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A review of amphibian fauna of Sri Lanka: distribution, recent taxonomic changes and conservation

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Abstract

The amphibian fauna of Sri Lanka comprises 120 species, including 107 (~90.0%) endemic species. They belong to five families: Bufonidae, Dicroglossidae, Ichthyophiidae, Microhylidae, and Rhacophoridae. Based on distribution, we recognized five zoogeographic zones for them, Central Hills, Dry Zone, Knuckles Range, Lowland Wet Zone, and Rakwana Hills. Fifty three species were reported from the Central Hills (48 endemics [90.6%] and 42 [79.2%] threatened species). 47 species were recorded from the Lowland Wet Zone, including 36 (76.6%) endemics and 28 (59.6%) threatened species. The Knuckles Range had 25 species, of which, 19 (76.0%) were endemics and 15 (60.0%) are threatened species. 19 species were reported from Dry Zone including seven endemics (36.8%) and four threatened species (21.1%). Out of 29 species, which inhabited in the Rakwana Hills, 26 were endemics (~89.7%) including 24 (82.8%) threatened species. Species diversity along the elevational gradient was also observed with the highest species richness in the mid-elevational localities. Family Ichthyophiidae can be considered as the least studied family. Recent rediscoveries and studies have helped to reduce the number of extinct species from 21 to 18. It is speculated that some of the other extinct species have to be rediscovered or probably were misidentified as other species. About 90% of Sri Lankan amphibians occur in the regions with the highest human populations where there are established agricultural lands. Loss of habitats, competition due to anthropogenic species and invasive species, pollution (cause for malformations, parasites, and other diseases), and climate change appear to be major threats.

Key words: Climate change, conservation, endemic, extinct, threatened, Sri Lanka

Introduction

Sri Lanka is a continental island in the south region of Asia with a high rate of biodiversity. Sri Lanka is also considered a reservoir of unique evolutionary history (Myers et al., 2000;

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Bossuyt et al., 2004). In addition, Sri Lanka is known as a biodiversity hotspot in the revised hotspots of the world along with the Western Ghats of India (Mittermeier et al., 1998). Moreover, recently, the Central Highland of Sri Lanka (Horton Plains, Knuckles Range, and Peak Wilderness) was declared as a World Heritage Site (UNESCO, 2010). Apart from that, a southwestern quarter of Sri Lanka is known as a unique conservation region (Gunatilleke et al., 2005). Gunatilleke et al. (2005) described a model river basin landscape-seascape conservation area for the southwestern hill forests of Sri Lanka along the Gin River. An assessment of forest resources in Sri Lanka in 1992 indicated that the total forest cover (including forest plantations) is about 32.2 % of its total land area (~6.7 million ha), while the percentage of closed-canopy natural forest areas was 23.9 %, sparse and open forests was about 7.0 % and the area of the forest plantations was about 1.3 % of total land area (Legg and Jewell, 1995).

Within this high biodiversity, amphibians can be considered as one of the best-studied groups among the other vertebrates (Manamendra-Arachchi and Pethiyagoda, 2006; Frost, 2018; Meegaskumbura et al, 2019). In the 18th century, based on Seba's drawing (Seba, 1735), the first amphibian species from Sri Lanka, 'Serpens caecilia ceylonica', synonym of *Ichthyophis glutinosus* (Linnaeus, 1758) was described. Subsequently, in the 19th century contributions are noticeable. Kelaart (1854) described a detailed summary of amphibians of Sri Lanka, which included 10 species. Following Kelaart (1854), several authors reported or described amphibians from Sri Lanka and species number peaked between mid-19th and mid-20th century owing to the works of following authors: Lichtenstein and Martens (1856), Günther (1858; 1859; 1864; 1869; 1872; 1876a, b), Boulenger (1882a, b; 1904; 1905), Méhely (1897), Ahl (1927), Parker (1934), Parker and Osman Hill (1948), and Shreve (1940).

Following this period, Kiritisinghe (1957) published his classic book on Sri Lankan amphibians, 'The Amphibia of Ceylon'. However, within the Sri Lankan amphibian assemblage, Kirtisinghe (1957) recognized a lesser number of *Pseudophilautus* Laurent, 1943 (as *Philautus* Gistel, 1848 or *Rhacophorus* Kuhl and van Hasselt, 1822 or as *Theloderma* Tschudi, 1838) species and synonymised many rhacophorid species that reduced the number of species from 34 to 8. Dutta and Manamendra-Arachchi (1996) elevated the number of rhacophorids to 17, and then Manamendra-Arachchi and Pethiyagoda (2001b; 2005), and Meegaskumbura and Manamendra-Arachchi (2005) increased it to 65, which includes 60 *Pseudophilautus* (excluding the *Pseudophilautus semiruber* (Annandale, 1913)). Manamendra-Arachchi and Pethiyagoda (2005) considered this species as a Data Deficient taxon. In addition, subsequent new species descriptions raised the *Pseudophilautus* species assemblage up to 77 (Meegaskumbura and Manamendra-Arachchi, 2011; Meegaskumbura et al., 2007; 2009; 2012a; Wickramasinghe et al., 2013a; 2015; Batuwita et al., 2019b). In addition to *Pseudophilautus* species, several new species were also added to the Sri Lankan amphibian assemblage as well (Fernando et al., 1994; Fernando and Siriwardhane, 1996; Manamendra-Arachchi and Gabadage, 1996; Manamendra-Arachchi and Pethiyagoda, 1998; 2001a, b; Fernando et al., 2007; Wickramasinghe et al., 2012a; Wijayathilaka et al., 2015; Senevirathne et al., 2018). Also, Kotagama et al. (1981) and De Silva (1995; 1996) published species checklists.

Currently, the amphibian fauna of Sri Lanka consists of five families: Bufonidae Gray, Dicroglossidae Anderson, Ichthyophiidae Taylor, Microhylidae Günther, and Rhacophoridae Hoffman (Frost, 2006). Sri Lanka is also known as a country with amphibian 'megadiversity' with about 250 species (Pethiyagoda and Manamendra-Arachchi, 1998), but to date, this number should revise to 120 (Dutta, 1997; Manamendra-Arachchi and Pethiyagoda, 2006; Fernando et al., 2007; Biju et al., 2014; Jayawardena et al., 2017; Meegaskumbura et al., 2015; Frost, 2018; Senevirathne et al., 2018; Batuwita et al., 2019b). This is only second to

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Costa Rica (Table 1), due to the highest density of species per unit area (~1.8 species per 1000 km^2). Even though Sri Lanka has a higher amphibian species diversity, threats to the species of amphibians are increasing at an alarming rate. According to the IUCN Red List of Threatened Species (IUCN, 2007), the threatened amphibian species were 52 (49.1%) in 2007 (Table 2). However, the recent report (IUCN, 2012) confirmed that the number of threatened species rapidly increased to 72 (64.9%). Based on this data, Sri Lankan amphibians are considered as one of the major threatened vertebrate species (see also Bopage et al., 2011; Manamendra-Arachchi and Pethiyagoda, 2006; De Silva and Wijayathilaka, 2019).

Thus, the purpose of this review is to evaluate the amphibian fauna of Sri Lanka by discussing their distribution, recent taxonomic changes, threats, and conservation.

Table 1: Species diversity of amphibians in selected 'megadiversity' countries of the world (Modified after Pethiyagoda and Manamendra-Arachchi, 1998).

Country	Total No. of amphibian species	Species density (1000 km^2)
China	389	0.04
Brazil	516	0.06
Zaire	216	0.09
India	384	0.12
Indonesia	270	0.13
Venezuela	197	0.22
Colombia	407	0.36
Ecuador	358	1.30
Sri Lanka	120	1.83
Costa Rica	140	2.75

Table 2: Species richness and endemism among Sri Lankan amphibians (National Red list; IUCN, 2007).

	Number of species	Number of endemic species
Total species	106	90
Critically endangered	12	12
Endangered	34	34
Vulnerable	6	5
Total threatened	52	51

Material and Methods

All extant species were allocated to five different separable groups (Fig. 1) according to their distribution, *viz.*, (1) the Lowland Wet Zone confined to the southwestern quarter of the island (mean annual precipitation >2000 mm), which extends from sea coast to the interior (from a.s.l. [0 m] up to about 1000 m a.s.l.) including the Haycock Mountain (~660 m), the Sinharaja World Heritage Site (WHS) (~600 m) and excluding the Central Hills, the Knuckles Range, and the eastern Sinharaja; (2) the Central Hills: from 500 m to its highest peak at Pidurutalagala (~2524 m) including the Peak Wilderness; (3) the Knuckles Range: from 500 m to about 1863 m (the highest peak) elevation; (4) the Dry Zone: from coast to interior from a.s.l. (0 m) to 500 m (mean annual precipitation <2000 m); and (5) the Rakwana Hills:

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including Gongala (Hayes) and Handapana Ella Plains (from 1000 m to its highest elevation, ~1358 m).

The distribution of species are based on the data gathered from previously published literature: monographs (Dutta and Manamendra-Arachchi, 1996; Manamendra-Arachchi and Pethiyagoda, 2006), periodicals (Fernando et al., 2007; Wickramasinghe et al., 2012a, b; Wickramasinghe et al., 2013b; 2015; Batuwita et al., 2019b), reports, IUCN (1999; 2007; 2012), WCSG (2008; 2009), together with personal observations based on field observations by the first three authors during 1997 to 2014. Elevations were classified as follows: (1) Low elevations (<800 m), (2) Mid-elevations (~800 m to ~1700 m), and (3) High elevations (1700 m to 2500 m).

For the distribution study, all putative extinct species were excluded. Photographs were taken by Cannon IXUS50 and Nikon D700 digital cameras. Elevations are given in metres (m) from mean sea level. Map with zoogeographic zones was prepared by using the ARC GIS 10.1 software.

For higher-level taxonomy, we followed Frost et al. (2006) and in species taxonomy the following literature were used: Frost et al. (2006), Manamendra-Arachchi and Pethiyagoda (2006), Fernando et al. (2007), Joshy et al. (2009), Li et al. (2013), Biju et al. (2014), Khajeh et al. (2014), Meegaskumbura et al. (2015), Oliver et al. (2015), Peloso et al. (2016), Wijayathilaka et al. (2016), Garg et al. (2018), Sanchez et al. (2018), Batuwita et al. (2019b), and Chandramouli et al. (2019). The conservation statuses of species were taken from the following published sources: Fernando et al. (2007); IUCN (1999; 2007; 2012); Manamendra-Arachchi and Pethiyagoda (2006); Wickramasinghe et al. (2013b; 2015); and Batuwita et al. (2019b). Recent taxonomic changes to the species were discussed after Manamendra-Arachchi and Pethiyagoda (2006).

Abbreviations used: BMNH, British Museum Natural History (Natural History Museum, London [NHM]); WCSG, Wildlife Conservation Society-Galle of Sri Lanka; WHT, Wildlife Heritage Trust of Sri Lanka; a.s.l., above sea level.

