic picture of what is needed to strengthen conservation efforts at all levels, including research, education, partnership, and policy. These conservation efforts should be accomplished first and foremost at the national level but also integrated into subregional (e.g., jointly for the Western Ghats of India and Sri Lanka biodiversity hotspots), regional, and global efforts toward amphibian and reptile conservation. These conservation efforts should be recognized in context to human impact on natural ecosystems and global climate change. Moreover, they should be part of Sri Lanka's overall effort towards biodiversity conservation and sustainable use of its ecosystem services (for an overview see TEEB 2010). More specifically, this paper outlines: (1) aspects of the biogeography of Sri Lanka; (2) the history of herpetological research and our current knowledge base; (3) conservation issues; and (4) a proposal intended to contribute to further discussions and elicit appropriate measures for future sustainable conservation of Sri Lanka's herpetofauna.

The tropical continental island of Sri Lanka—A note on biogeography

Historical remarks

Based on detailed studies of the flora and fauna of India over thirty-five years ago, attempts were made to subdivide the Indo-Ceylonese region into biogeographical subregions and other units (e.g., Mani 1974). The first zoogeographical studies, carried out in the 19th century, were based on distributional patterns of terrestrial mollusks (Blanford 1870), reptiles (Günther 1858, 1864), and birds (Jerdon 1862-1864). The definition of floristic regions began in the middle of the 19th century (e.g., Hooker and Thomson 1855; Clarke 1898) and the beginning of the 20th century (e.g., Prain 1903; Hooker 1906).

Collectively, these studies revealed a strong similarity between Sri Lanka and neighboring India, especially with regard to the more humid regions of the Western Ghats and southwestern Sri Lanka. Repeatedly, south India and Sri Lanka were seen as a single biogeographical subunit comprising two major pairs of similarities, i.e., the Malabar Tract, southwestern and hill regions of Sri Lanka, southeastern India, and drier parts of Sri Lanka (e.g., Bhimachar 1945; Phillips 1942; Wait 1914). These patterns of similarity encompass the majority of plant and animal species, particularly the herpetofauna discussed here (for an overview of the biogeography of the reptiles of south Asia, see Das 1996a).

Geological past

The geological history of Sri Lanka is subdivided into the following phases (after Dietz and Holden 1970; Keast 1973; McKenna 1975; Pielou 1979; Raven and Axelrod 1974):

- Pre-drift phase where Sri Lanka and India were part of Gondwana (> 100 MYBP).
- Drift phase ending with the collision of the Indian plate and the Asiatic continent (66 and 45 MYBP).
- Miocene epoch (ca. 25 MYBP), Sri Lanka's separation from India, following a series of complex

tectonic movements, which began in the Jurassic (see Cooray 1984; Katz 1978; Swan 1983).

- Quaternary epoch (two MYBP to present), eustatic sea level changes, climate cycles, and repeated formation of land bridges between India and Sri Lanka, in the Palk Strait region.

Similarities observed between flora and fauna of Sri Lanka and India are linked to having been part of the Indian plate and an isolated unit in the Tethys Sea, after its separation from the Gondwanan landmass and before it collided with Asia. Additionally, the biogeographical evolution of India and Sri Lanka was certainly shaped by the global K-T event, the Deccan volcanism (Cretaceous to Eocene; Wadia 1976), the orogenic processes leading to formation of the Himalayas, the development of the monsoon pattern, and floristic and faunistic exchanges between the Indian plate and Asia (early Tertiary 45-25 MYBP), particularly with southeast Asia (see Klaus et al. 2010). This phase was followed by Quaternary climate fluctuations and eustatic changes in sea level leading to repeated formation of land bridges between India and Sri Lanka (Palk Strait region; for pollen data see Premathilake and Risberg 2003). During Quaternary sea level maxima, when Sri Lanka was isolated from India, biogeographical patterns most likely changed independently from India. The Quaternary is often seen as the decisive period for shaping the present plant and animal distribution patterns in Sri Lanka (e.g., Erdelen 1993a; Erdelen and Preu 1990a). "Time lags" between eustatic sea level changes, climate change, and the "reaction" of plant and animal species may explain some of the similarities among rain forest species in southern India and Sri Lanka (Erdelen and Preu 1990a).

Many unanswered questions exist regarding the biogeographical evolution of Sri Lanka's flora and fauna (for more recent analyses see Biswas 2008; Biswas and Pawar 2006). Most speciation events among amphibians and reptiles pre-date the Quaternary period. This notion is supported by several recent papers on genetic divergence within rhacophorid frogs. A study on rostral horn evolution of the endemic genus *Ceratophora* suggests a Miocene origin of the genus and several speciation events dating approximately between 12.6 and 2.4 MYBP (Schulte II et al. 2002). A similar situation was reported for the remarkable radiation of Sri Lanka's freshwater crabs (50 endemics from a total of 51 species for the island; Beenaerts et al. 2010). The uropeltid snake species of southern India and Sri Lanka may have been separated for a period longer than 10-15 MYBP (e.g., Cadle et al. 1990). In fact, many of the speciation events thought to have been associated with different phases of the Pleistocene are much older and likely the result of speciation events in the Tertiary (e.g., see Maxson 1984, Roberts and Maxson 1985a, 1985b, for Australian frogs).

Speciation rates may have varied within groups such as birds in Sri Lanka and India (Erdelen 1993a). Migration patterns into and out of the Indian-Sri Lankan region likely differed substantially among and within taxa (for Cincidelid beetles, see Pearson and Ghorpade 1989), and exchanges of floral and faunal elements need not have been symmetric but may show a marked asymmetry if India and neighboring regions are compared. The results of these highly variable processes are rather complex extant patterns of geographic distribution. Further studies are essential for a more complete understanding of the major evolutionary processes that formed Sri Lanka's flora and fauna. The basis of such studies would be the understanding of undisturbed, "pristine" geographic distribution patterns allowing for the reconstruction of historical processes producing Sri Lanka's biodiversity.

