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ON THE DISCOVERY OF SECOND LIVING POPULATION OF *ADENOMUS KANDIANUS* (GÜNTHER, 1872) FROM SRI LANKA: WITH THE BIOECOLOGY, AND DETAILED REDESCRIPTION TO THE SPECIES

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Abstract: *Adenomus* is an endemic genus of toads to Sri Lanka known from three species. *Adenomus kandianus* had been considered extinct until its recent rediscovery from the Peak Wilderness in 2012, after a lap of 136 years. Here we report the second existing population of *Adenomus kandianus* from lower part of the Pidurutalagala Forest Reserve, in central Sri Lanka. Detailed descriptions of male and female *Adenomus kandianus* along with the holotype are provided. Habitats around this forest area up to 1300 m elevation have been replaced rapidly by human encroachments primarily for tea plantations, cultivated lands and human settlements. Lower part of the Pidurutalagala Forest Reserve, which supports high faunal diversity, has long been under studied and requires further exploration.

Key words: Amphibia, Bufonidae, Conservation, Distribution, Extinction, Population, Taxonomy, Threats.

Resumen: D.E. Gabadage, A. De Silva, W.M.S. Botejue, M.M. Bahir, T.D. Surasinghe, M.B. Madawala, A.A.T. Amarasinghe y D.M.S.S. Karunarathna. "Sobre el descubrimiento de una segunda población viviente de *Adenomus kandianus* (Günther, 1872) de Sri Lanka: con la bioecología y redescripción detallada de la especie". *Adenomus* es un género de sapos endémico de Sri Lanka conocido por tres especies. *Adenomus kandianus* había sido considerado extinto hasta su reciente redescubrimiento en el pico Wilderness en 2012, después de un lapso de 136 años. Aquí se presenta la segunda población existente de *Adenomus kandianus* de la parte inferior de la Reserva Forestal Pidurutalagala, en el centro de Sri Lanka. Se proporcionan descripciones detalladas de *Adenomus kandianus* machos y hembras junto con el holotipo. Los hábitats en torno a esta zona forestal hasta 1300 m de altitud han sido reemplazados rápidamente por las invasiones humanas principalmente para plantaciones de té, tierras cultivadas y asentamientos humanos. La parte baja de la Reserva Forestal Pidurutalagala, que sostiene una gran diversidad de fauna, ha estado bajo estudio durante mucho tiempo y requiere más exploración.

Palabras Clave: Amphibia, Bufonidae, Conservación, Distribución, Extinctión, Población, Taxonomía, Amenazas.

INTRODUCTION

Amphibians are among the most threatened vertebrate taxa in the world; nearly one-third of the known species are threatened with extinction, while half of the global amphibian fauna are undergoing dramatic population declines worldwide (IUCN 2012, McCallum 2007, Stuart *et al*. 2004, Sodhi *et al*. 2008). Sri Lanka is recognized as one of the global amphibian hotspots (Bossuyt *et al*. 2004). Among 119 described species (101 living, aprox. 85%) of Sri Lankan amphibians, 103 (~86%) species are endemic to the island, most of which are restricted to the wet zone (>2,000 mm of annual average precipitation) (Wickramasinghe *et al*. 2013a, 2013b,

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2013c). Molecular phylogenetic analyses have suggested four endemic genera from Sri Lanka, namely: *Adenomus*, *Nannophrys*, *Lankanectes* and *Taruga* (Bossuyt *et al*. 2004, Meegaskumbura *et al*. 2010).

Among the endemic amphibian genera of Sri Lanka, the genus *Adenomus* is remarkable because of its rarity and represents the Adenominae clade: the genus represents three species listed in the IUCN redlist under different categories (MOE 2012). *Adenomus kelaarti* is found in the Southeastern lowland rainforests, lower elevations around central highlands and is categorized endangered. The two critically endangered species, *A. kandianus* (Günther 1872) and *A. dasi* Manamendra-Arachchi and Pethiyagoda 1998, have been previously recorded only from the Peak Wilderness Sanctuary in Central Province (Manamendra-Arachchi and Pethiyagoda 1998, Karunarathna *et al*. 2012, Wickramasinghe *et al*. 2012). *Adenomus kandianus* was considered as extinct (Stuart *et al*. 2008) until it's rediscovery from Peak Wilderness (>1800 m elevation) in 2012 after 136 years (Wickramasinghe *et al*. 2012). So far, the species is known only from one extant population and three preserved specimens: the holotype, a paralectotype of *A. kelaarti*, and one specimen collected by Wickramasinghe *et al*. (2012).

Here we report the second existing wild population of the rare stream dwelling toad *A. kandianus* from mid elevations of Pidurutalagala Forest Reserve (1400–1600 m elevations) in Nuwara Eliya District of the Central Highlands, which is ~42 km Euclidean distance from the previous population recorded in Peak Wilderness. In addition, we record the second known extant population of *A. dasi*, which is sympatric with *A. kandianus* at the lower part of the Pidurutalagala Forest Reserve (PFR). Furthermore, we provide a detailed description of both sexes of *A. kandianus* from the material observed in this new locality.