Results

Endemic and threatened amphibians

Sri Lanka has 120 amphibian species (Appendix 1; Table 3), of which 107 (~90.0%) are endemics and more than 80% are restricted to rain forests (Manamendra-Arachchi and Pethiyagoda, 2006; Fernando et al., 2007; Meegaskumbura et al., 2009; Meegaskumbura and Manamendra-Arachchi, 2011; Wickramasinghe et al., 2012a, b; Wickramasinghe et al., 2013a; 2015; Batuwita et al., 2019b). Eighteen endemic species of amphibians are currently confirmed as extinct (Manamendra-Arachchi and Pethiyagoda, 2005; 2006; Meegaskumbura et al., 2007; 2012a; 2015; Wickramasinghe et al., 2012b; 2013b, c), which includes a single species from a relic genus, *Nannophrys* Günther, 1869 and 17 species from *Pseudophilautus*. Thus, once the extinct species are excluded, the total number of amphibian species are 102 (including 89 endemics). All species of the family Rhacophoridae (with the exception of *Polypedates maculatus* (Gray, 1834)) and three species that belong to the family Ichthyophiidae are endemic to Sri Lanka (Fig. 2A, B). Family Microhylidae contains 70% of the endemic species. As a percentage, Bufonidae and Dicroglossidae are showing more or less similar figures (Fig. 2B). Out of seven species reported from the family Bufonidae, four taxa are endemics. Seventeen species of Dicroglossidae were recorded including 10 endemics (Fig. 2A).

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The endemic genera in Sri Lanka are: *Adenomus* Cope, 1861, *Lankanectes* Dubois and Ohler, 2001, *Nannophrys*, and *Taruga* Meegaskumbura, Meegaskumbura, Bowatte, Manamendra-Arachchi, Pethiyagoda, Hanken and Schneider, 2010. Species of the endemic genera are confined to all zoogeographic zones, but in the Dry Zone, they are restricted to the highest elevations only (i.e., isolated hills with humid forests). When considering the threatened species, except families Dicroglossidae and Microhylidae, all the other families contained a higher percentage (~60%) of threatened species (Fig. 2B).

Table 3: Putative extinct amphibian species of Sri Lanka.

Family	Species	Type locality
Dicroglossidae	*Nannophrys guentheri* Boulenger, 1882	'Ceylon'
Rhacophoridae	*Pseudophilautus adspersus* (Günther, 1872)	Nuwara Eliya
	Pseudophilautus dimbullae (Shreve, 1940)	Queenwood Est., Dimbullen (= Dimbulla), 'Ceylon'
	Pseudophilautus eximius (Shreve, 1940)	Queenwood Est., Dimbullen (= Dimbulla), 'Ceylon'
	Pseudophilautus extirpo (Manamendra-Arachchi and Pethiyagoda, 2005)	'Ceylon'
	Pseudophilautus halyi (Boulenger, 1904)	Pattipola
	Pseudophilautus leucorhinus (Lichtenstein and Martens, 1856)	'Ceylon'
	Pseudophilautus maia (Meegaskumbura, Manamendra-Arachchi, Schneider and Pethiyagoda, 2007)	"Poojagodde" [Poojagoda] Estate, Ramboda, Sri Lanka
	Pseudophilautus malcolmsmithi (Ahl, 1927)	'Ceylon'
	Pseudophilautus nanus (Günther, 1869)	'Ceylon'
	Pseudophilautus nasutus (Günther, 1869)	'Ceylon'
	Pseudophilautus oxyrhynchus (Günther, 1872)	'Ceylon'
	Pseudophilautus pardus (Meegaskumbura, Manamendra-Arachchi, Schneider and Pethiyagoda, 2007)	'Ceylon'
	Pseudophilautus rugatus (Ahl, 1927)	'Taralanda' or 'Farnlands'
	Pseudophilautus temporalis (Günther, 1864)	'Ceylon'
	Pseudophilautus variabilis (Günther,1859)	'Ceylon'
	Pseudophilautus zal (Manamendra-Arachchi and Pethiyagoda, 2005)	'Ceylon'
	Pseudophilautus zimmeri (Ahl, 1927)	'Point de Galle, Ceylon'

Even though Sri Lanka possesses diverse ecosystems throughout its terrain, endemic amphibians are mostly restricted to the Central Hills, Knuckles Range, Lowland Wet Zone and Rakwana Hills (mean annual precipitation >2000 mm). Senanayake et al. (1977) stated that southern rain forests and montane forests contain a rich assemblage of endemic animals (i.e., excluding the Dry Zone). The above authors view on the endemic fauna is the same as the present findings. Endemic and threatened species that are reported from different zoogeographic zones of Sri Lanka are discussed below.

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Zoogeographic zones and amphibians

Five different zoogeographic zones for Sri Lankan amphibians were recognized based on their zoogeography (Fig. 1; Appendix 1).

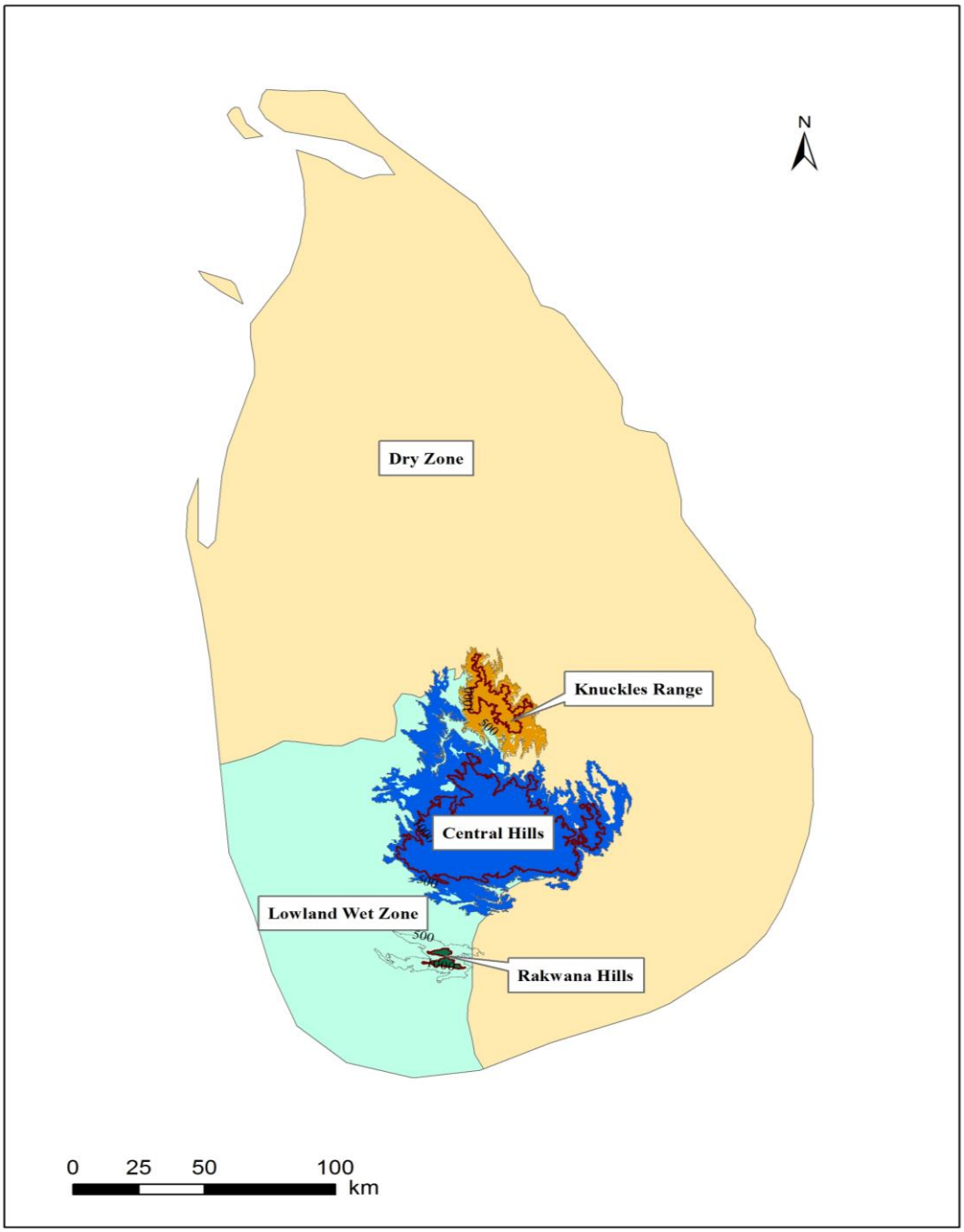

Figure 1: Map showing zoogeographic zones for amphibian fauna of Sri Lanka (Central Hills in blue; Dry Zone in light yellow; Knuckles Range in brown; Lowland Wet Zone in light blue; and Rakwana Hills in dark green; and 1000 m contour line in maroon color).

The Central Hills zoogeographic zone is starting from 500 m elevation and located within the central region of the island (Fig. 1). Several major forest reserves (e.g., Ambagamuwa, Namunukula, and Pedro; the highest peak 2524 m), sanctuary (e.g., Peak Wilderness), a Strict Nature reserve (e.g., Hakgala) and National Park (e.g., Horton Plains) are included in this zone. Major vegetation types includes: hill rainforest, montane forests, montane grasslands

(wet patanas) and moist semi-evergreen (intermediate) forests (Ashton et al., 1997). Fifty three species were recorded from this region. This is more than one third of the total extant amphibian fauna of Sri Lanka, and includes 48 endemics (90.6%) of which 42 (79.2%) are threatened species. Out of 53 species recorded from the Central Hills, more than half of the species (34 species, 64.2%) belong to the family Rhacophoridae. Apart from these species, 19 species of amphibians are from other families that were reported from the Central Hills. Therefore, the Central Hills has the highest number of amphibian species as well as threatened amphibians (Fig. 3A).