Extant ecosystems and landscapes

Sri Lanka's rich biodiversity is reflected in its diverse extant ecosystems and landscapes. Ecosystems may be classified into the following (for more details and references, see Dela 2009; Gunatilleke et al. 2008; Ministry of Forestry and Environment 1999):

- Forest and grassland
- Inland wetland
- Coastal and marine
- Agricultural
- Urban

The most important ecosystems for amphibians and reptiles are certainly the first two categories, especially if minimally disturbed by humans, although coastal and marine ecosystems are important to reptile taxa like marine turtles and crocodiles. Agricultural and urban systems may provide habitats for species with broad habitat requirements, especially those that live commensally with humans.

Often underestimated in their role of maintaining viable populations are secondary forests or, more generally, "novel ecosystems." These are described as heavily influenced by humans but not under human management, or "lands without agricultural or urban use embedded in agricultural and urban regions" (Marris 2009). More than 90% of amphibian species in Sri Lanka occur in secondary forests, highlighting the importance of novel ecosystems (R. Pethyiagoda, pers. comm.). Long-term conservation efforts should consider the landscape mosaic of Sri Lanka, which comprises ecosystems that vary in geographic extent and human perturbation. System interlinkages and scale may be essential parameters for understanding and managing such diverse environments (Erdelen 1993b).

Vegetation maps for Sri Lanka date to the 1930s. Based on the three climatic zones of the island, namely the wet, intermediate, and dry zones, the National Atlas of Sri Lanka distinguished 11 different types of plant communities (Somasekaram 1988). For analyses of fau-

nal distribution patterns in Sri Lanka a simplified subdivision into seven zones with six different types of natural vegetation has been frequently used (e.g., Crusz 1984, 1986; Crusz and Nugaliyadde 1978; Erdelen 1984, 1989, 1993a).

Based on distribution data for angiosperm plants, recent studies have shown that within these major vegetation units 15 floristic regions may be distinguished, located largely within the wet zone and the mountain region of Sri Lanka (Ashton and Gunatilleke 1987; Gunatilleke and Gunatilleke 1990). Even within these floristic regions, forest communities show a patchy distribution, sometimes with rather different species compositions (Gunatilleke and Gunatilleke 1983). Individual hills may have unique forest communities (Abeywickrama 1956), for example Hinidumkande in the southwestern part of the wet zone. The rainforests of this mountain show a striking concentration of endemic tree species (Gunatilleke and Gunatilleke 1984). Another well-known example is Ritigala, a 766 m high mountain in the northern part of Sri Lanka's dry zone. Although located in the dry zone this mountain contains endemic plant species characteristic of the wet zone and species which otherwise occur only in the mountain region and not elsewhere in the dry zone. Some plant species are endemic to Ritigala (for details see Jayasuriya and Pemadasa 1983; Jayasuriya 1984).

Although numerous attempts have been made to explain these highly localized concentrations of endemic species (see Willis 1916, for one of the earlier discussions), we still do not know whether, and to what extent, these are possibly a result of Quaternary dynamics of vegetation patterns (related to glacial and interglacial cycles and associated climate regimes). Moreover, it is not clear whether, and if so to what extent, such small-scale mosaics in vegetation patterns are reflected in endemic animal taxa, and thus may need more attention as part of the overall efforts of biodiversity conservation in Sri Lanka (see Raheem et al. 2009).

When we try to reconstruct the evolution of Sri Lanka's biota and its relationship to Indian flora and fauna, "biogeographical reconstruction" is increasingly hampered by anthropogenic alterations of habitats. Relatively undisturbed ecosystems and associated distribution patterns within a floral or faunal setup should be the basis for reconstructing historical events, which shaped the extant composition of Sri Lanka's flora and fauna. Only if the spatio-temporal dynamics of anthropogenic effects on natural ecosystems are well-known and documented will such a reconstruction process be facilitated and the "true" patterns and underlying historical processes involved be discovered.

Modern humans settled in Sri Lanka between 75,000 and 125,000 YBP or earlier (Deraniyagala 1993). Estimates of human densities during different periods of human history in Sri Lanka would provide indirect evidence of potential impacts on natural vegetation and associated fauna. During the pre-historic phase, between 75,000 YBP and 10,000 YBP, when humans were essentially subsistence hunters and food gatherers, the wet zone and hills of Sri Lanka were already settled, although in low densities. Deraniyagala (1993) provides an estimate for the wet zone during this phase of up to 10,000 YBP of some 0.1 individuals/km^2. The transition period (pre-historic to proto-historic and early historic phases), saw high human densities in the dry zone increasing during the Singhalese high culture (beginning ca. 200 BC), a time associated with the advent of Buddhism in Sri Lanka. During the Anuradhapura Period (250 BC-1017; first urbanization phase) and the Polonnaruwa Period (1017-1235) extensive systems of irrigation tanks were established in the dry zone for rice cultivation (see Abeywickrama 1993).