MATERIALS AND METHODS

***Study area and habitat*:** The lower part of the Pidurutalagala Forest Reserve (Mount Pedro) (7°00'56.10", 7°01'27.87"N; 80°47'13.97", 80°47'35.70"E) situated in the north-eastern slope of the mountain between 1400–1600 m elevation is managed by the Nuwara Eliya District Forest Department (FD). The peak is currently designated as an "Ultra-high security zone", and is protected by a military base; being strictly off limits to the general public (Werner 1986). This forest belongs to five sub divisional secretariats: Udawela, Malsara-Nuwara, Hunukotuwa, Mandaram-Nuwara, and Madawela. The vegetation is comprised of sub-montane and montane evergreen forest communities with the following dominant hardwood genera: *Doona*, *Stemonoporus*, *Calophyllum*, *Syzygium*, *Shorea*, *Dipterocarpus*, *Cullenia*, and *Mesua* (Gunatilleke and Gunatilleke 1990). The annual mean precipitation is >3000 mm (range 1800–3500mm) and annual mean temperature <18°C (range: <10°C minimum and 24°C maximum) during the day time. Our study area was situated ~5 km (North) from the Nuwara Eliya town, ~35 km from Kandy and ~42 km direct distance from the Peak Wilderness Sanctuary, respectively. The Pidurutalagala Forest Reserve (PFR) is one of the largest and most important forest areas (Fig. 1) comprised largely of endemic biodiversity, and designated as a World Heritage Site (UNESCO 2011).

***Data collection and analysis*:** The observations and field work were done during four weeks; 6–12 April 2011, 21–27 August 2012, 16–22 October 2013 and recently on 8-15 May 2014 to document the basic ecological data. Specimens of *Adenomus kandianus* and *A. dasi* from Pidurutalagala were compared with the type material and relevant publications as follows: Günther (1872), Dutta and Manamendra-Arachchi (1996), Karunarathna *et al*. (2012), Manamendra-Arachchi and Pethiyagoda (1998 and 2006), Wickramasinghe *et al*. (2012), and also with available specimens in the National Museum of Sri Lanka (NMSL), Colombo (*A. dasi* and *A. kelaarti*). Sex of the specimens was determined by the presence of a gular vocal sac and nuptial pads. We followed Manamendra-Arachchi and Pethiyagoda (1998 and 2005) in taking measurements. The following characters were measured with a Mitutoyo® digital vernier caliper to the nearest 0.1 mm for symmetrical characters (Table 1): DBE, Distance between back of eyes; DFE, Distance between fronts of eyes; ED, Eye diameter— horizontal diameter of eye; EN, Eye-to-Nostril distance— measured between anterior-most point of eye and middle of nostril; UEW, Upper eyelid width—measured from bony edge of supraorbital to outer edge of upper eyelid; ES, Eye to snout (snout length)— distance between anterior-most point of eye and tip of snout; MBE, Mandible–back of eye distance— distance between angle of jaws and posterior-most point of eye; MFE, Mandible–front of eye distance— taken as distance between angle of jaws and anterior-most point of eye; MN, Mandible–nostril distance— taken as distance between angle of jaws and middle of nostril; NS, Nostril–snout distance— taken as distance between middle of nostril and tip of snout; TND, Tympanum–nostril distance— distance between anterior-most point of inner margin of inner rim of tympanum and middle of nostril; TPD, Tympanum–front of eye distance— taken as distance between anterior-most point of inner margin of inner rim of tympanum and anterior-most point of eye; TAD, Tympanum–back of eye distance— distance between anterior-most point of inner margin of inner rim of tympanum and posterior-most point of eye; TYE, Tympanum diameter— greatest diameter of inner rim; FL, Finger lengths— distance between posterior margin of most proximal subarticular tubercle or crease of articulation and tip of finger; HL, Head length— distance between angle of jaws and snout tip; HW, Head width— measured across angle of jaws; IML, Inner metatarsal tubercle length; IN, Internarial distance— least distance between the inner margins of nares; IO, Interorbital width— least distance between the upper margins of orbits; LAL, Lower arm length— taken from elbow to posterior-most margin of inner palmar tubercle; UAL, Upper arm length— distance between axilla and elbow; PAL, Palm length, taken from posterior-most margin of inner palmar tubercle to tip of disk of third finger; FEL, Femur (thigh) length— the distance between vent and knee with both thigh and shank flexed; TBL, Tibia (shank) length— the distance between knee and heel with both shank and foot flexed; FOL, Foot length— distance between heel and tip of fourth toe with both foot and shank flexed; TL, Toe lengths— distance between