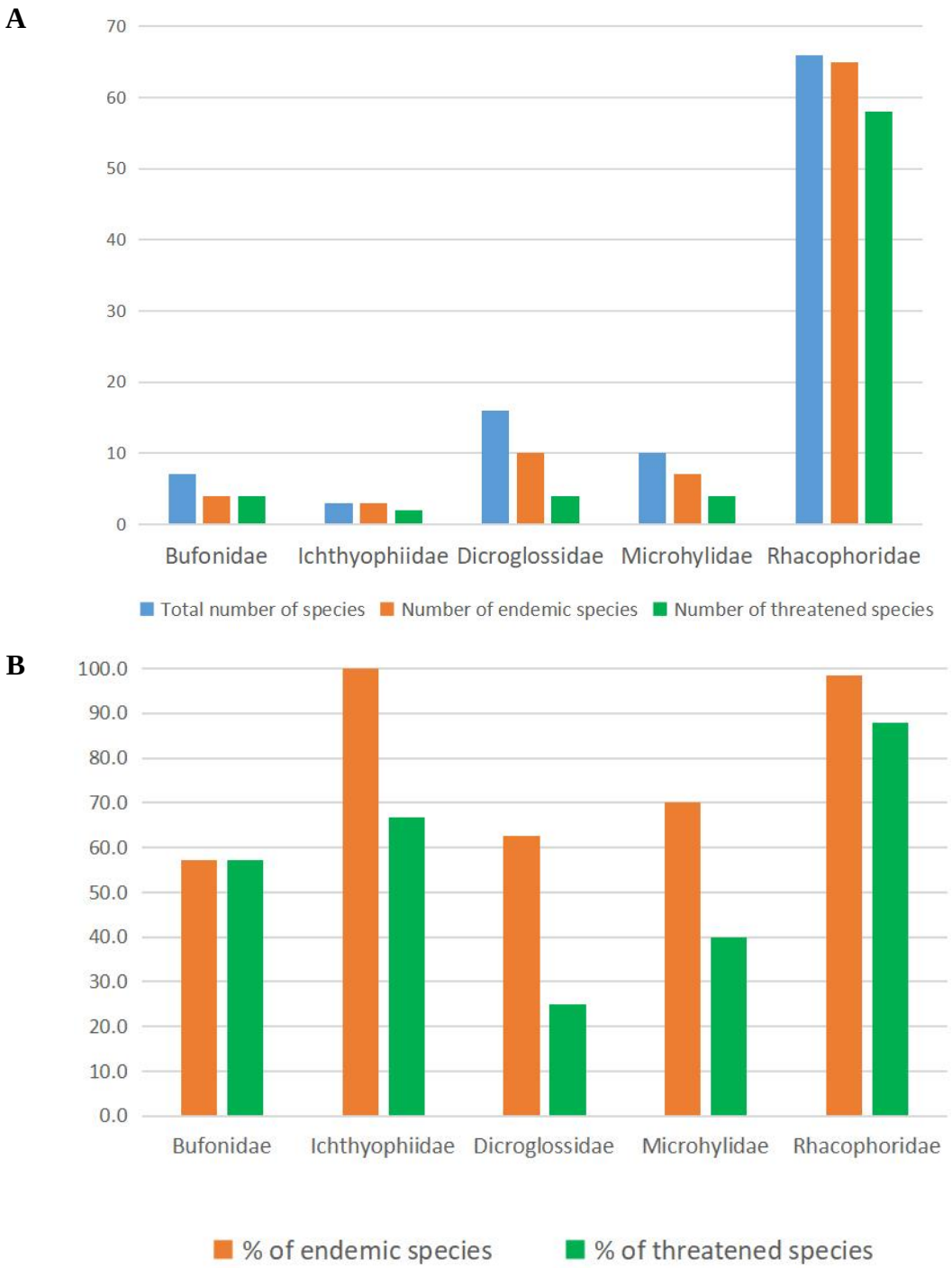

Figure 2: Amphibian fauna of Sri Lanka: species diversity, endemism and threatened species (A); endemic and threatened species percentages (B).

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The Lowland Wet Zone (Fig. 1) consists of rain forests (below 300 m a.s.l.) and hill rain forests (300–1000 m a.s.l. [up to 500 m]) as major forest types, which are evergreen forests without significant seasonal changes (Ashton et al., 1997), e.g., Kanneliya-Dediyagala-Nakiyadeniya Forest Reserves (known as KDN complex), Haycock and Sinharaja WHS. The latter two forests are hill rain forests. This zone receives an annual rainfall of about 2000–3000 mm. Forty seven species of amphibians were recorded from the Lowland Wet Zone, of which 36 (76.6%) are endemic to Sri Lanka (Fig. 3A, B). The threatened species percentage reported from this area is more or less the same (~60.0%) as the threatened species in the Knuckles Range (Fig. 3B).

The Knuckles Range is very recently recognized as a zoogeographic zone (Fig. 1) in Sri Lanka (Pethiyagoda and Manamendra-Arachchi, 1998), which lies within the mid-elevational zone (> ~500 m). Major forest types observed in this zone belong to hill rainforest, montane forests, montane grasslands (wet patanas) and moist semi-evergreen (intermediate) forests (Ashton et al., 1997). Twenty five species were recorded from the Knuckles Range, of which 19 (76.0%) are endemic to Sri Lanka and 15 (60.0%) are considered as threatened species (Fig. 3A, B). It has been proven that this is yet another unique zone not only for amphibians e.g., *Nannophrys marmorata* Kirtisinghe, 1946, three species of *Pseudophilautus*, *viz.*, *P. mooreorum* (Meegaskumbura and Manmendra-Arachchi, 2005), *P. steineri* (Meegaskumbura and Manmendra-Arachchi, 2005), and *P. stuarti* (Meegaskumbura and Manamendra-Arachchi, 2005), but also for restricted reptile species as well (Batuwita and Udugampala, 2017).

The Dry Zone (Fig. 1) is the largest zoogeographic zone, which has dry mixed evergreen forests (monsoonal); savannas and thorn scrub major vegetation types (Ashton et al., 1997). However, it has the lowest number of amphibian species, i.e., 19, of which only seven species (36.8%) are endemic to Sri Lanka. Out of the 19 amphibian species, four are considered as threatened species (Fig. 3A, B). When compared with the other zones, the endemic amphibian diversity in the Dry Zone was very low (Fig. 3A), but two endemic amphibians each from the family Dicroglossidae, *Nannophrys naeyakai* Fernando, Wickramasinghe, and Rodrigo, 2007 and Rhacophoridae, *Pseudophilautus regius* (Manamendra-Arachchi and Pethiyagoda, 2005), are confined to the Dry Zone. Many isolated unexplored hilly areas are scattered in this larger zoogeographic zone, e.g., Dolukanda, Gowindahela, Kataragama, Moneragala, Nilgala, Nuwaragala, Rathugala, Ritigala, and Sandagala. Recording vertebrate fauna from these unique areas is difficult, but productive (Bahir and Silva, 2005; Fernando et al., 2007; Wickramasinghe and Munindradasa, 2007; Batuwita et al., 2019a; Karunrathna et al., 2019a, b). Interestingly, a few widely distributed *Pseudophilautus* species were reported from the above mentioned isolated mountains (Manamendra-Arachchi and Pethiyagoda, 2005; Karunarathna et al., 2008). It is suggested that further studies are needed to evaluate these isolated populations, because unique new species of herpetofauna were described from these hills (Fernando et al., 2007; Wickramasinghe and Munindradasa, 2007; Batuwita et al., 2019a; Karunarathne et al., 2019a, b).

The eastern Sinharaja, Gongala (Hayes) and Hadapana Ella Plains are classified as the Rakwana Hills (Fig. 1), which is a separate zone. Major vegetation types found in this zone belong to submontane forests and submontane grasslands (wet patanas) (Ashton et al., 1997). Within the past two decades, 11 new species of amphibians were discovered from this unique zoogeographic zone (Fernando and Siriwardana, 1996; Manamendra-Arachchi and Pethiyagoda, 2001b; 2005; Meegaskumbura and Manamendra-Arachchi, 2005). A total of 29 species were recorded from the Rakwana Hills (Fig. 3A), which accounted for the highest percentage of threatened species (82.8%) and the second largest number of endemic species percentage, 89.7% (Fig. 3B). Some species inhabiting the Rakwana Hills are considered as

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point endemics, e.g., *Taruga fastigo* (Manamendra-Arachchi and Pethiyagoda, 2001b) (Fig. 4), and several *Pseudophilautus* species, including: *P. ocularis* (Manamendra-Arachchi and Pethiyagoda, 2005), *P. lunatus* (Manamendra-Arachchi and Pethiyagoda, 2005), *P. papillosus* (Manamendra-Arachchi and Pethiyagoda, 2005), *P. decoris* (Manamendra-Arachchi and Pethiyagoda, 2005), and *P. procax* (Manamendra-Arachchi and Pethiyagoda, 2005).

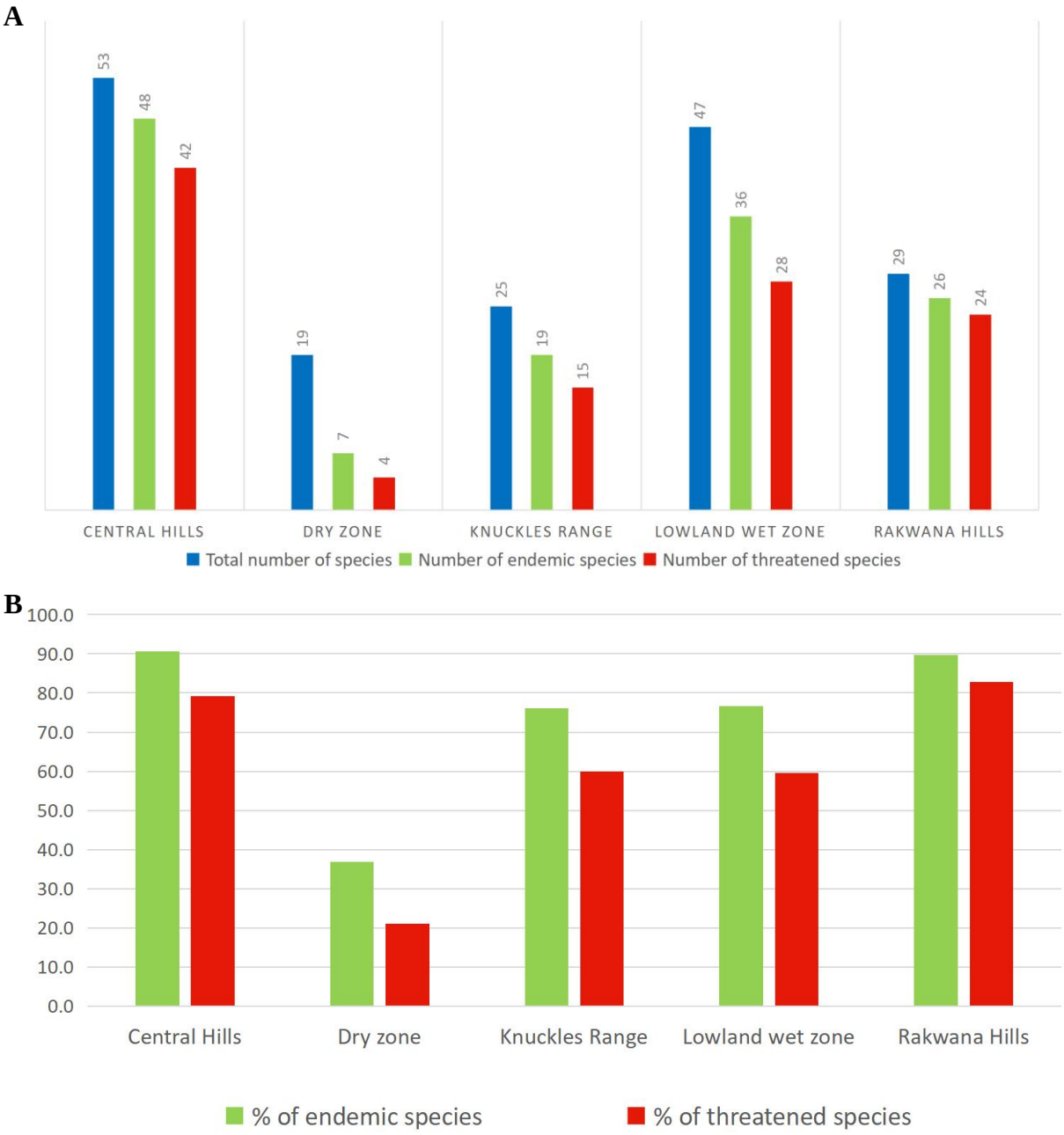

Figure 3: Species compositions in the different zoogeographic zones including endemic and threatened species (A); percent of endemic, and threatened species in different zone geographic zones, respectively (B).