During the Late Historic Phase, from the 14th century onwards, the political, economic, and cultural centers shifted from the north-central, eastern and southeastern parts of the island towards the lowlands of the wet zone, the central highlands, and into the extreme northern parts of Sri Lanka (Erdelen 1993a). This restructuring process was associated with the downfall of high cultures in the dry zone and the beginning of the colonial periods (Portuguese, Dutch, and British). During the British Period (1796-1948) in particular, massive impacts on the natural forests of southwestern Sri Lanka and the central hills were recorded. The introduction of plantation industry (cinchona, coffee, tea, and rubber) and infrastructural measures caused changes for these regions. Following Sri Lanka's independence (1948), there was a period of intensified man-made alterations to the natural ecosystems of Sri Lanka, with the objective of supporting both a rapidly increasing population and an accelerated economic growth (Erdelen 1988b, 1993; Erdelen and Preu 1990b; Erdelen et al. 1993; Ministry of Forestry and Environment 1999).

The population of Sri Lanka has tripled in size in some 60 years, from 7.2 million inhabitants in 1948 to over 21 million in 2011. Population density, formerly being highest in the dry zone of Sri Lanka, has now reached over 500 individuals/km^2 in the wet zone (Dela 2009; see Cincotta et al. 2000, with regard to global biodiversity hotspots). These historical processes have led to a considerable change in the distribution of natural vegetation in Sri Lanka (see Erdelen 1996). More extensive areas under natural forest cover are essentially found in the dry zone. The forests of the wet zone and the central hill range have become highly fragmented. No continuous primary forest cover remains from sea level to over 2,500 m of the central hill range. Note these statements refer to "vegetation" and major types of ecosystems but do not reflect the fine-scale analysis and implications these changes might have for plant and animal species/populations and their long-term viability.

Analysis of the following questions may be useful in gaining a better understanding of processes at relevant scales and for subsequent appropriate conservation measures:

1) Concomitant with anthropogenic impacts on natural vegetation: have plant communities changed significantly both in structure, and therefore, in microhabitat and microclimatic conditions, as well as in species composition?

2) If so, at what scale has this happened and what does the extant mosaic of differentially impacted plant ecosystems look like?

3) How do distribution patterns of amphibians and reptiles relate to vegetation or plant community patterns? If they do, what is the "reference" equivalent with regard to vegetation type or "structural" habitat parameters against which distribution patterns could be calibrated?

4) What are the projections of population or species viabilities if questions 1-3 are analyzed simultaneously?

5) What would be the implications of such analyses for biodiversity conservation measures, specifically in regards to amphibians and reptiles?

In conclusion, we need a better understanding of proximate and ultimate factors (i.e., knowledge of the crucial ecosystem or habitat parameters) decisive in the long-term persistence of amphibian and reptile populations. These factors vary intrinsically with species' ecologies and are shaped by human impacts on natural ecosystems and habitats. These concepts need to be taken into account for monitoring long-term population trends in Sri Lanka.

History of herpetological research in Sri Lanka

Herpetological research has a long history in Sri Lanka (de Silva 2001) and has been part of the general history of biodiversity exploration in Sri Lanka (Pethiyagoda 2007). Interest during the British period (1796-1948) was mainly in horticulture for the introduction of commercially-used crops and for exporting plants from Sri Lanka. Except for earlier work by French workers and scientists associated with the British Museum in the 19th century, the focus on the fauna of Sri Lanka began with the establishment of the Colombo Museum in 1877. For the most part, until about the time of independence, it would be amateurs who led efforts to explore the island's herpetofauna (Pethiyagoda 2007).

A detailed analysis of factors shaping herpetological research in Sri Lanka would be worth undertaking but is beyond the scope of this paper. The most recent scientific research efforts have been vital for a more thorough understanding of the herpetofauna of Sri Lanka, especially in regard to the number of species on the island as well as their taxonomic status. It is clear from these studies that several species have become extinct in recent times and more work is needed to preserve Sri Lanka's herpetofaunal diversity into the future (see below).

Amphibians

Species lists for amphibians of Sri Lanka have been compiled since the 19th century. These were first published within the framework of regional compilations such as the works of Günther (1864) and Boulenger (1890). The first lists of exclusively Sri Lankan amphibians were published by Kelaart (1852) and Haly (1886a) followed by numerous publications on individual amphibian taxa (for compilations see Dutta and Manamendra-Arachchi 1996; Erdelen 1993a). In the 1950s, de Silva published a species list for Sri Lanka, including the specimens housed in the Colombo Museum (de Silva 1955). This

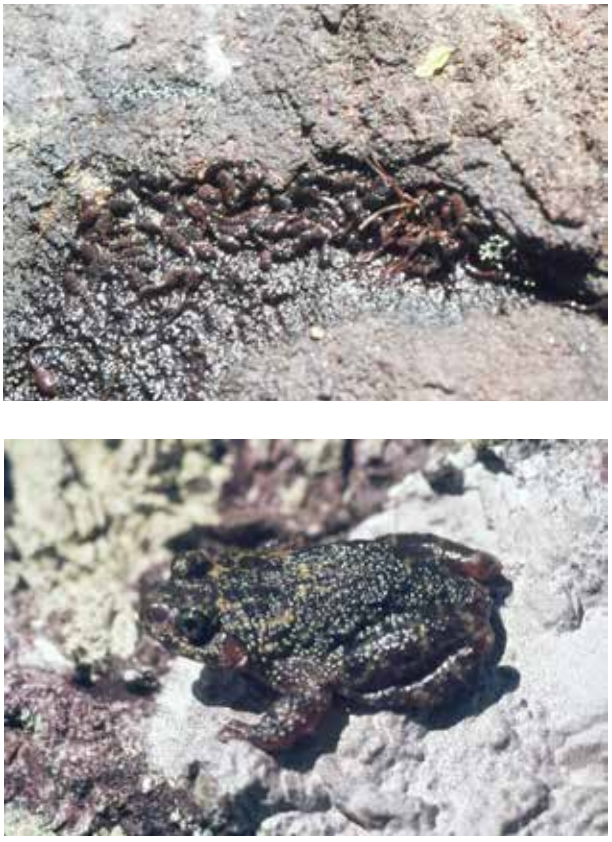

Figure 2. Tadpoles (top) and adult specimen (bottom) of *Nannophrys marmorata*, an endemic species restricted to the Knuckles range; Critically Endangered. Mainly found under boulders on wet, flat, rocky surfaces (Dutta and Manamendra-Arachchi 1996; confirmed by own observations). The genus is endemic to Sri Lanka, comprising four species, one of them (*N. naeyakai*) described only in 2007 (Fernando et al. 2007). *Photos by Walter R. Erdelen*.