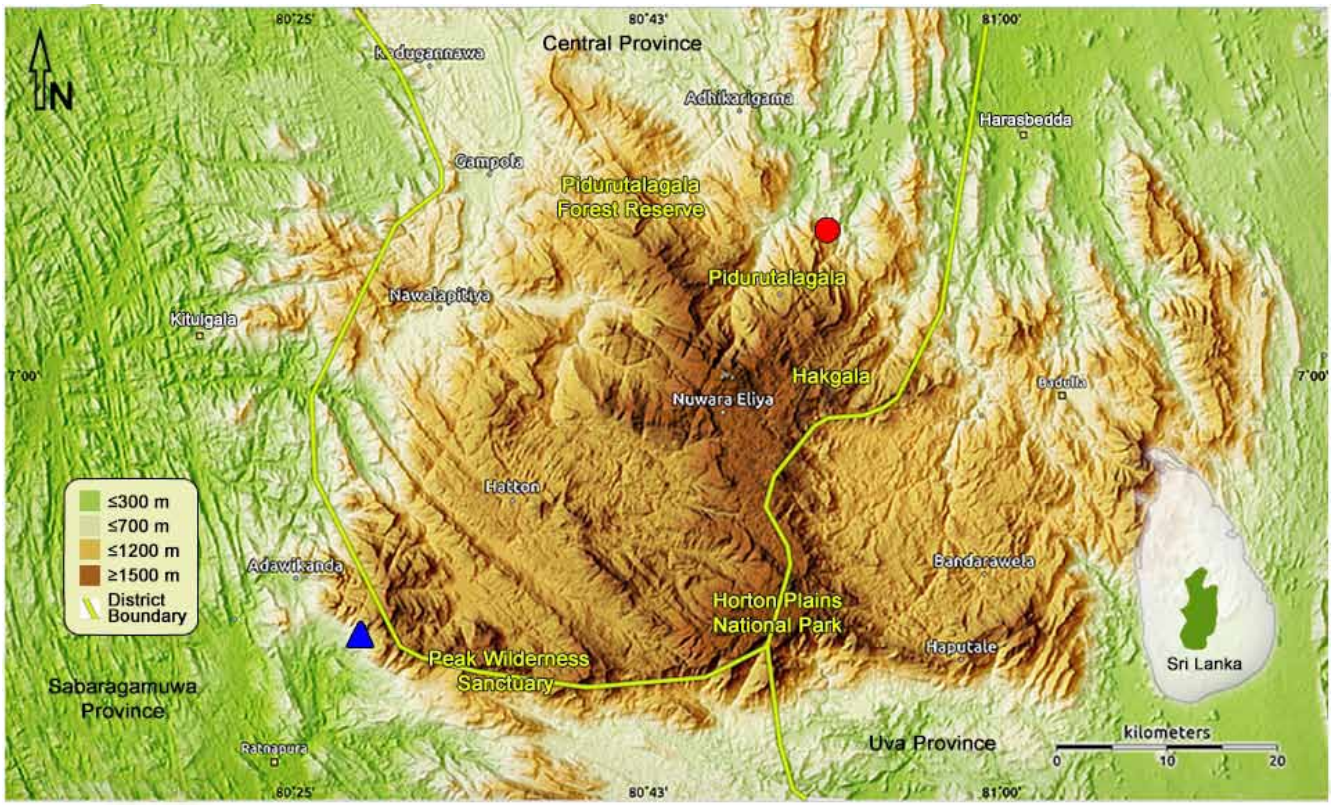

FIG.1. Map showing known distribution of *Adenomus kandianus* in Peak Wilderness (blue-color triangle) and lower Pidurutalagala (red-color circle) in two corners of the Central Highland (Elevation given by meters above sea level).

Mapa que muestra la distribución conocida de Adenomus kandianus *en Peak Wilderness (triángulo de color azul) y bajo Pidurutalagala (círculo rojo) en dos esquinas de la Meseta Central (elevación dada en metros sobre el nivel del mar).*

posterior margin of most proximal subarticular tubercle or crease of articulation and tip of toe; SVL, Snout-vent length— measured from tip of snout to vent; PGL, Paritoid gland length— anterior-most point of parotid gland to posterior-most point of parotid gland; PGW, Parotid gland width—widest area of paritoid gland; SPE, Snout to end point of Parotid gland— measured from tip of snout to posterior-most point of Parotid gland.

Specimens examined are in the collection of the Natural History Museum, London, UK (BMNH); National Museum of Sri Lanka, Colombo, Sri Lanka (NMSL) and the collection of Wildlife Heritage Trust (WHT), Colombo, Sri Lanka, now deposited in NMSL (Appendix 1). We used a Cannon® EOS 7D SLR digital camera for photography. Conservation status of the species was evaluated based on IUCN Red List categories and Criteria – 2013 "Version 10.1" (IUCN 2013). Natural history observations of this amphibian were made by the naked eye at a distance at least 2–4 m between day times, without making any disturbance. We conducted six non-overlapped 4×50 m (200m^2) belt transects along the stream in six different sites, three transects at 09:00h and another three at 20:00h were conducted. Standard thermometer, hygrometer and lux meters were used to record the environmental parameters during the observations (Table 2). Altitudes were measured using a Garmin eTrex® 10 GPS and given in meters above mean sea level.

RESULTS

All the specimens examined and observed matched the holotype of *Adenomus kandianus*, Günther (1872), original description and the description given by Manamendra-Arachchi and Pethiyagoda (1998 and 2006) (Fig. 2). Furthermore, the specimens somewhat matches with the brief description given by Wickramasinghe *et al.* (2012). SVL of mature males are 29.5–31.2 mm and females 40.8–40.9 mm. Furthermore, two critically endangered species, *A. kandianus* and *A. dasi* have been previously known only from the Peak Wilderness Sanctuary in Central Province. But according to Manamendra-Arachchi and Pethiyagoda (2006) there are evidences from European museums that *A. dasi* once occurred commonly around Nuwara Eliya a century ago. Here we also rediscover a locally extinct population of *A. dasi* once from an around Nuwara Eliya (1400–1600 m mid elevation) after a century.

Taxonomy

Redescription of *Adenomus kandianus* based on the holotype and specimens from Pidurutalagala

***Adenomus kandianus* (Günther 1872)** (Figs. 2, 3 and 4c; Table 1)

TABLE 1. Morphometric measurements (mm) of *Adenomus kandianus* from lower part of the Pidurutalagala Forest Reserve, Sri Lanka (abbreviations as in methodology section / SD - standard deviation).