Apart from the above zoogeographic zones, certain localities with high amphibian richness can be considered as ecotones, e.g., Lowland Wet Zone-Central Hills (Peabotuwage et al., 2012) and Lowland Wet Zone-Rakwana Hills (Janzen and Bopage, 2011). Gosz (1993) and

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Risser (1995) showed that transitional areas share the two types of environments of the habitats that coincide in the ecotone and also have a unique ecotonal environment. Ecotones often support a unique community with additional characteristics to those of the communities adjoining it (Odum, 1953). Recent studies revealed that species inhabiting ecotones have the highest genetic and morphological diversity and also these species have rare and unique alleles (Kark and van Rensburg, 2006). In addition, ecotones are also known as centers of evolutionary novelty, where parapatric (or sympatric) speciation processes may take place (Schilthuizen, 2000).

Species diversity along elevation gradient

The species distribution according to the elevational gradient for Sri Lankan amphibians were observed (Fig. 5). Elevation ranges starting from a.s.l. (0 m) to 500 m and from 500 m to 1300 m represented the higher number of species (Fig. 5). These elevations lie within the Central Hills, Knuckles Range, Lowland Wet Zone and Rakwana Hills (Fig. 1). Naniwadekar and Vasudevan (2007) conducted a study in the Western Ghats of Southern India and reported about 12 species as the highest amphibian species richness around 1200 m elevation. In contrast, present data revealed about 20 species inhabiting more or less similar elevations (from 900 m to 1200 m) and the highest species richness (~37) were recorded from a.s.l. (0 m) to 700 m (Fig. 5). Hu et al. (2012) also showed that the distribution of amphibians has great variation according to the differences in the elevations of the respective habitats.

Two species from the family Bufonidae exhibited wide distribution ranges: i.e., *Adenomus kelaartii* (Günther, 1858) and *Duttaphrynus melanostictus* (Schneider, 1799). However, the former was not found in the Dry Zone. *Adenomus kandianus* (Günther, 1872) is restricted to the highest elevational areas (1500–2300 m), whereas *Duttaphrynus noellerti* (Manamendra-Arachchi and Pethiyagoda, 1998) is distributed from 200 m to 500 m in the Lowland Wet Zone. All but *Ichthyophis orthoplicatus* Taylor, 1965 are confined to the low and mid-elevations (60 m to 1500 m).

Figure 4: *Taruga fastigo*, male, from the Morningside Forest Reserve, Rakwana Hills. Photo by Sudesh Batuwita.

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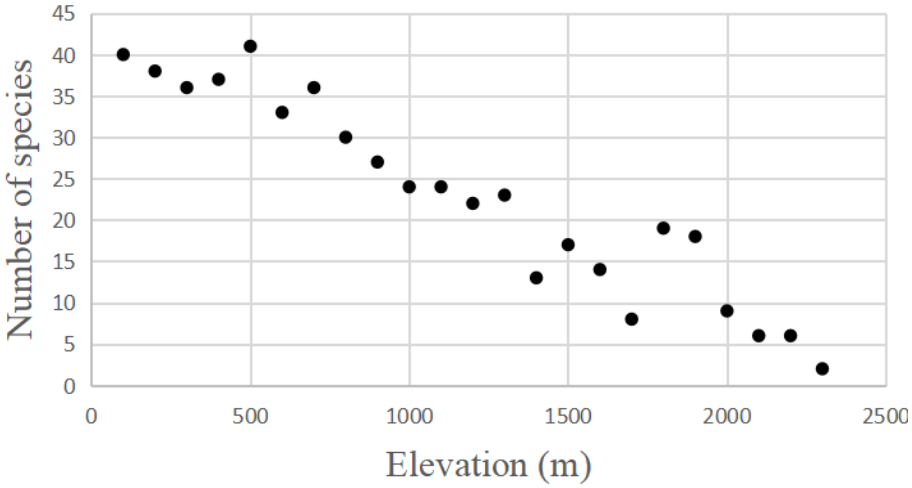

Figure 5: Number of species in different elevations (100 meter intervals).

Microhyla karunaratnei Fernando and Siriwardhane, 1996 and *Uperodon obscurus* (Günther, 1864) are confined to the low and mid-elevational areas (500 m to 1200 m), whereas *Microhyla zeylanica* Parker and Osman Hill, 1948 and *Uperodon palmatus* (Parker, 1934) are found only in high elevational regions. All other species from Microhyliidae were reported from elevations from the coast to up to 500 m elevation.

Most of the species from the family Dicroglossidae were distributed within the low elevation range (e.g., *Hoplobatrachus crassus* (Jerdon, 1853), *Nannophrys ceylonensis* Günther, 1868, *Hydrophylax gracilis* (Gravenhorst, 1829), *Indosylvirana serendipi* (Biju, Garg, Mahony, Wijayathilaka, Senevirathne and Meegaskumbura, 2014), *Sphaerotheca rolandae* (Dubois, 1983)), two species were confined to low and mid-elevation areas between 500–1500 m, *Nannophrys marmorata* and *Lankanectes pera* Senevirathne, Samarawickrama, Wijayathilaka, Manamendra-Arachchi, Bowatte, Samarawickrama and Meegaskumbura, 2018, while a single species was confined to elevations ranging from 1500–2500 m within the mid and high elevation areas, *viz.*, *Minervarya greenii* (Boulenger, 1905). Another five species inhabited wide elevational ranges, *sc.*, *Euphlyctis mudigere* Joshy, Alam, Kurabayashi, Sumida and Kuramoto, 2009, *Indosylvirana temporalis* (Günther, 1864), *Lankanectes corrugatus* (Peters, 1863), *Minervarya kirtisinghei* (Manamendra-Arachchi and Gabadage, 1996), *M. agricola* (Jerdon, 1953), and *Nannophrys naeyakai*. In addition, two species, *Euphlyctis hexadactylus* (Lesson, 1834) and *Sphaerotheca breviceps* (Schneider, 1799) were distributed at low elevations 0–760 m and 0–200 m, respectively.

However, the distribution of the species of Rhacophoridae was quite complex. Hence, based on their distribution, these species were subdivided into three groups in each major elevation group (Appendix 2). About one third of the Rhacophoridae species have wide distributional ranges (Appendix 2), of which, 10 species were noticeable: *Pseudophilautus alto* (Manamendra-Arachchi and Pethiyagoda, 2005), *P. cavirostris* (Günther, 1869), *P. folicola* (Manamendra-Arachchi and Pethiyagoda, 2005), *P. fulvus* (Manamendra-Arachchi and Pethiyagoda, 2005), *P. popularis* (Manamendra-Arachchi and Pethiyagoda, 2005), *P. reticulatus* (Günther, 1864) (Fig. 6), *P. schmarda* (Kelaart, 1854), *P. singu* (Meegaskumbura, Manamendra-Arachchi and Pethiyagoda, 2009), *P. sordidus* (Manamendra-Arachchi and Pethiyagoda, 2005), and *P. stictomerus* (Günther, 1876). By summarizing this data (Appendix 2), it is speculated that the species distribution data are insufficient on the genus *Pseudophilautus*. Hence, a need for further studies to understand their distribution patterns is hereby suggested.

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Discussion

Recent taxonomic changes

Frost et al. (2006) named a new genus *Duttaphrynus* for previously recognized *Bufo melanostictus* group (sensu Inger, 1972). Only *Bufo melanostictus* and *B. noellerti* were placed in this new genus from Sri Lanka. Other small to medium-sized Sri Lankan species (*Bufo atukoralei* Bogert and Senanayake, 1966, *B. kotagamai* Fernando and Dayawansa, and *B. scaber* (Schneider, 1799)) were not allocated to *Duttaphrynus* (Frost et al., 2006). Subsequently, Van Bocxlaer et al. (2009) showed that *Bufo atukoralei*, *B. kotagamai* and *B. scaber* are in fact members of *Duttaphrynus.* Apart from the above mentioned species, two other species from the family Bufonidae exist and they belong to an endemic genus *Adenomus*, *sc.*, *A. kelaartii* and *A. kandianus* (Wickramasinghe et al., 2012b; Meegaskumbura et al., 2015). Until Wickramasinghe et al. (2012b) rediscovered the latter species, it was considered as an extinct species (Manamendra-Arachchi and Pethiyagoda, 1998). Moreover, Meegaskumbura et al. (2015) showed that previously described *Adenomus dasi* Manamendra-Arachchi and Pethiyagoda, 1998 is a new junior synonym of *A. kandianus.* Also, recent studies revealed that *Duttaphrynus atukoralei* is conspecific with *D. scaber* and the population that inhabits the Lowland Wet Zone (Fig. 7) is a distinct cryptic species related to *D. scaber* (Jayawardena et al., 2017).

Figure 6: *Pseudophilautus reticulatus*, from the Dediyagala Forest Reserve, Lowland Wet Zone. Photo by WCSG.

Figure 7: *Duttaphrynus* cf. *scaber*, from Thalalla near Matara, Lowland Wet Zone. Photo by Sudesh Batuwita.