publication was followed by Kirtisinghe's (1957) monograph *The Amphibia of Ceylon*. Thereafter, and repeatedly, checklists for the amphibians of Sri Lanka were compiled (Kotagama et al. 1981; de Silva 1994, 1996, 2001). In parallel, taxonomic revisions were undertaken for the first time (for details see Dutta and Manamendra-Arachchi 1996 and Erdelen 1993a). Dutta (1985), in his Ph.D. dissertation, updated information on the amphibians of Sri Lanka and India and in 1996 published the first modern account of the amphibian fauna of Sri Lanka (Dutta and Manamendra-Arachchi 1996). Possibly the first indication that Sri Lanka may be home to many more amphibian species is indicated in publications from the mid-90s where new amphibian species were described (e.g., Fernando et al. 1994; Manamendra-Arachchi and Gabadage 1996). As Dutta and Manamendra-Arachchi (1996) wrote in their introduction: "We expect there to be a dramatic increase in the diversity of amphibians of Sri Lanka, especially among the Rhacophoridae." Indeed in 2002 detailed information on Sri Lanka's outstanding amphibian diversity was published in an article in *Science* (Meegaskumbura et al. 2002) indicating that rhacophorid frogs may comprise over 100 species in Sri Lanka. In this paper it was stated that "Sri Lanka's amphibian diversity (about 140 species on an island of 65,610 km^2) now approaches or exceeds that of many amphibian diversity hotspots and is comparable to those of tropical islands an order of magnitude larger, such as Borneo (746,300 km^2; 137 species), Madagascar (587,000 km^2; 190 species), New Guinea (775,200 km^2; 225 species), and the Philippines (299,800 km^2; 96 species)."

Meanwhile, species numbers for amphibians in Sri Lanka stand at 111, of which some 90% are endemic (Fig. 2; for regularly updated information see: http://amphibiaweb.org). Still more species await description and the percentage of endemism is expected to rise, as seen in the 2007 list of threatened fauna and flora of Sri Lanka which already mentions 106 amphibian species of which 90 (85%) are endemic (IUCN Sri Lanka and MoENR 2007).

Reptiles

The earliest publications on Sri Lankan reptiles are included in those of a more general nature already mentioned above. Ferguson (1877) and Haly (1886b, 1891) compiled information about reptiles in collections of the Colombo Museum. Most famous have been the publications of P. E. P. Deraniyagala (for an overview, see de Silva 1977). He published three outstanding volumes on the turtles and crocodiles, lizards, and snakes of Sri Lanka (Deraniyagala 1939, 1953, 1955). At that time, the only comparable publications were Smith's *Fauna of British India* (Smith 1931, 1935, 1943) and Taylor's work on individual taxa (Taylor 1947, 1953b) and his overviews of the Sri Lankan snakes, skinks, and lizards (Taylor 1950a, 1950b, 1953a).

This period was followed by a number of systematic/taxonomic and ecological studies of individual taxa (overviews in Erdelen 1993a; de Silva 2006). De Silva (1998a, 1998b, 1998c) published checklists and annotated bibliographies of the turtles and crocodiles, lizards, and snakes of Sri Lanka. Comprehensive publications are available on snakes (de Silva 1980) and color guides were more recently published on snakes (de Silva 1990) and lizards (Somaweera and Somaweera 2009) of Sri Lanka.

The *2007 Red List of Threatened Fauna and Flora of Sri Lanka* (IUCN Sri Lanka and MoENR 2007) lists a total of 171 reptile species where 101 (59%) are endemic (Fig. 3), with more being added (e.g., Gower et al. 2011; Maduwage et al. 2009).

The herpetofauna of Sri Lanka—A short summary of the evolution of our knowledge base

Although our knowledge of Sri Lankan herpetofauna has considerably improved, new species still await discovery. This applies particularly to amphibians where traditional morphological approaches have fallen short of adequately describing species diversity (for comparison see Oliver et al. 2009; Stuart et al. 2006; Vieites et al. 2009). Modern genetic analyses have shown a much higher species diversity than previously expected (overview in Pethiyagoda et al. 2006). In addition, new species of reptiles have been discovered during the last years of intensified field work in Sri Lanka. This includes "seemingly" better known agamid genera such as *Calotes*, *Ceratophora*, *Cophotis*, and *Otocryptis* (for an overview, see references in Bahir and Surasinghe 2005 and Somaweera and Somaweera 2009; Fig. 4). In addition, new species of scincid and gekkonid lizards and snakes were recently

Figure 3. Male specimen of *Lyriocephalus scutatus*, the most charismatic lizard of Sri Lanka. The genus is monotypic and endemic to Sri Lanka. *Photo by Walter R. Erdelen.*

described (overviews in de Silva 2006; Somaweera and Somaweera 2009).