TABLA 1. *Medidas morfométricas (mm) de* Adenomus kandianus *de parte baja de la Reserva Forestal Pidurutalagala, Sri Lanka (abreviaturas como en la la sección de metodología / SD - desviación estándar).*

Character Abbreviation	Males (*n*=3)				Females (*n*=3)			
	(1)	(2)	(3)	Mean ± SD	(1)	(2)	(3)	Mean ± SD
DBE	8.9	8.8	8.7	8.8 ± 0.1	10.5	10.3	10.4	10.4 ± 0.1
DFE	4.6	4.3	4.2	4.4 ± 0.2	5.5	5.8	5.6	5.6 ± 0.1
ED	4.8	4.4	4.1	4.4 ± 0.3	4.2	4.3	4.2	4.2 ± 0.0
EN	2.8	2.7	2.7	2.7 ± 0.0	3.7	3.6	3.8	3.7 ± 0.1
UEW	3.0	3.1	3.2	3.1 ± 0.1	3.8	3.8	3.8	3.8 ± 0.0
ES	4.2	4.3	4.4	4.3 ± 0.1	5.8	5.6	5.7	5.7 ± 0.1
MBE	4.1	3.8	3.9	4.0 ± 0.1	6.2	6.3	6.2	6.2 ± 0.0
MFE	7.9	6.4	5.3	6.6 ± 1.1	8.6	8.5	8.7	8.6 ± 0.1
MN	9.0	8.9	9.1	9.0 ± 0.1	11.4	11.5	11.5	11.5 ± 0.0
NS	1.8	1.7	1.9	1.8 ± 0.1	2.4	2.4	2.4	2.4 ± 0.0
TND	7.4	7.2	7.0	7.2 ± 0.2	8.8	8.7	8.6	8.7 ± 0.1
TPD	5.2	4.7	4.4	4.7 ± 0.3	5.6	5.5	5.7	5.6 ± 0.1
TAD	1.0	1.1	1.2	1.1 ± 0.1	1.9	1.9	1.8	1.8 ± 0.1
TYE	3.3	2.7	1.9	2.6 ± 0.5	3.2	3.1	3.3	3.2 ± 0.1
FL1	3.4	3.3	3.4	3.4 ± 0.0	3.2	3.2	3.1	3.2 ± 0.0
FL2	3.8	3.1	2.8	3.3 ± 0.4	3.7	3.8	3.9	3.8 ± 0.1
FL3	5.7	4.5	4.2	4.8 ± 0.7	6.4	6.4	6.4	6.4 ± 0.0
FL4	3.7	3.3	3.0	3.3 ± 0.3	5.3	5.2	5.2	5.2 ± 0.0
HL	10.5	10.4	10.6	10.5 ± 0.1	13.4	13.4	13.5	13.5 ± 0.0
HW	10.3	10.1	10.2	10.2 ± 0.1	13.1	13.2	13.2	13.1 ± 0.1
IML	1.6	1.5	1.3	1.4 ± 0.1	2.4	2.3	2.3	2.3 ± 0.0
IN	1.7	1.8	1.7	1.7 ± 0.0	2.3	2.3	2.2	2.3 ± 0.0
IO	3.2	3.1	3.3	3.2 ± 0.1	3.6	3.7	3.5	3.6 ± 0.1
LAL	9.0	8.4	8.1	8.5 ± 0.4	10.9	10.8	10.8	10.8 ± 0.1
UAW	7.1	7.1	7.0	7.1 ± 0.0	9.5	9.5	9.5	9.5 ± 0.0
PAL	8.8	8.5	8.4	8.6 ± 0.1	12.3	12.2	12.4	12.3 ± 0.1
FEL	11.2	11.8	11.9	11.7 ± 0.3	15.3	15.0	15.1	15.1 ± 0.1
TBL	13.5	13.0	12.6	13.0 ± 0.4	16.4	16.3	16.5	16.4 ± 0.1
FOL	20.0	19.7	19.2	19.6 ± 0.3	26.3	26.4	26.5	26.4 ± 0.1
TL1	1.8	2.1	2.2	2.0 ± 0.2	2.5	2.4	2.6	2.5 ± 0.1
TL2	2.5	2.9	2.9	2.8 ± 0.2	3.5	3.4	3.4	3.4 ± 0.0
TL3	4.1	4.3	4.4	4.3 ± 0.1	5.6	5.5	5.6	5.6 ± 0.0
TL4	7.7	7.5	7.2	7.4 ± 0.2	8.7	8.8	8.5	8.7 ± 0.1
TL5	4.7	4.5	4.5	4.5 ± 0.1	5.2	5.3	5.2	5.2 ± 0.0
SVL	31.2	31.1	31.2	31.2 ± 0.0	40.8	40.8	40.9	40.8 ± 0.0
PGL	8.4	8.2	8.0	8.2 ± 0.2	10.5	10.4	10.6	10.5 ± 0.1
PGW	1.9	1.8	2.0	1.9 ± 0.1	2.2	2.1	2.3	2.2 ± 0.1
SPE	15.4	14.9	14.6	15.0 ± 0.3	19.1	19.0	19.2	

Specimens examined: Holotype, Male, 29.5 mm SVL, BMNH1947.2.20.63, Ceylon, G.H.K. Thwaites; Sex unknown 23.6 mm SVL, BMNH1947.2.20.62, Ceylon (paralectotype of *Bufo kelaartii* Günther, 1858). Voucher specimens, 32.2 mm SVL, DWC 201201001, Peak Wilderness Sanctuary, Sri Lanka, 1879 m attitude (06°48'34.16"N, 080°30'19.07" E), collectors L.J.M. Wickramasinghe and D.R. Vidanapathirana on 23rd October 2009; Male 31.1 mm SVL and Female 40.8 mm SVL, NMSL un-cataloged (new material), lower Pidurutagala, Sri Lanka, 1400–1600 m attitude (7°00'56.10",7°01'27.87"N; 80°47'13.97", 80°47'35.70"E), collector A. de Silva on 16th September 2010.