In 2007, Fernando et al. (2007) described a new species of *Nannophrys* from Sri Lanka. This species is the only member of the congeners that occur in the Dry Zone. Taxonomy and phylogeny of the Asian Dicroglossidae species have been well studied recently (Alam et al., 2008; Biju et al., 2014; Khajeh et al., 2014; Oliver et al., 2015; Sanchez et al., 2018; Chandramouli et al., 2019). On the basis of these studies, Sri Lankan members of the genus *Fejervarya* Bolkay, 1915 are now placed in a different genus, *Minervarya* Dubois, Ohler and Biju, 2001 (Sanchez et al., 2018). Sanchez et al. (2018) allocated the Southeast Asian species in the genus *Fejervarya* and the South Asian species to the genus *Minervarya*. Based on recent studies (Sanchez et al., 2018; Chandramouli et al., 2019), three species of *Minervarya* are known from Sri Lanka, *sc.*, *M. greenii*, *M. kirtisinghei*, and *M. agricola*. The latter species was previously known as *Fejervarya limnocharis* (Gravenhorst, 1829) (Manamendra-Arachchi and Pethiyagoda, 2006) and has recently been assigned to *M. syhadrensis* (Annandale, 1919), but now it is known as *M. agricola* (Sanchez et al., 2018; Chandramouli et al., 2019). Recently, a cryptic new species was described from the endemic genus *Lankanectes*, *L. pera* from the Knuckles Range (Senevirathne et al., 2018).

Sri Lankan frog species that have been previously placed in the genus *Rana* Linnaeus, 1758 (Manamendra-Arachchi and Pethiyagoda, 2006) were recently revised and also allocated to the genus *Hylarana* Tschudi, 1838 (Biju et al., 2014). In 2015, the phylogeny of this group was revised again and found that, two genera occur in Sri Lanka, *sc.*, *Hydrophylax* Fitzinger, 1843 and *Indosylvirana* Oliver, Prendini, Kraus and Raxworthy, 2015 (Oliver et al., 2015). On the basis of above studies, the following species are recorded from Sri Lanka: *Indosylvirana serendipi*, *I. temporalis* and *Hydrophylax gracilis* (Biju et al., 2014; Oliver et al., 2015; Frost, 2018). *Indosylvirana aurantiaca* (Boulenger, 1904) has long been reported

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from Sri Lanka (Kirtisinghe, 1957; Dutta and Manamendra-Arachchi, 1996; Manamendra-Arachchi and Pethiyagoda, 2006), however, Biju et al. (2014) stated that this species is confined to India.

A recent study revealed that the Sri Lankan skipper frog belongs to the newly described *Euphlyctis mudigere* (Joshy et al., 2009; Khajeh et al., 2014). This species has a wide distribution range in India and Sri Lanka (Alam et al., 2008; Khajeh et al., 2014). In addition, Dahanukar et al. (2017) resurrected *Sphaerotheca pluvialis* (Jerdon, 1853) and mentioned that a few specimens from Sri Lanka, which they have examined, belong to this species. Hence, according to Dahanukar et al. (2017) three species of the genus *Sphaerotheca* Günther, 1859 are found in Sri Lanka: *S. breviceps*, *S. pluvialis* and *S. rolandae*. Dahanukar et al. (2017) placed *Sphaerotheca rolandae* in their *breviceps* group. Interestingly, based on the keys of Dahanukar et al. (2017), Sri Lankan material referred to *S. rolandae*, which depicted in Dutta and Manamendra-Arachchi (1996; fig. 154) affine to the *dobsoni* group. Hence, we speculate this material might belong to *Sphaerotheca pluvialis* from Sri Lanka. However, we did not include this species in our species list. Comprehensive studies on the genus in Sri Lanka may reveal their taxonomy.

Peloso et al. (2016) reviewed the higher-level taxonomy of the family Microhylidae. Except the species of the genus *Microhyla* Tschudi, 1838, all Sri Lankan species of the family Microhylidae are now placed in *Uperodon* Duméril and Bibron, 1841 (Peloso et al., 2016). However, Peloso et al. (2016) further mentioned that *Kaloula* Gray, 1831 is paraphyletic and the South Asian (Sri Lankan+Indian) populations of this genus can be separated from the Southeast Asian populations. Moreover, external morphology of these species (i.e., Sri Lankan *Uperodon* sensu Peloso et al.) showed distinguishable characters that can separate them into different genera as previously recognized (Dutta and Manamendra-Arachchi, 1996; Manamendra-Arachchi and Pethiyagoda, 2006). Hence, future integrated taxonomic approaches, including the internal morphology (e.g., osteology) will reveal the identity of supra-specific level taxonomy of them. Two new cryptic species were also recently added to the family Microhylidae: *Microhyla mihintalei* Wijayathilaka, Garg, Senevirathne, Karunarathna, Biju, and Meegaskumbura, 2016; and *Uperodon rohani* Garg, Senevirathne, Wijayathilaka, Phuge, Deuti, Manamendra-Arachchi, Meegaskumbura, and Biju, 2018 (Wijayathilaka et al., 2016; Garg et al., 2018).

The South and Southeast Asian shrub frogs, which were previously referred to *Philautus*, were placed in two separated genera (Yu et al., 2010). Yu et al. (2010) resurrected *Pseudophilautus* for the South Asian species. In the same year, Biju et al. (2010) described a new genus, *Raorchestes* Biju, Shouche, Dubois, Dutta, and Bossuyt, 2010. Biju et al. (2010) placed most of the Indian *Pseudophilautus* species in *Raochestes* and mentioned only three species of *Pseudophilautus* from India. In 2007, based on museum material, two new extinct species of *Pseudophilautus* were described from Sri Lanka (Meegaskumbura et al., 2007), *sc.*, *P. maia* (Meegaskumbura, Manamendra-Arachchi, Schneider, and Pethiyagoda, 2007) and *P. pardus* (Meegaskumbura, Manamendra-Arachchi, Schneider, and Pethiyagoda, 2007). Wickramasinghe et al. (2012a; 2013a; 2015) also added many rhacophorid species to the assemblage of amphibians of Sri Lanka, which includes a new species of *Polypedates* as well. Interestingly, Wickramasinghe et al. (2012b) uncovered *Adenomus kandianus* from the Peak Wilderness. In addition, Meegaskumbura et al. (2012a) provided detailed description of a Data Deficient *Pseudophilautus semiruber*. Apart from that, Wickramasinghe et al. (2013b, c) rediscovered two extinct *Pseudophilautus* species, *P. stellatus* (Kelaart, 1853), and *P. hypomelas* (Günther, 1876) from the Central Hills zoogeographic zone. Batuwita et al. (2019b) also described a new species of *Pseudophilautus* from Southern Sri Lanka (in the Lowland Wet Zone).

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Doubtful or obscure records

Taylor (1965; 1969) described five species of *Ichthyophis* Fitzinger (Caecilians: Ichthyophiidae Taylor) from Sri Lanka, including: *Ichthyophis forcati* Taylor, 1965, *I. glutinosus*, *I. orthoplicatus* Taylor, 1965, *I. pseudangularis* Taylor, 1965, and *I. taprobanicensis* Taylor, 1969. However, Nussbaum and Gans (1980) synonymized *Ichthyophis forcati* and *I. taprobanicensis* under *I. glutinosus* and *I. orthoplicatus*, respectively. Subsequently, Gower et al. (2005) showed Sri Lankan caecilians represent a monophyletic clade and also uncovered a cryptic species from Sabaragamuwa Province. Gower et al. (2005) further stated that this cryptic species either might represents Taylor's (1965) *Ichthyophis forcarti* or might belong to a hitherto undescribed species. Taylor (1965) also mentioned a record of another species from Sri Lanka, *Caudacaecilia asplenia* (Taylor, 1965). This species has recently been allocated to *Ichthyophis* by Nishikawa et al. (2012). In addition, Carl Gans (unpublished data) announced an occurrence of *Uraeotyphlus* Peters species from Sri Lanka. A comprehensive review of the caecilians of Sri Lanka may confirm the validity of the above records and undescribed species.

Kirtisinghe (1957) mentioned records of *Duttaphrynus stomaticus* (Lütken, 1862) (three specimens [not examined by us], now in BMNH: 1932.5.7.2–3 [2ex.], 1955.1.10.85) from Mutwal (06°57'N, 79°52'E) near Colombo. He considered that these specimens were transported to Sri Lanka by means of sailing vessels. Also, Dutta and Manamendra-Arachchi's (1996) records of *Hoplobatrachus tigerinus* (Daudin, 1802) from Sri Lanka were subsequently refuted by Dutta (1997) and considered that those Sri Lankan specimens are in fact misidentified specimens of *Hoplobatrachus crassus*.

Endemic and extinct amphibians

Sri Lankan amphibians are unique, as 90 percent of the species are endemics (Manamendra-Arachchi and Pethiyagoda, 2006; Fernando et al., 2007; Meegaskumbura et al., 2007; 2012a; Wickramasinghe et al., 2012a, b; 2013b, c; Meegaskumbura et al., 2015; Batuwita et al., 2019b). Up to now 120 species of amphibians have been recorded from Sri Lanka. Recent explorations have helped to reduce the number of extinct species from 21 (*Adenomus kandianus*, *Nannophrys guentheri* Boulenger, 1882 and 19 species of *Pseudophilautus*) to 18 (*N. guentheri* and 17 *Pseudophilautus* spp.). Three species that had been previously assigned to the extinct species list (*Adenomus kandianus* (misidentified as a new species by Manamendra-Arachchi and Pethiyagoda (1998)), *Pseudophilautus hypomelas* and *P. stellatus*) and the Data Deficient species (*Pseudophilautus semiruber*) were recently rediscovered (Wickramasinghe et al., 2012b; 2013b, c; Meegaskumbura et al., 2012a; 2015). The above recent rediscoveries of amphibians from Sri Lanka suggest the need for further surveys of other extinct species, especially the *Pseudophilautus* spp., because direct-developing amphibians are less prone to threats (Stuart et al., 2004; Xie et al., 2007). This speculation is further confirmed by the discovery of certain other hitherto unknown species from Knuckles Range and Rakwana Hills (Figs. 8–10) (see also WCSG, 2008; 2009; Janzen and Bopage, 2011).

Nothing is known of the biology of the only other extinct *Nannophrys guentheri*, but its biology might be same as the other three living congeners (Clarke, 1983; Dutta and Manamendra-Arachchi, 1996; Manamendra-Arachchi and Pethiyagoda, 2006). Hence, the conservation of other congeners is mandatory. Clarke (1983) described the heavily ossified cranium condition that was observed in adults of *Nannophrys ceylonensis* and *N. marmorata*, but the same condition was not found in *N. guentheri*. And he suggested that the holotype of *Nannophrys guentheri* might be a juvenile specimen. However, it is not certain that the

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description of *N. guentheri* was based on a juvenile specimen of *N. ceylonensis.* Current distributions of all but *Nannophrys naeyakai* are within the Central Hills, Knuckles Range, and Lowland Wet Zone of Sri Lanka that have an ample supply of water (perennial streams) and humid conditions. Thus, the survival of these species will persist as long as adequate forest cover and perennial water bodies remain. Even though *Nannophrys naeyakai* was described from the Dry Zone of Sri Lanka, its habitats are much more similar to the habitats within the Central Hills, Knuckles Range and Lowland Wet Zone of Sri Lanka (i.e., with humid, shaded forests, perennial streams and also situated in relatively high elevations, ~200–600 m (Fernando et al., 2007)).