As already indicated by Pethiyagoda et al. (2006), despite recent work on taxonomy and systematics comparatively little is known about the biology of Sri Lankan amphibians. Basic ecological information at both the population and species levels is unavailable for most, if not all taxa. Additionally, geographic distribution patterns and their dynamics are poorly understood or not known at all. The rarity of amphibian species, their patchy distribution, and possibly highly fragmented or small populations have neither been adequately recorded nor monitored over time, especially in view of human-induced habitat or microhabitat changes. Similarly, we lack this information for most Sri Lankan reptile species as well. An exception may be studies on the genus *Calotes* including analyses of geographic distribution patterns, intraspecific variability, and population dynamics (Erdelen 1977, 1983, 1984, 1988a; for a more recent study of *C. nigrilabris* see Amarasinghe et al. 2011).

Our knowledge of amphibian and reptile diversity in Sri Lanka has profoundly improved during recent times (within the last decade). This improvement has been the result of a "new age of herpetology, characterized both by increased international cooperation in research and by the blossoming of herpetology as a research discipline for many young Sri Lankan zoologists" (de Silva 2006). This process was influenced or catalyzed by major herpetological events held in Sri Lanka, including the 1996 International Conference on the Biology and Conservation of the Amphibians and Reptiles of South Asia, held at the University of Peradeniya (de Silva 1998), and the 4th World Congress of Herpetology, held at Bentota, Sri Lanka in 2001 (see Dodd and Bartholomew 2002).

Conservation issues

General observations

Sri Lanka has a long tradition of preserving its wildlife. It was one of the earliest countries to set aside areas for wildlife protection and take conservation measures for its plant and animal life. Ideas of preserving nature in Sri Lanka may date back to the advent of Buddhism, about 2,500 YBP. Sanctuaries were already established in Sri Lanka in the 12th century, possibly earlier (see Crusz 1973; DeAlwis 1969; Erdelen 1988b; Ministry of Forestry and Environment 1999).

Currently, Sri Lanka has over 500 protected areas including over 90 key biodiversity areas recently identified jointly by the Wildlife Heritage Trust and the University of Peradeniya. Sri Lanka's protected areas—covering about 18% of the island's total land area—are principally

Figure 4. Range restricted endemic forest lizards. Top left: *Ceratophora tennentii*, male; top right: *Cophotis ceylanica*, male; bottom left: *Calotes liocephalus*, juvenile; bottom right: a newly discovered endemic but widespread species of scincid lizard (*Eutropis tammanna*; described by Das et al. 2008). *Eutropis tammanna photo by Indraneil Das; all others by Walter R. Erdelen.*


Figure 5. Two species of reptiles endemic to the Knuckles range, the gekkonid *Cyrtodactylus soba* (left) and the scincid *Nessia bipes* (right). *Photos by Indraneil Das.*

managed by the Forest Department and the Department of Wildlife Conservation (for details see Dela 2009). The most recent significant international achievement has been the recognition of the Central Highlands of Sri Lanka, including the Peak Wilderness Protected Area, the Horton Plains National Park, and the Knuckles Conservation Forest (see Fig. 5), as a World Heritage Site.

As stated in the relevant text of the World Heritage Committee (34 COM8B.9) decision: "the property includes the largest and least disturbed remaining areas of the submontane and montane rain forests of Sri Lanka, which are a global conservation priority on many accounts. They include areas of Sri Lankan montane rain forests considered as a super-hotspot within the Western Ghats and Sri Lanka biodiversity hotspot. More than half of Sri Lanka's endemic vertebrates, half of the country's endemic flowering plants and more than 34% of its endemic trees, shrubs, and herbs are restricted to these diverse montane rain forests and adjoining grassland areas." In the same text it is further noted that: "Of the 408 species of vertebrates, 83% of indigenous fresh water fishes and 81% of the amphibians in Peak Wilderness Protected Area are endemic, 91% of the amphibians and 89% of the reptiles in Horton Plains are endemic, and 64% of the amphibians and 51% of the reptiles in the Knuckles Conservation Forest are endemic."

As indicated above, conservation efforts in Sri Lanka previously focused largely on charismatic and well-known species such as the larger mammal and bird species and endemic plant and animal species. Amphibians and reptiles have largely been ignored, a situation similar to other Asian countries such as Indonesia (Iskandar and Erdelen 2006). This fact underscores the importance of specific mention of amphibians and reptiles in the nomination of this new World Heritage Site, which is of outstanding importance to the long-term conservation of a significant segment of Sri Lanka's herpetofauna and its fauna and flora in general.

Sri Lanka's fourth country report to the Convention of Biological Diversity lists the following major threats to Sri Lanka's biodiversity: (1) habitat loss and fragmentation, in particular regarding wet zone ecosystems; (2) habitat degradation; (3) overexploitation of biological resources; (4) loss of traditional crop and livestock varieties and breeds; (5) pollution; (6) human-wildlife conflicts; (7) spread of alien invasive species; and (8) increasing human population density (Dela 2009). Without doubt numbers one and two above are the most important direct threats to the herpetofauna of Sri Lanka, particularly in regards to endemic species. Pesticide use and air pollution possibly affect amphibian populations more drastically than reptiles, due to their complex life histories (Ariyasiri et al. 2011). The long-term viability of amphibian populations critically depends on the state of both the aquatic ecosystems they use during their "bimodal" life cycle and the associated terrestrial ecosystems they inhabit (see Becker et al. 2007).

As pointed out by Pethiyagoda et al. (2006), the area of greatest concern for amphibians is the southwestern region of Sri Lanka where over 95% of forest cover has been lost and amphibian species are restricted in their geographic distribution. The wet zone of Sri Lanka currently comprises well over 100 forest fragments, and areas where continuous forest exists from lowlands to higher elevations are rare. This situation is further aggravated by high human population density in the southwestern region of Sri Lanka with over 500 individuals/km^2 (Dela 2009; see above).