Diagnosis: *Adenomus kandianus* differs from *A. dasi* and *A. kelaartii* by having complete webbing between toes (vs. incomplete webs), presence of golden colored ventral and lateral body (vs. black and white colored ventral and lateral body), and inner edge of first toe and outer edge of fifth toe with dermal ridges (vs. absent). Furthermore, it differs from *Adenomus kelaatii* by absence of cranial ridges and canthal ridges (vs. present), and from *A. dasi* by having granules on chin area and parotid gland smooth (vs. chin area smooth and parotid glands with granules), it further different from *A. dasi* by absence of hourglass-shaped tubercle pattern on the dorsum.

Descriptions

***Description of male*:** Based on the new material (details of holotype, BMNH 1947.2.20.63 are given in square brackets). An adult male SVL of 31.1mm [29.5mm]. Head slightly concave, smooth and longer than wide (HL = 102.6% [96.1%] of HW; HL = 33.4% [33.2%] of SVL).

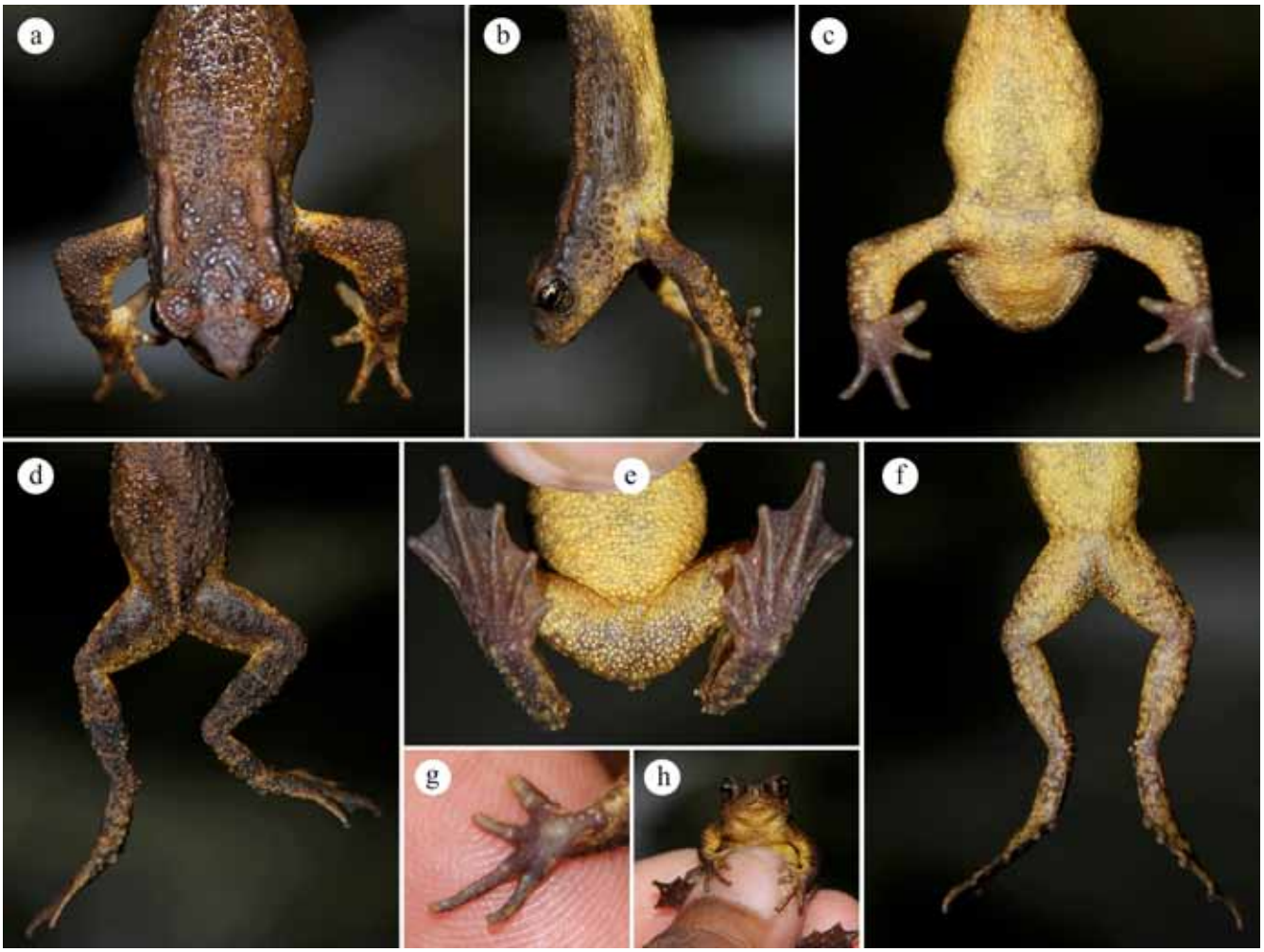

FIG.2. Different characters of male *Adenomus kandianus*: (a) dorsal head tubercles randomly scattered and cranial ridges absent; (b) parotid glands and the round snout; (c) gold colored venter, and smooth finger edges; (d) dorsal hind limbs granular with golden margin and dark cross bands; (e) fully webbed toes with the presence of dermal ridges on first and fifth toes; (f) fairly maculated color on hind limbs; (g) webless fingers with a prominent nuptial pad; (h) canthal ridges and snout shape.