In terms of higher number of extinct species (Table 3), the family Rhacophoridae represents the majority. Manamendra-Arachchi and Pethiyagoda (2005) suggested that these extinct species may be anthropogenic species that might have been collected from home gardens and their extinctions may be due to massive deforestation during the colonial period. However, in contrast to Manamendra-Arachchi and Pethiyagoda's (2005) suggestion, some anthropogenic species (habitat generalists) have been reported after the late 19th century, e.g., *Pseudophilautus sarasinorum* (Müller, 1887), *P. pleurotaenia* (Boulenger, 1904), and *P. fergusonianus* (Ahl, 1927) (Manamendra-Arachchi and Pethiyagoda, 2005). Moreover, Weerawardhena and Russell (2012) showed that about 48% of species were entirely from closed canopy (from forest), while all other species were habitat generalists. Thus, in an amphibian community, habitat generalists may be the majority and the most vulnerable members seem to be the habitat specialists (forest dwellers).

Figure 8: *Pseudophilautus* sp., from Riverstone, Knuckles Range. Photo by Sudesh Batuwita.

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Figure 9: *Pseudophilautus* sp., from Riverstone, Knuckles Range. Photo by Sudesh Batuwita.

Figure 10: *Pseudophilautus* cf. *sarasinorum*, from the Morningside Forest Reserve, Rakwana Hills. Photo by Sudesh Batuwita.

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Although most of the species of *Pseudophilautus* showed the ground nesting breeding behavior (bury their fertilized eggs in loose soil; Bahir et al., 2005, figs. 2–3), a single species, *P. femoralis* and probably its sister species, *P. mooreorum* and *P. poppiae* (Meegaskumbura and Manamendra-Arachchi, 2005) exhibit the leaf-nesting behavior (Bahir et al., 2005, fig. 4). These three species were known as endangered species (Manamendra-Arachchi and Pethiyagoda, 2005; Meegaskumbura and Manamendra-Arachchi, 2005). Even though the distribution of *Pseudophilautus femoralis* was restricted to undisturbed high elevational forests in the Central Hills (Manamendra-Arachchi and Pethiyagoda, 2005), it was found from Uda Malibada (06°53'01''N, 80°26'31''E) in the Peak Wilderness at an elevation of 700 m (Peabotuwage et al., 2012). Therefore, *Pseudophilautus femoralis* is no longer confined to the higher areas of Central Hills as mentioned by Manmendra-Arachchi and Pethiyagoda (2005). Hence, this leaf nesting behaviour may even occur in other places like Uda Malibada (not in montane forests). Moreover, *Pseudophilautus femoralis* has also been recorded from secondary forests (Bahir et al., 2005; pers. obs.).

Yet another point needs to be considered when investigating the extinct species, and that is the preponderance of Sri Lanka's amphibian fauna due to the recent discoveries of arboreal/semiarboreal rhacophorids. This species number is quite unusual by the standards of the other known Sri Lankan amphibian fauna (Fig. 2A). However, the direct development breeding behavior of *Pseudophilautus* might help the existence of a large number of species (Bogart, 1981; Meegaskumbura et al., 2019). Manamendra-Arachchi and Pethiyagoda (2005) allocated all rhacophorids (then as Rhacophorinae Hoffman) that showed direct development breeding mode to the genus *Philautus* (= *Pseudophilautus*) and also recognized 52 species. However, numbers of previously described species, which have long been disputed due to lack of recent material were a handful in their study, 10 out of 25 (Manamendra-Arachchi and Pethiyagoda, 2005; Table 1). Moreover, it was mentioned above (in the Results section) there are certain species, which have wide distribution ranges (Appendix 2): *Pseudophilautus alto*, *P. cavirostris*, *P. folicola*, *P. fulvus*, *P. popularis*, *P. reticulatus*, *P. schmarda*, *P. singu*, *P. sordidus*, and *P. stictomerus*. Out of 10 of these species, six species were recently described (Manamendra-Arachchi and Pethiyagoda, 2005; Meegaskumbura et al., 2009). Hence, it is remarkable why these rather common (see Appendix 2) species had not been collected during the colonial period. Therefore, based on these observations and data, it is concluded that some of the other extinct species either have to be rediscovered (Data Deficient) or most probably were misidentified as other species (Udugampala and Batuwita, in prep.).

Interestingly, it was observed (see also Batuwita et al., 2019b) that certain characters have intraspecific variations in *Pseudophilautus*, e.g., presence or absence of the median lingual process. In addition, we uncovered another character that was used to diagnose species, that is apparently due to the sexual dimorphism, e.g., horn-like spinules on dorsum, (Manamendra-Arachchi and Pethiyagoda, 2005) and the third one or the condition that might wrongly be interpreted or identified in the previous works is calcar vs. tarsal tubercle and/ or presence vs. absence of this character/s (Manamendra-Arachchi and Pethiyagoda, 2005; Meegaskumbura et al., 2007). On the basis of our data of the species with this character (calcar/ tarsal tubercle) this also appears to be due to sexual dimorphism i.e., either well-developed or weakly developed/ rudimentary (Udugampala and Batuwita, in prep.).

Threats, conservation and recommendations

Sri Lanka's cloud forests are restricted to above ~1000 m a.s.l. within the three major zoogeographic zones (i.e., Central Hills, Knuckles Range, and Rakwana Hills). In terms of area of remaining natural habitats, Beralagala, Gongala Hills, Hadapan Ella Plains,

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Kabaragala, and Suriyakanda, are the smallest forests in the Rakwana Hills, but they harbour most of the point endemic species (Manamendra-Arachchi and Pethiyagoda, 2006).

Massive deforestation during the colonial period has resulted in severe threats to the fauna in Sri Lanka (Pethiyagoda and Manamendra-Arachchi, 1998; Manamendra-Arachchi and Pethiyagoda, 2005). At present, the same threat occurs due to agricultural practices in and around remnant forest reserves (often near to forest borders/ buffer zones). Encroachments around buffer zones and further exploitation of forests are the major threats (Bahir and Surasinghe, 2005). This leads to reduction of forest cover, fragmentation and eventually loss of unique habitats (Bahir and Surasinghe, 2005). Consequently, it affects most habitat specialists due to the invasions of anthropogenic species (e.g., *Duttaphrynus melanostictus* [found in many rain forests buffer zones], *D. scaber* [observed in Hiyare Forest reserve and Oliyagankele Forest reserve], *Minervarya agricola*, *Pseudophilautus tanu* (Meegaskumbura, Manamendra-Arachchi, and Pethiyagoda, 2009), *P. schneideri* Meegaskumbura and Manamendra-Arachchi, 2011 [Dediyagala Forest Reserve], *P. popularis*, *P. rus* (Manamendra-Arachchi and Pethiyagoda, 2005) [Gannoruwa Forest reserve]). Loss of forest cover (e.g., deforestation, due to anthropogenic forest fires) causes streams to dry (perennial water bodies) within forests or adjoining them, which in turn limit the distribution and reproduction of amphibians (e.g., fragmented forest patches in the Lowland Wet Zone and Central Hills: Atamassakanda, Gannoruwa, Kunduppakanda, Rumasswala; Batuwita, 2000; Batuwita and Bahir, 2005; WCSG, 2008; 2009).

Apart from the Dry Zone, rapid increase of human population in the other zones of Sri Lanka (Anon., 2003) cause the loss of habitats of fauna and flora. Myers et al. (2000) estimated that the Western Ghats range of mountains together with Sri Lanka has lost more than 70% of its original habitat due to the rapid growth of human population. Even though the Dry Zone zoogeographic zone is larger than others, only two restricted species are found in this zone, *sc.*, *Nannophrys naeyakai* and *Pseudophilautus regius*. Most of the endangered and threatened amphibian species are restricted to the forests (some even fragmented) within the highly populous districts like Galle, Kalutara, Kandy, Matara, and Nuwaraeliya. Due to increase in infrastructure in these highly populous areas, more destruction occurs, e.g., clearing of wetland vegetation and forest borders/ buffer zones (Karunarathna et al., 2016). Thus, the forest reserves/ wetlands are fragmenting. This may lead to diminishing of the gene pool of particular species due to inbreeding depression (Perl et al., 2018). Therefore, without having a potential gene pool, certain species with restricted distributions may become extinct in the future. Recent studies (e.g., Bierregaard et al., 2001; Brook et al., 2003; Ferraz et al., 2003) have shown that extreme rain forest fragmentation could lead to catastrophic declines and extinctions of species in decadal time frames.

Irrational infrastructure developments, passively cause loss of amphibians due to road-kills in Sri Lanka: this accounts for not only loss of amphibians but also the other fauna as well (Maduwage et al., 2003; Karunarathna et al., 2017). In Sri Lanka, anthropogenic noise is a little known threat to the amphibians, which are living beside roads. Anthropogenic noise alters the behaviour of amphibian populations (Sun and Narins, 2005; Kaiser and Hammers, 2009; Kaiser et al., 2011; Caorsi et al., 2017). A case study showed that male frogs, which have been exposed to anthropogenic noise, exhibited both a decrease in days performing chorus and chorus duration at night (Kaiser et al., 2011). According to Kaiser et al. (2011), this may substantially affect the reproductive success because females generally join choruses late at night to breed.

Distribution of *Duttaphrynus melanosticus* in all zoogeographic zones is remarkable (from coast to ~1700 m a.s.l.) (Manamendra-Arachchi and Pethiyagoda, 2006). Interspecific competition of anurans and their larvae has been reported (De Benedictis, 1974; Seale, 1980;

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Sredl and Collins, 1992). Due to deforestation, anthropogenic species like *Duttaphrynus melanostictus* undoubtedly compete with threatened or uncommon species for food, space and for breeding sites: e.g., with *Duttaphrynus* cf. *scaber* and *Polypedates cruciger* (Blyth, 1852) in the Lowland Wet Zone; with *Microhyla zeylanica* Parker and Osman Hill, 1948, *Uperodon obscurus* (Günther, 1864), *U. palmatus* and *Minervarya greenii* in the Central Hills; and with *Microhyla karunaratnei* and *Uperodon obscurus* in the Rakwana Hills.

A recent study showed that invasive alien species like the guppy fish (*Poecilia* spp.) feed on amphibian eggs (Bambaradeniya, 1999). Studies on the impact of invasive alien fish species on amphibians are limited in Sri Lanka (Bambaradeniya, 1999). Hence, studies should be extended, especially on the invasive exotic fish species of the genus *Oreochromis*, which breed in brackish water and also due to their island-wide distribution (Pethiyagoda, 1991).