Ecoregions and hotspots of biodiversity—The case of Sri Lanka

In their paper "Global 200," Olson and Dinerstein (1998) identified the 200 biologically most valuable ecoregions. The terrestrial ecoregions are defined as relatively large units of land containing a distinct assemblage of natural communities and species, with boundaries that approximate the original extent of natural communities prior to major land-use change (Olson et al. 2001). Biological distinctiveness was measured in terms of species richness, endemism, taxonomic uniqueness, unusual eco-

logical or evolutionary phenomena, and global rarity of habitat types (for details see Olson and Dinerstein 1998). This included the moist forests of the Western Ghats and Sri Lanka—both classified as Critical or Endangered as their conservation status. A more detailed analysis was presented in the Indo-Pacific terrestrial ecoregions conservation assessment (Wikramanayake et al. 2002). This assessment provided a detailed subdivision of the Western Ghats and also distinguished three ecoregions within Sri Lanka: (1) lowland rain forests, (2) montane rain forests, and (3) evergreen forests of the dry zone. The first two were considered globally outstanding with a conservation status of "critical" and given the highest assessment of need for effective biodiversity conservation - "class I" (see Fig. 6). The third was classified as regionally outstanding, vulnerable, and assigned "class II" as its conservation assessment (for details, see Wikramanyake et al. 2002).

In parallel, the assignment of global conservation priorities was based on the concept of "biodiversity hotspot," a term coined by Myers in the late 1980s (Myers 1988, 1990). The term originally referred to areas where "exceptional concentrations of endemic species are undergoing exceptional loss of habitat" (Myers et al. 2000). Other definitions include parameters like species richness, degree of endemism, numbers of rare or threatened species, and intensity of threat (see Reid 1998). One persistent discordant issue is that rare species may not occur in the most species-rich areas (e.g., Prendergast et al. 1993; see also Reid 1998; for vascular plant diversity and hotspots see discussions in Küper et al. 2004; Mutke and Barthlott 2005; Mutke et al. 2011).

Early work described the Western Ghats and Sri Lanka as a single unit in the list of global biodiversity hotspots (e.g., in Myers 1990). Based on the following factors: endemic plant species, endemic vertebrates, the occurrence of endemic plant and vertebrate species per 100 km^2, and the percentage of remaining primary vegetation, Myers et al. (2000) identified the "eight hottest hotspots" and included the Western Ghats and Sri Lanka.

The relationship between the hotspot and ecoregion approaches is not further discussed here (see e.g., Ladle and Whittaker (2011) for discussions of the two approaches) but a short comment on their interrelationships is of benefit. Regarding scale, the ecoregional approach generally is more fine-scale in nature. For instance, the Western Ghats and Sri Lanka comprise eight different ecoregions. In general, there is over 90% congruence between biodiversity hotspots and the global 200 ecoregions (for more details see Wikramanayake et al. 2002).

Statements outlined above show evidence of a highly unique and diverse herpetofauna in Sri Lanka. During the last decade Sri Lanka has become recognized as an amphibian hotspot of high global significance (Meegaskumbura et al. 2002; Pethiyagoda and Manamendra-Arachchi 1998) and a mega-hotspot of reptile diversity

Figure 6. Lowland rain forest at Sinharaja (top) and montane forest in the Knuckles Range (bottom; cardamom factory in the foreground). *Photos by Walter R. Erdelen*.

(Somaweera and Somaweera 2009). This recognition may be seen as a bottom-up approach, i.e. a taxon-specific approach to the issue of prioritizing biodiversity conservation, as used in the IUCN lists of threatened fauna and flora (see below). It may be seen as an indicator or a reaction to the fact that overall species and ecosystem conservation have been biased towards certain taxa (see above).

The consequence may be use of taxon-specific approaches to ensure specific characteristics in overall long-term conservation of species or species analyzed

Figure 7. Variability in geographic distribution among Sri Lankan reptiles. (A) *Chamaeleo zeylanicus*, a non-endemic species of the dry zone lowlands; (B) *Naja naja*, non-endemic and found all over the island below some 1500 m asl; (C) *Geckoella triedrus*, a wet zone species which is also locally found in the dry zone and intermediate zone; (D) *Geckoella yakhuna*, restricted to the dry zone lowlands of the north; both species are endemic to Sri Lanka and need further study as regards to intraspecific variation. The status of the third species occurring in Sri Lanka (*G. collegalensis*) is unclear (Somaweera and Somaweera 2009); (E) *Rhinophis homolepis*, an endemic uropeltid snake found in the wet zone lowlands; fossorial amphibians and reptiles may be environmental indicators and key groups for an understanding of species evolution in Sri Lanka (see Gans 1993); (F) *Haplocercus ceylonensis*, an endemic colubrid snake found in the wet zone highlands. *Photos by Indraneil Das.*

(for examples of variation in status and distribution of species see Figs. 1 and 7). This approach may lead to a new insight regarding conservation aspects specific to the herpetofauna of Sri Lanka and be vital for overall or "holistic" conservation of biodiversity. Concretely, this approach may relate to rarity, small population sizes, and patchy geographic distribution of many of Sri Lanka's amphibian species.

IUCN Lists

The 2007 IUCN red list of threatened fauna and flora of Sri Lanka lists 33% of all vertebrates as nationally threatened (63% endemic to Sri Lanka). Among major groups of vertebrates reptiles and amphibians rank first in numbers of threatened species, followed by bird, mammal, and freshwater fish species (IUCN Sri Lanka and MoENR 2007).