Diferentes caracteres de Adenomus kandianus *macho: (a) tubérculos dorsales de la cabeza dispersos al azar y crestas craneales ausentes; (b) glándulas parótidas, y hocico redondeado; (c) vientre de color dorado, y bordes de dedos lisos; (d) parte dorsal de extremidades posteriores granular con margen dorado y bandas transversales oscuras; (e) pies totalmente palmeados, con presencia de crestas dérmicas en primero y quinto dedos de los pies; (f) color bastante maculado en miembros posteriores; (g) dedos sin membranas, con un prominente almohadilla nupcial; (h) crestas del canto y forma del hocico.*

Nostril round in shape, dorsolaterally oriented, with a fleshy inner margin, internarial area smooth and concave. Canthal ridges feebly defined and angular in dorsal aspect. Snout rounded in lateral aspect and smooth, obtusely pointed in dorsal aspect also smooth (ES = 41.3% [40.8%] of HL; ES = 13.8% [13.6%] of SVL), Nostril-to-snout distance is less than the distance between eye and nostril (NS = 61.8% [66.7%] of EN). Loreal region oblique and smooth. Small submerged tympanum [right tympanum entirely hidden by skin and left tympanum very small], vertically oval (TYE = 81.7% [63.2%] of FL1; TYE = 26.2% [12.2%] of HL). Throat and belly area is rough with small granules. Both sides of the gape with a large conical wart, and front edges of lower and upper jaws are obviously granulated. Very smooth granules present on axila-to-groin area.

Parotid glands elongated, narrow (posteriorly wider), smooth and divided in to several bulges arterially (PGW = 21.8% [20.3%] of PGL; PGL = 79.2% [70.4%] of HL), unlobulated, the anterior half elevated in lateral aspect, anteriorly confluent with upper eyelid. Interorbital flat and smooth, internarial distance less than interorbital width (IN = 58.4% [69.4%] of IO). Upper eyelids convex, its outer edge acute, its width more than inter orbital width (UEW = 101.3% [77.8%] of IO). Anterior end of mandible with a symphysial tubercle. Lower arm much shorter than head (LAL= 80.4% [95.9%] of HL; LAL = 26.9% [31.9%] of SVL). Both upper and lower arms covered with sharp and rough small warts in dorsal aspect. Fingers without web and tips of fingers rounded and smooth, third finger is the longest one (FL3 = 52.8% [56.1%] of PAL; FL3 = 53.7% [48.9%] of LAL; FL3 = 104.4% [115.0%] of ES). Relative length of fingers 2<1<4<3 [1<2<4<3], and first finger stouter than others, a nuptial pad on both dorsal and lateral sides of first finger in males (this character is present throughout the study period). Subarticular tubercles on fingers rounded or oval, two palmar tubercles, the outer one larger (146.3%) than the inner.

Femur somewhat shorter than tibia (FEL = 91.2% [99.2%] of TBL; FEL = 38.1% [41.0%] of SVL; TBL = 41.7% [41.4%] % of SVL). Foot length greater than tibia length (FOL = 151.5% [153.3%] of TBL; FOL = 63.2% [63.4%] of SVL). Inner edge of first toe and outer edge of fifth toe with well developed dermal ridges (dermal ridge present only the outer edge of fifth toe). Two metatarsal tubercles present, the inner one oval, the outer one is rounded and larger (136.3%), than the inner one. A ridge on inner edge of tarsus present, tarsal ridge confluent with inner metatarsal tubercle. Fourth toe is the longest (TL4 = 38.0% [34.8%] of FOL; TL4 = 71.9% [66.3%] of HL; TL4 = 174.0% [162.5%] of ES; TL4 = 174.4% [147.7%] of TL3). Toes completely webbed, the dorsal and ventral surfaces of all toes smooth, their tips rounded, subarticular tubercles smaller than those on fingers. Relative length of toes 1<2<3<5<4 [1<2<5<3<4], and fourth toe stouter than others. Subarticular tubercles normal in males [an additional subarticular tubercle present on fourth toe of left foot]. Snout smoothes both dorsally and laterally; mid-dorsal area covered with few quite large warts (0.9–1.4 mm width and 0.6–0.8 tall), and mixed with sharp small warts (0.3–0.6 mm width and 0.2–0.5 tall). Larger warts present on dorsal aspects of tibia rather than femur and feet on dorsal area. Sharp and quite large warts present on cloacal region, and thigh comparatively smooth in both front and back sides.

FIG.3. First ever photographic record of *Adenomus kandianus* in axillary amplexus (natural) on top of moss covered rock boulder in lower Pidurutalagala Forest Reserve.

Primer registro fotográfico de Adenomus kandianus *en amplexus axilar (natural) sobre roca cubierta de musgo en la parte baja de la Reserva Forestal Pidurutalagala.*

***Description of female*:** Based on the new material. An adult female SVL of 40.8 mm. Head slightly concave and forehead flat, smooth and quite longer than wide (HL = 102.6% of HW; HL = 32.9% of SVL; HL = 108.8% of PAL; HW = 32.1% of SVL). Nostril round in shape, dorsolaterally oriented, with a fleshy inner margin. Internarial area smooth and fairly concave. Internarial distance less than interorbital width and nostril–snout distance (IN = 64.1% of IO; IN = 96.2% of NS). Canthal ridges feebly defined and angular in dorsal aspect, but not sharp. Snout rounded in lateral aspect and smooth granuled, obtusely pointed in dorsal aspect and smooth (ES = 138.6% of ED; ES = 43.1% of HL; ES = 14.2% of SVL), Nostril to snout distance less than distance between eye and nostril (NS = 63.8% of EN). Loreal region oblique and fairly rough. Small submerged tympanum, vertically oval and rather equivalent to finger I but larger than toe 1(TYE = 100.9% of FL1; TYE = 126.4% of TL1; TYE = 23.9% of HL). Throat and belly area rough with tiny granules. Both sides of the gape with a large conical wart, and front edges of lower and upper jaws are obviously granulated. Very smooth granules present on axila-to-groin area.