In Sri Lanka, water bodies are polluted with high loads of water-soluble chemicals (Amarasekara et al., 2013). According to Amarasekara et al. (2013), a massive volume of polluted water is discharged into natural water bodies in the hills during the monsoon. Due to this polluted water, middle and lower streams contaminate and may cause severe problems for aquatic fauna and flora. Stream or river associated (breed in water and/or live in semiaquatic habitats) malformed amphibians have been reported from Sri Lanka as well (WCSG, 2008; De Silva, 2011). These malformed stream-associated amphibians might breed in polluted waters (Gower et al., 2005; Taylor et al., 2005; Gurushankara et al., 2007). Parasitic attacks on amphibians were also reported (Rajapaksa and De Silva, 2001). This may be due to pollution in the particular areas as described by Johnson et al. (2007).

Fortunately, no records of chytridiomycosis have been reported in Sri Lanka (Surasinghe, 2009). However, as an infectious disease in the high-elevation inhabiting and stream-breeding species (Pounds and Puschendorf, 2004), *Batrachochytrium dendrobatidis* will drastically affect the following threatened species: *Adenomus kandianus*, *Taruga eques* (Günther, 1858), *Uperodon palmatus*, and *Microhyla zeylanica* in the Central Hills. As an example, Min et al. (2011) mentioned that chytridiomycosis in South Korea is due to the introduction (for consumption) of American bullfrog, *Lithobates catesbeianus* (Shaw, 1802). *Lithobates catesbeianus* is one of the 'Black list' invasive alien species of Sri Lanka as well (Silva and Kurukulasuriya, 2010). *Lithobates catesbeianus* has shown the highest prevalence, about 18%, for *Batrachochytrium dendrobatidis* (Min et al., 2012). Fortunately, as a cultural taboo, amphibians are not consumed as a food item in Sri Lanka. The wildlife trade is a severe threat to amphibians, because some invasive exotic species have been introduced to Sri Lanka through wildlife trade as pets (Silva and Kurukulasuriya, 2010). As a recent example, the urodelan pathogen, *Batrachochytrium salamandrivorans* has been introduced to Europe through wild anuran trade (Nguyen et al., 2017).

The most recent and growing threat to the fauna and flora in the world is climate change. In Sri Lanka, changes in weather patterns have become more pronounced in the past few decades, i.e., shifting or decrease of monsoon rainfall, floods, landslides, and prolonged droughts (Basnayake, 2007; De Costa, 2008). Climate change may drastically affects the amphibian fauna of Sri Lanka (Bahir et al., 2005; Kottawa-Arachchi and Wijeratne, 2017). As an example, it was observed that *Taruga longinasus* (Ahl, 1931) breeds in lentic habitats that are adjacent to lotic habitats in the Kanneliya Forest reserve. These shallow lentic habitats were situated parallel to the stream and with a litter layer at the bottom. Hundreds of tadpoles were observed in these pools. It was also observed about 15 males and two females of *Taruga longinasus* in the particular area and it is believed that the presence of regular precipitation might be needed for the formation of such lentic habitats. Especially, that species with aquatic breeding phase (except *Pseudophilautus* spp.) may drastically get affected by abrupt changes

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in rainfall, e.g., prolonged droughts, devastating torrential rains (Taigen et al., 1984; Seymour, 1999; Ryan et al., 2015).

Werner (1988) reported forest dieback in the Nuwaraeliya District in the late 20th century and speculated that cloud forest dieback in the Horton Plains and in Hakgala might be due to climate change. The same situation was recently observed in the Rakwana Hills, in the Morningside Forest reserve.

When considering the point endemics or restricted species, it is mandatory to initiate population viability tests in order to ascertain their survival and also document their new distribution record data. Interestingly, certain species, which had long been considered as point endemics or restricted species to a few localities were subsequently reported from new localities, *viz.*, *Pseudophilautus alto*, *P. asankai* (Manamendra-Arachchi and Pethiyagoda, 2005), *P. auratus* (Manamendra-Arachchi and Pethiyagoda, 2005), *P. cavirostris*, *P. femoralis*, *P. nemus* (Manamendra-Arachchi and Pethiyagoda, 2005), *Taruga eques*, and *Uperodon nagaoi* (Manamendra-Arachchi and Pethiyagoda, 2001) (Kandamby, 2001; Kandamby and Batuwita, 2001; WCSG, 2008; 2009; Bopage et al., 2011; Janzen and Bopage, 2011; Peabotuwage et al., 2012). In 2004, the Wildlife Conservation Society-Galle of Sri Lanka (WCSG) initiated a conservation program for the threatened *Uperodon nagaoi* in the fragmented Hiyare Forest reserve (De Silva, 2006), by providing artificial breeding grounds (water filled tree holes), because in the wild, *Uperodon nagaoi* breeds in phytotelmic habitats (Manamendra-Arachchi and Pethiyagoda, 2001a; De Silva, 2006). Within a few weeks the project goal was achieved: the attached cement-made water holes were accepted by *Uperodon nagaoi* individuals and they bred in artificial habitats (Fig. 11).

Figure 11: *Uperodon nagaoi*, developing embryos in an artificial breeding apparatus. Photo by WCSG.

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This project can be used as a base study for the future conservation programs for the other related threatened species, *viz.*, *Uperodon palmatus* with similar behavior. Recently, ecology and demography of *Adenomus kandianus* were assessed in the Peak Wilderness (Karunarathna et al., 2016). Karunarathna et al. (2016) mentioned the need for further studies to assess their breeding biology and population viability. Also, Janzen and Bopage (2011) stated that there is a lack of studies on the distribution and ecology of amphibians in Sri Lanka. Most recently, De Silva and Wijayathilaka (2019) discussed bioacoustics and its applications for conservation of amphibians. Therefore, it is mandatory to assess Sri Lankan amphibians' distribution, population viability (especially for threatened species with restricted distributions), and breeding biology behaviors in order to conserve them in the future.

Conclusions

Sri Lankan amphibian fauna comprises 120 species, of which 108 are endemics. On the basis of their distribution, five zoogeographic zones were introduced, *viz.*, Central Hills, Dry Zone, Knuckles Range, Lowland Wet Zone, and Rakwana Hills. The species composition of each zone is recorded. The highest number of species was reported from the Central Hills (53 species). The Rakwana Hills represented the highest threatened species (83%), whereas the Dry Zone had both lowest numbers of endemic and threatened species. Species diversity along the elevational gradient was also reported with the highest species assemblages around 0 to 1300 m elevation. Some reasons for the presence of many extinct species appears to be due to misidentifications or lack of studies. Sri Lankan amphibians face the following multiple threats due to the island effect: forest fragmentation, increasing human population, exotic species, pollution, and climate change.

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Appendix 1: Species checklist of Sri Lankan amphibians (102 species), excluding the extinct species (Native species*; Exotic #; and + indicates present/ included).

Family	Species	Lowland Wet Zone	Central Hills	Knuckles Range	Dry Zone	Rakwana Hills	Endemic species	Threatened species
Bufonidae	*Adenomus kandianus* (Günther, 1872)		+				+	+
	Adenomus kelaartii (Günther, 1858)	+	+	+		+	+	+
	Duttaphrynus kotagamai (Fernando and Dayawansa, 1994)	+	+				+	+
	Duttaphrynus melanostictus (Schneider, 1799)*	+	+	+	+	+		
	Duttaphrynus noellerti (Manamendra-Arachchi and Pethiyagoda, 1998)	+					+	+
	Duttaphrynus scaber (Schneider, 1799)*	+			+			+
	Duttaphrynus stomaticus (Lütken, 1862)#	+						
Ichthyophiidae	*Ichthyophis glutinosus* (Linnaeus, 1758)	+	+	+			+	+
	Ichthyophis orthoplicatus Taylor, 1965		+				+	+
	Ichthyophis pseudangularis Taylor, 1965	+	+			+	+	+
Microhylidae	*Microhyla karunaratnei* Fernando and Siriwardhane, 1996					+	+	+
	Microhyla ornata (Dumeril and Bibron, 1841)*	+		+	+			
	Microhyla mihintalei Wijayathilaka, Garg, Senevirathne, Karunarathna, Biju, and Meegaskumbura, 2016	+			+		+	
	Microhyla zeylanica Parker and Osman Hill, 1948		+				+	+
	Uperodon nagaoi (Manamendra-Arachchi and Pethiyagoda, 2001)	+					+	+
	Uperodon obscurus (Günther, 1864)		+	+		+	+	+
	Uperodon palmatus (Parker, 1934)		+				+	+
	Uperodon rohani Garg, Senevirathne, Wijayathilaka, Phuge, Deuti, Manamendra-Arachchi, Meegaskumbura, and Biju, 2018	+			+		+	
	Uperodon systomus (Schneider, 1799)*				+			
	Uperodon taprobanicus (Parker, 1934)*	+			+			
Dicroglossidae	*Euphlyctis mudigere* Joshy, Alam, Kurabayashi, Sumida, and Kuramoto, 2009*	+	+	+	+	+		
	Euphlyctis hexadactylus (Lesson, 1834)*	+	+		+			
	Minervarya greenii (Boulenger, 1904)		+				+	+
	Minervarya kirtisinghei (Manamendra-Arachchi and Gabadage, 1996)	+	+	+		+	+	+
	Minervarya agricola (Jerdon, 1953)*	+	+	+	+	+		
	Hoplobatrachus crassus (Jerdon, 1853)*	+			+			
	Lankanectes corrugatus (Peters, 1863)	+	+	+		+	+	+
	Lankanectes pera Senevirathne, Samarawickrama, Wijayathilaka, Manamendra-Arachchi, Bowatte, Samarawickrama, and Meegaskumbura, 2018			+			+	
	Nannophrys ceylonensis Günther, 1868	+	+				+	+
	Nannophrys marmorata Kirtisinghe, 1946			+			+	+
	Nannophrys naeyakai Fernando, Wickramasinghe, and Rodirigo, 2007				+		+	+
	Hydrophylax gracilis (Gravenhorst, 1829)	+		+	+		+	
	Indosylvirana serendipi (Biju, Garg, Mahony, Wijayathilaka, Senevirathne, and Meegaskumbura, 2014)	+					+	
	Indosylvirana temporalis (Günther, 1864)	+	+	+		+	+	
	Sphaerotheca breviceps (Schneider, 1799)*			+	+			
	Sphaerotheca rolandae (Dubois, 1983)*	+			+			

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Appendix 1. (Continued)