The 2009 *IUCN State of Amphibians of Sri Lanka*, based on a total species number of 105, draws a particularly bleak picture of endangerment: 20% are reported Extinct, 10% Critically Endangered, 34% Endangered, 6% Vulnerable, and 5% Near-threatened. Only 23% are of least concern and for 2% insufficient data are available to assess their status. Sri Lanka ranks highest among Asian countries, having the greatest percentage of threatened amphibians. It has lost some 20% of its amphibian species during the last century, and over 50% of the remaining species are prone to extinction (*IUCN State of Amphibians of Sri Lanka*, update of 7 April 2009, accessed through www.iucn.org).

Sri Lanka therefore is not only characterized by the highest degree of endemism among amphibians in Asia but also by the highest number of extinct amphibian species reported for an individual country. The loss of 20% of its amphibian species has been a result of human impacts on natural ecosystems during the last 100 years, particularly to natural forest ecosystems of the wet zone and central hills of Sri Lanka. It should be noted, however, that the meaning of "extinct" in this context is not based on absolute proof but on the lack of more recent species records.

One hundred and seventy-one indigenous reptile species, excluding marine species, were assessed by IUCN (2007). Of these, 16 (9.3%) species are considered Critically Endangered, 23 (13.5%) Endangered, and 17 (10%) Vulnerable. This translates into a total of 56 (32.7%) species with their existence threatened. Of these, 37 (66%) are species endemic to Sri Lanka.

In the 2007 IUCN list, concern is expressed *inter alia* about the facts that: (1) national red lists have not been integrated into national policies or other ongoing national conservation actions; (2) better awareness of the contents of these lists needs to be created among relevant line ministries; and (3) the status of most threatened species has remained unchanged or worsened with time. These concerns need to be seriously addressed and jointly translated into concrete action by decision makers, the scientific community, and the public at large.

Institutional arrangement in Sri Lanka

Although this paper focuses on specific issues related to the conservation of amphibians and reptiles in Sri Lanka, this newer comprehensive understanding presented needs to be made relevant and tangible within the overall setup of institutions and agencies managing the environment, biodiversity, and sustainable development of the country. The key ministry mandated with sustainable development and environmental management in Sri Lanka is the Ministry of Natural Resources and Environment (MoENR). MoENR's regulatory commission is to monitor, revise, and report progress of the Environmental Action Plan and to formulate national policies for environmental protection and management. MoENR houses the National Biodiversity Secretariat who is responsible for policies and plans for national biodiversity conservation and attends to national implementation of the Convention on Biological Diversity (CBD) and the Cartagena Protocol (see Dela 2009 for further details). The main sectoral institutions within the MoENR are the Forest Department, the Department of Wildlife Conservation, the Central Environmental Authority, and the Marine Environment Protection Authority. An overview of national stake holders for implementing the CBD and the National Biodiversity Conservation Action Plan (BCAP)—main legislation relating to environmental conservation and management—and key state agencies outside the environmental sector dealing with biodiversity conservation in Sri Lanka are listed in Dela (2009).

De Silva (2001) compiled a list of government departments and organizations which have more specifically contributed to Sri Lankan herpetology. He lists some major non-governmental organizations (NGOs) who specially contribute to improving our knowledge of amphibians and reptiles in Sri Lanka. These NGOs are listed in alphabetic order below (from de Silva 2001; founding dates are given in brackets where available):

- Amphibia and Reptile Research Organization of Sri Lanka (ARROS).
- Conservation Breeding Specialist Group (IUCN/CBSG/SSC), Sri Lanka Network.
- Declining Amphibian Population Task Force, Working Group Sri Lanka (1999).
- March for Conservation.
- The Neo Synthesis Research Centre.
- The Royal Asiatic Society of Sri Lanka (1845).
- Snakebite Expert Committee, Sri Lanka Medical Association (1983).
- Turtle Conservation Project.
- The Wildlife and Nature Protection Society of Sri Lanka (1894).
- The Wildlife Heritage Trust of Sri Lanka (1990)
- The Young Zoologists Association (1972)

These institutions and agencies have enormous potential for enhancing efforts to jointly contribute to mainstreaming biodiversity conservation into cross-sectoral strategies and plans. This potential applies in particular to the development aspects and, therefore, for the sustainable development of Sri Lanka in general. Better cooperation and planning among conservation stake holders in Sri Lanka would greatly increase conservation efforts and are essential in saving the largest portion of biodiversity in Sri Lanka.

Conservation of Sri Lanka's herpetofauna—A proposal

Knowledge of amphibian and reptile geographic distribution in Sri Lanka, especially endemic species, highlights the close association between their geographic distribution patterns and natural ecosystems. For most species we lack precise information about how species distributions are linked to specific habitats or microhabitats. This applies in particular to amphibians which show highly patched distributions and fragmented or small populations. Further studies are needed to determine if this is a result of "natural" patchiness, habitat fragmentation, or sampling artifact (see Janzen and Bopage 2011 for a forest patch herpetofauna study at approximately 1000 m asl).

Studies on extinction risks and population vulnerability have not been carried out for most species. Ecological and biogeographical studies are lagging far behind taxonomic and systematic studies. Without doubt, ecological and biogeographical studies should be continued and should parallel population studies (including monitoring of population dynamics), especially in view of severe habitat fragmentation and additional negative impacts expected to result from climate change.

All these efforts toward a better understanding of the status and endangerment of Sri Lanka's amphibians and reptiles need not only be sustained but considerably increased. This will require increased support and effort at national and international levels and must be embedded in the overall resolve for reinforcing biodiversity conservation in Sri Lanka.

Toward an Action Plan

Many important proposals have been made for the conservation of Sri Lanka's biodiversity and its herpetofauna (e.g., Das 1996b; de Silva 2006; IUCN Sri Lanka and MoENR 2007; Pethyiagoda et al. 2006). These are not repeated here, but an integrated action plan is proposed below which focuses on several areas of prime importance.