Parotid glands rather elongated, narrow (mid-area wider), smooth and divided into four bulges anteriorly (PGW = 20.9% of PGL; PGL = 78.6% of HL; PGL = 80.6% of HW) but somewhat equal in size to back-of-eyes length (PGL = 100.6% of DBE; PGL = 96.9% of LAL), unlobulated, the anterior half elevated in lateral aspect, anteriorly confluent with upper eyelid. Interorbital flat and smooth, but rarely quite small 3–4 rectangle shape granules present. Upper eyelids convex, its outer edge acute, its width more than inter-orbital width and eye-to-nostril distance (UEW = 106.2% of IO; UEW = 101.6% of EN). Anterior end of mandible with a quite large symphysial tubercle. Lower arm much shorter than head and palm length (LAL = 81.1% of HL; LAL = 88.2% of PAL; LAL = 26.7% of SVL), but longer than snout, parotid gland and upper arm length (LAL = 188.2% of ES; LAL = 103.2% of PGL; LAL = 115.0% of UAW). Both upper and lower arms covered with sharp and rough small warts on dorsal aspect.

FIG.4. Another *Adenomus kandianus* in axillary amplexus (natural) hiding on top of moss-covered rock boulder (covered with wet leaf litters) in the lower part of the Pidurutalagala Forest Reserve by daytime.

Otro Adenomus kandianus *en amplexo axilar (natural) escondido en la parte superior de una roca cubierta de musgo (cubierto con camadas de hojas húmedas) en la parte baja de la Reserva Forestal Pidurutalagala, de día.*

Fingers without webbing and tips of fingers rounded and smooth, third finger is the longest one (FL3 = 67.3% of UAW; FL3 = 58.5% of LAL; FL3 = 51.7% of PAL; FL3 = 110.2% of ES). Relative length of fingers 1<2<4<3, and first finger stouter than others, nuptial pads absent on first finger in females. Subarticular tubercles on fingers rounded to oval, two palmar tubercles, the outer one larger (152.5%) than the inner.

Femur rather shorter than tibia and foot (FEL = 93.5% of TBL; FEL = 58.2% of FOL; FEL = 37.6% of SVL; TBL = 40.2% of SVL). Foot length greater than head length, paritoid gland length and palm length (FOL = 196.2% of HL; FOL = 249.6% of PGL; FOL = 213.4% of PAL; FOL = 64.5% of SVL). Inner edge of first toe and outer edge of fifth toe with prominent dermal ridges, but outer edge of fifth toe has the most prominent dermal ridge. Two metatarsal tubercles present, the inner one oval, the outer one rounded and larger (148.2%) than the inner one. A ridge on inner edge of tarsus, tarsal ridge confluent with inner metatarsal tubercle. Fourth toe is the longest one (TL4 = 151.0% of ES; TL4 = 156.7% of TL3; TL4 = 70.8% of PAL; TL4 = 65.1% of HL; TL4 = 33.2% of FOL). Toes completely webbed and well developed, the dorsal and ventral surfaces of all toes smooth, their tips rounded, subarticular tubercles smaller than on fingers. Relative length of toes 1<2<5<3<4, and fourth toe very stout than others. Subarticular tubercles normal in females. Snout somewhat smoothes both dorsally and laterally; mid dorsal area covered with few quite larger warts (width = 0.8–1.6 mm and height = 0.7–0.9 mm), and mixed with sharp small warts (width = 0.4–0.8 mm and height = 0.4–0.6 mm). Larger warts present on dorsal aspect of tibia rather than on the dorsal area of femur and feet. Sharp and quite large warts present on cloacal area, and thigh comparatively smooth on both anterior and posterior sides.

Colour in life: The dorsum of both sexes were yellowish brown and head is reddish compared to the body; a gold coloured tiny strip on the vertebral region; parotid glands chocolate or dark brown; lips with black and gold dots; upper arms paler, lower arm with reddish brown cross markings; fingers yellowish brown; Mid femur with a dark brown patch, margined yellow (Fig. 2); posterior side of the thigh with black and gold dots, while base of the inner thigh golden yellow; dark wide cross bars on tibia and foot. Venter gold, limbs lighter; webbing between toes with dark gold dots. Lateral side of the body dark brown, but loreal region and back of eye lighter; lower flank completely golden yellow; iris golden yellow with black markings (see Wickramasinghe *et al*., 2012 for further details).

Colour in preservation: The dorsum of both sexes turned to light brown; vertebral strip, inner thigh, venter, lower flank, iris and other golden yellow patches turned to dirty cream colour; reddish brown areas and brown cross marking on both arms and limbs were converted to dark brown (see Manamendra-Arachchi and Pethiyagoda 1998, 2006; Wickramasinghe *et al*. 2012 for further details).

Conservation status: The results of the application of the IUCN Red List criteria B1-b(i) - c(ii) shows that *A. kandianus* is restricted

to an area of occupancy (AOO) <15 km^2 (two isolated sites) and extent of occurrence (EOO) <85 km^2 in the wet zone (montane and sub-montane) within two well separated forest areas in central highland of Sri Lanka. Thus the suggested conservation status is Critically Endangered (CR).