Family	Species	Lowland Wet Zone	Central Hills	Knuckles Range	Dry Zone	Rakwana Hills	Endemic species	Threatened species
Rhacophoridae	*Pseudophilautus abundus* (Manamendra-Arachchi and Pethiyagoda, 2005)	+					+	+
	Pseudophilautus alto (Manamendra-Arachchi and Pethiyagoda, 2005)		+				+	+
	Pseudophilautus asankai (Manamendra-Arachchi and Pethiyagoda, 2005)		+				+	+
	Pseudophilautus auratus (Manamendra-Arachchi and Pethiyagoda, 2005)	+				+	+	+
	Pseudophilautus bambaradeniyai Wickramasinghe, Vidanapathirana, Rajeev, Ariyarathne, Chanaka, Priyantha, Bandara, and Wickramasinghe, 2013		+				+	+
	Pseudophilautus caeruleus (Manamendra-Arachchi and Pethiyagoda, 2005)		+				+	+
	Pseudophilautus cavirostris (Günther, 1869)	+	+	+		+	+	+
	Pseudophilautus conniffae Batuwita, De Silva, and Udugampala, 2019	+					+	
	Pseudophilautus cuspis (Manamendra-Arachchi and Pethiyagoda, 2005)	+					+	+
	Pseudophilautus dayawansai Wickramasinghe, Vidanapathirana, Rajeev, Ariyarathne, Chanaka, Priyantha, Bandara, and Wickramasinghe, 2013		+				+	+
	Pseudophilautus decoris (Manamendra-Arachchi and Pethiyagoda, 2005)					+	+	+
	Pseudophilautus dilmah Wickramasinghe, Bandara, Vidanapathirana, Tennakoon, Samarakoon, and Wickramasinghe, 2015		+				+	+
	Pseudophilautus femoralis (Günther, 1864)		+				+	+
	Pseudophilautus fergusonianus (Ahl, 1927)	+	+		+	+	+	+
	Pseudophilautus folicola (Manamendra-Arachchi and Pethiyagoda, 2005)	+				+	+	+
	Pseudophilautus frankenbergi (Meegaskumbura and Manamendra-Arachchi, 2005)		+				+	+
	Pseudophilautus fulvus (Manamendra-Arachchi and Pethiyagoda, 2005)			+			+	+
	Pseudophilautus hallidayi (Meegaskumbura and Manamendra-Arachchi, 2005)		+				+	+
	Pseudophilautus hankeni (Meegaskumbura and Manamendra-Arachchi, 2005)			+			+	+
	Pseudophilautus hoffmanni (Meegaskumbura and Manamendra-Arachchi, 2005)			+			+	+
	Pseudophilautus hypomelas (Günther, 1876)		+				+	
	Pseudophilautus hoipolloi (Manamendra-Arachchi and Pethiyagoda, 2005)	+					+	+
	Pseudophilautus jagathgunawardanai Wickramasinghe, Vidanapathirana, Rajeev, Ariyarathne, Chanaka, Priyantha, Bandara, and Wickramasinghe, 2013		+				+	+
	Pseudophilautus karunarathnai Wickramasinghe, Vidanapathirana, Rajeev, Ariyarathne, Chanaka, Priyantha, Bandara, and Wickramasinghe, 2013		+				+	+
	Pseudophilautus limbus (Manamendra-Arachchi and Pethiyagoda, 2005)	+					+	+
	Pseudophilautus lunatus (Manamendra-Arachchi and Pethiyagoda, 2005)					+	+	+
	Pseudophilautus macropus (Günther, 1869)			+			+	+
	Pseudophilautus microtympanum (Günther, 1859)		+				+	+
	Pseudophilautus mittermeieri (Meegaskumbura and Manamendra-Arachchi, 2005)	+					+	+
	Pseudophilautus mooreorum (Meegaskumbura and Manamendra-Arachchi, 2005)			+			+	+
	Pseudophilautus nemus (Manamendra-Arachchi and Pethiyagoda, 2005)	+					+	+

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Appendix 1. (Continued)

Family	Species	Lowland Wet Zone	Central Hills	Knuckles Range	Dry Zone	Rakwana Hills	Endemic species	Threatened species
Rhacophoridae	*Pseudophilautus newtonjayawardanei* Wickramasinghe, Vidanapathirana, Rajeev, Ariyarathne, Chanaka, Priyantha, Bandara, and Wickramasinghe, 2013		+				+	
	Pseudophilautus ocularis (Manamendra-Arachchi and Pethiyagoda, 2005)					+	+	+
	Pseudophilautus papillosus (Manamendra-Arachchi and Pethiyagoda, 2005)					+	+	+
	Pseudophilautus pleurotaenia (Boulenger, 1904)		+				+	+
	Pseudophilautus poppiae (Meegaskumbura and Manamendra-Arachchi, 2005)					+	+	+
	Pseudophilautus popularis (Manamendra-Arachchi and Pethiyagoda, 2005)	+	+				+	
	Pseudophilautus procax (Manamendra-Arachchi and Pethiyagoda, 2005)					+	+	+
	Pseudophilautus puranappu Wickramasinghe, Vidanapathirana, Rajeev, Ariyarathne, Chanaka, Priyantha, Bandara, and Wickramasinghe, 2013		+				+	+
	Pseudophilautus regius (Manamendra-Arachchi and Pethiyagoda, 2005)				+		+	+
	Pseudophilautus reticulatus (Günther, 1864)	+	+			+	+	+
	Pseudophilautus rus (Manamendra-Arachchi and Pethiyagoda, 2005)		+			+	+	+
	Pseudophilautus samarakoon Wickramasinghe, Vidanapathirana, Rajeev, Ariyarathne, Chanaka, Priyantha, Bandara, and Wickramasinghe, 2013		+				+	+
	Pseudophilautus sarasinorum (Müller, 1887)		+	+			+	+
	Pseudophilautus schmarda (Kelaart, 1854)		+				+	+
	Pseudophilautus schneideri Meegaskumbura and Manamendra-Arachchi, 2011	+					+	
	Pseudophilautus semiruber (Annandale, 1913)		+				+	
	Pseudophilautus silus (Manamendra-Arachchi and Pethiyagoda, 2005)		+				+	+
	Pseudophilautus silvaticus (Manamendra-Arachchi and Pethiyagoda, 2005)	+				+	+	+
	Pseudophilautus simba (Manamendra-Arachchi and Pethiyagoda, 2005)					+	+	+
	Pseudophilautus singu (Meegaskumbura, Manamendra-Arachchi and Pethiyagoda, 2009)	+				+	+	+
	Pseudophilautus sirilwijesundarai Wickramasinghe, Vidanapathirana, Rajeev, Ariyarathne, Chanaka, Priyantha, Bandara, and Wickramasinghe, 2013		+				+	+
	Pseudophilautus sordidus (Manamendra-Arachchi and Pethiyagoda, 2005)	+	+			+	+	+
	Pseudophilautus steineri (Meegaskumbura and Manamendra-Arachchi, 2005)			+			+	+
	Pseudophilautus stellatus (Kelaart, 1853)		+				+	+
	Pseudophilautus stictomerus (Günther, 1876)	+				+	+	+
	Pseudophilautus stuarti (Meegaskumbura and Manamendra-Arachchi, 2005)			+			+	+
	Pseudophilautus tanu (Meegaskumbura, Manamendra-Arachchi and Pethiyagoda, 2009)	+					+	+
	Pseudophilautus viridis (Manamendra-Arachchi and Pethiyagoda, 2005)		+				+	+
	Pseudophilautus zorro (Manamendra-Arachchi and Pethiyagoda, 2005)		+				+	+
	Polypedates cruciger (Blyth, 1852)	+	+	+	+	+	+	
	Polypedates maculatus (Gray, 1834)*	+	+	+	+			
	Polypedates ranwellai Wickramasinghe, Munindradasa and Fernando, 2012	+					+	+
	Taruga eques (Günther, 1858)		+				+	+
	Taruga fastigo (Manamendra-Arachchi and Pethiyagoda, 2001)					+	+	+
	Taruga longinasus (Ahl, 1931)	+	+				+	+
	Total	47	53	25	19	29	89	77

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Appendix 2: Rhacophoridae species distribution according to the elevational gradient (+ indicates present).

Species	Low elevations			Mid-elevations			High elevations	
	0–200 m	200–500 m	500-800 m	800–1100 m	1100–1400 m	1400–1700 m	1700–2000 m	2000–2300 m
Pseudophilautus abundus	+							
Pseudophilautus alto			+	+	+	+	+	+
Pseudophilautus asankai			+	+	+			
Pseudophilautus auratus		+						
Pseudophilautus bambaradeniyai							+	
Pseudophilautus caeruleus				+	+			
Pseudophilautus cavirostris	+	+	+	+				
Pseudophilautus conniffae	+							
Pseudophilautus cuspis		+						
Pseudophilautus dayawansai							+	
Pseudophilautus decoris				+				
Pseudophilautus dilmah						+		
Pseudophilautus femoralis			+			+	+	
Pseudophilautus fergusonianus		+	+					
Pseudophilautus folicola	+	+	+	+				
Pseudophilautus frankenbergi							+	+
Pseudophilautus fulvus		+	+	+	+			
Pseudophilautus hallidayi			+	+	+			
Pseudophilautus hankeni					+	+		
Pseudophilautus hoffmanni				+				
Pseudophilautus hypomelas			+	+	+			
Pseudophilautus hoipolloi	+	+	+					
Pseudophilautus jagathgunawardanai							+	
Pseudophilautus karunarathnai							+	
Pseudophilautus limbus		+						
Pseudophilautus lunatus					+			
Pseudophilautus macropus			+					
Pseudophilautus microtympanum						+	+	+
Pseudophilautus mittermeieri	+							
Pseudophilautus mooreorum						+		
Pseudophilautus nemus		+	+					
Pseudophilautus newtonjayawardanei							+	
Pseudophilautus ocularis					+			
Pseudophilautus papillosus					+			
Pseudophilautus pleurotaenia			+					
Pseudophilautus poppiae					+			
Pseudophilautus popularis	+	+	+	+				
Pseudophilautus procax			+					
Pseudophilautus puranappu							+	
Pseudophilautus regius	+							
Pseudophilautus reticulatus	+	+	+	+				
Pseudophilautus rus			+					
Pseudophilautus samarakoon							+	

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Appendix 2. (Continued)

Species	Low elevations			Mid-elevations			High elevations	
	0–200 m	200–500 m	500-800 m	800–1100 m	1100–1400 m	1400–1700 m	1700–2000 m	2000–2300 m
Pseudophilautus sarasinorum			+		+			
Pseudophilautus schmarda				+	+	+	+	+
Pseudophilautus schneideri	+							
Pseudophilautus semiruber							+	
Pseudophilautus silus						+		
Pseudophilautus silvaticus			+	+	+			
Pseudophilautus simba					+			
Pseudophilautus singu	+	+	+	+				
Pseudophilautus sirilwijesundarai							+	
Pseudophilautus sordidus	+	+	+	+				
Pseudophilautus steineri					+			
Pseudophilautus stellatus						+		
Pseudophilautus stictomerus	+	+	+	+				
Pseudophilautus stuarti					+			
Pseudophilautus tanu	+							
Pseudophilautus viridis						+	+	
Pseudophilautus zorro			+					
Polypedates cruciger	+		+			+		
Polypedates maculatus	+	+						
Polypedates ranwellai	+							
Taruga eques			+				+	+
Taruga fastigo						+		
Taruga longinasus	+	+	+					

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