1) Mapping existing schemes of cooperation, identifying shortcomings, and providing an optimized scenario for partnership arrangements at national and international levels to make the best "use" of existing capacities.

2) Reinforcing scientific work on the amphibians and reptiles of Sri Lanka through a targeted approach and using all national capacities (governmental institutions and other entities, universities, NGOs, and other stake holders) and schemes of international cooperation. Scientific work should include a continuation of the highly successful taxonomic work of the past decade but should increasingly include ecological and biogeographical work to complement our knowledge of systematic relationships among taxa (for some recent problems see Pethyiagoda 2004).

3) Linking this endeavor to work on ecosystem or plant community classification and conservation as carried out by Sri Lankan universities, particularly in regards to botanical research or work in the fields of plant ecology and plant biogeography.

4) Developing schemes and scientific programs supported by the latest space technologies for monitoring the status of ecosystems in Sri Lanka for habitat restoration and recreating continuous habitat or ecosystems (particularly in the wet zone and central hills). Replanting and reconnecting forest fragments through planting of indigenous species, as has been carried out for years by the Department of Botany at Peradeniya University (e.g., Ashton et al. 2001).

5) Fostering joint education, research, and degree work in these fields at universities in Sri Lanka. This may need to be coordinated among universities interested in inter-university cooperation. Such a plan could create better employment opportunities and promote qualified staff to work in conservation and sustainable development sectors.

6) Making biodiversity education more inclusive, encompassing all levels of the education system including formal and informal education and arrangements for life-long learning. In addition, biodiversity education should become part of a massive effort to champion education for sustainable development in the country, closely linked to public awareness programs, particularly as needed for the conservation of amphibians and reptiles.

7) The results of these works should be interconnected to conservation work carried out by the Sri Lank-

an government authorities, in particular the Forest Department, the Department of Wildlife Conservation, and the Biodiversity Secretariat.

8) Fostering the role and capacity of the National Museum in overall conservation efforts for Sri Lankan herpetofauna in a national and international context, and in particular through reinforcing and facilitating the museum's international collaboration and programs of work.

9) Reinforcing *in situ* and *ex situ* conservation efforts for amphibians and reptiles in Sri Lanka. The zoological gardens at Dehiwela and the establishment of a new facility such as a "Sri Lanka Aquarium" might generate the needed public attention for the conservation needs of Sri Lanka and its herpetofauna (see 6).

10) Extending existing activities and programs in national and international ecotourism programs to include amphibians and reptiles as specific examples for creating environmental awareness and the need for biodiversity conservation.

11) Closer liaison between all stake holders in joint conservation efforts regarding biodiversity hotspots of south India's Western Ghats and Sri Lanka. A model approach could be developed for preserving biodiversity in both hotspots (sometimes considered a single hotspot), serving as a template for similar analysis in other biodiversity hotspots. This needs to be based on a changed mind-set, with a paradigm shifted from "protection" to "conservation," which includes active, research-based management interventions (R. Pethiyagoda, pers. comm.).

For examining the feasibility of such an action plan or a similar initiative, a workshop or other "kick-off" meeting with all relevant governmental and non-governmental stake holders might be a useful first step. A proposed meeting may contribute to significant positive efforts in capacity and resource development (a multiple win situation for all stake holders) and for sustaining Sri Lanka's faunal and floral wealth for future generations.

Conclusions and outlook

Our knowledge of Sri Lanka's biodiversity has experienced a quantum leap during the last decade. This is underscored by massive efforts to scale up taxonomic research, in particular of the fauna of Sri Lanka, which has led to the discovery of a substantial number of new species among invertebrate and vertebrate taxa. Specifically, genetic studies have contributed to new insights into the country's biological diversity. The increase in numbers of amphibian species scientifically described has been outstanding, making it the vertebrate group with the highest percentage of endemic species (some 90%) in Sri Lanka; also more than twenty new reptile species have been described during the last decade.

Biodiversity efforts in Sri Lanka need to be further streamlined between all governmental and non-governmental institutions and agencies. This should include the consideration of global climate change as possibly the most important factor affecting the future of Sri Lanka's biodiversity, particularly the exceptional biodiversity in montane areas. A specific focus must be put on connectivity of natural habitat, particularly in the lowland wet zone and highlands where forests have been severely fragmented—a phenomenon making these ecosystems particularly prone to impacts of climate change and exacerbated by the large number of aggressive invasive alien species now found in the highlands of Sri Lanka (R. Pethyiagoda, pers. comm.).

The division of institutional activities and the enormous number of ongoing projects related to the conservation of Sri Lanka's biodiversity may need to be inventoried and mapped at both national and international levels in order to optimize future efforts. This is especially needed because of the limited human and financial resources available to address biodiversity issues in Sri Lanka. These efforts should be accompanied by the formation of an inter-institutional coordination plan for biodiversity research, monitoring, and identification of threats, as is already proposed in the *Fourth Country Report from Sri Lanka to the Convention on Biological Diversity* (see Dela 2009, Appendix III, p. vii). Such an initiative may benefit from a regional approach, exchanging experience and addressing common issues especially since Sri Lanka and the Western Ghats of southern India are one of the most important global biodiversity hotspots containing ecoregions of outstanding regional and global value.

The Decade on Biodiversity (2011-2020) and the implementation recommendations of the Nagoya COP 10 conference such as the new biodiversity strategy and the biodiversity targets might offer a unique platform for launching and sustaining the initiatives outlined here. This platform could facilitate the release of an updated National Biodiversity Strategy and Action Plan for Sri Lanka which might be cast as a living strategic document, closely linked to the country's efforts to implement sustainable development, with an increased focus on coping with the effects of global climate change and using the potential of a green economy.

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