Natural history

All the adult and juvenile toads live in and around clear, relative cold, and fast flowing streams. Water temperature in the streams range between 16.9–18.6 °C (17.8 ± 0.5°C) and the depth of water varies from 40–80 cm. The air temperature was measured between 24.5–26.3 (25.4 ± 0.6°C) and the humidity 66–88% (Tab.2). The toads were commonly observed on the moss-covered boulders by the streams. Most boulders are trapped with leaf litter on the surface. According to author's eyewitness, this species prefers well-camouflaged habitat that blend well with their body colors. The juveniles were never observed around boulders in the mid streams, but all near the banks covered with leaf litter and gravel. All other individuals were found on the land, but in close proximity (~1-2 m) to water and they mostly were facing water in the day time, perhaps to escape from predation or finding opportunistic prey. 89% of males were found on boulders (2–4 m circumference, 30–50 cm above the water level) in the mid stream. Habitats of *A. kandianus* in this area were shaded with 70–90% canopy cover. When disturbed, they dive into the stream and retreat into submerged rocky crevices, and remain underwater up to 15–25 minutes without emerging. According to author's eyewitness, this species is well adapted for aquatic life and the swimming pattern is similar to *Hoplobatrachus crassus* juveniles (see Manamendra-Arachchi and Pethiyagoda 2006).

The females are larger in size 3.5–3.7g (3.6 ± 0.1g) compared to males 2.2–2.5 (2.4 ±0.1g) (Table 2). The male : female sex ratio was 3:1 and ~50% of observed individuals were juveniles. We observed a few pairs in amplexus (axillary) in daytime on boulders during April 2012 (Fig. 3), and three amplectant pairs were observed on 10 May 2014, at around 10:00h while they were dwelling on moss covered rock boulders in the middle of the stream; those boulders were about 70 cm above water level and covered with wet leaf litter (Fig. 4). The temperature and the humidity were 14.5°C and 75%, respectively. Those amplectant pairs were waiting for nearly 50 minutes without any movements, and at once jumped into the fast flowing water and disappeared. Therefore we searched the sandy bottom to find them out; interestingly, we have found more than 10 amplectant pairs diving near to the bottom of the stream; unfortunately we were unable to observe any egg-laying behaviours. We could not observe any tadpoles or eggs of this species even that we extensively searched in nearby water pools and phytotelmata such as water collected on decaying logs and leaves, tree holes on ground level, and rocky crevices. We assumed they would not lay eggs on the fast moving stream water (Fig. 5) as the larval stages and eggs may drift away due to the high velocity of the stream currents. The bottom of the stream is clear, and no leaf litter is trapped in the streambed. This species may also lay eggs in habitats similar to those of other bufonids (Haas *et al*. 1997), in small water pools trapped with leaf litter. They prefer light intensity range from 1.6–5.3 (3.6 ± 1.2) lux during the day time. We only recorded 7 females, 22 males and 28 juveniles in all 6 transects (1200 m^2).

DISCUSSION

Recent research has rediscovered three species of amphibians that were considered extinct (EX) and one species that was considered Data Deficient (DD) (*Adenomus kandianus*, *Pseudophilautus hypomelas*, *P. semiruber* and *P. stellatus*). All of these species were rediscovered from the highlands (Meegaskumbura *et al*. 2012; Wickramasinghe *et al*. 2012, 2013a,c). Thus, further extensive surveys and observations in the central highlands of Sri Lanka may reveal more species that are currently considered extinct species.

The new population of *A. kandianus* in lower Pidurutalagala and the population in Peak Wilderness (Wickramasinghe *et al*. 2012) are completely isolated by tea plantations, introduced plantations (*Albizia*, *Cupressus*, *Eucalyptus* and *Pinus*), agricultural lands, human settlements and other human activities. Even though Wickramasinghe *et al*. (2012) claimed that the type specimen of *A. kandianus* might actually have been collected by George Henry Kendrick Thwaites from somewhere else out of present Kandy (Holotype labeled as Ceylon), we do not agree that Peak Wilderness or Pidurutalagala may had been considered as Kandy even in the 19th century (see Amarasinghe *et al*. 2014). However, we partially agree with Wickramasinghe *et al*. (2012) that the species may not have been collected from present Kandy or its surroundings (~500m elevation); alternatively, that species could have been collected from mid highlands that were still considered as Kandy or from a mountain near Kandy.

According to Wickramasinghe *et al*. (2012) a single *A. kandianus* specimen was collected from the Peak Wilderness for rediscovery. However it is difficult to conduct a proper taxonomic comparison and come to a conclusion observing a single specimen (DWC 201201001) collected by Wickramasinghe *et al*. (2012) from peak Wilderness. It is imperative to collect more data from both Peak Wilderness and Pidurutalagala populations to investigate the divergence of morphological, anatomical, physiological, and behavioral traits of this species between the two populations. Further, comparative molecular phylogenetic analyses among topotypes, and additional specimens from Pidurutalagala (PFR) and Peak Wilderness my also reveal genetic divergence and/or any bottlenecking this species sustained. The geographic isolation between the two extant populations may have led to reproductive isolation and subsequently to accumulation of substantial genetic differences.

It is interesting to note that *A. dasi* (Fig. 6) and *A. kandianus* are sympatric in Peak Wilderness and as well as in lower part of the Pidurutalagala (PFR), though Wickramasinghe *et al*. (2012) pointed that the main diagnostic character of *A. dasi* suggested by Manamendra-Arachchi and Pethiyagoda (1998) to be not suitable to diagnose *A. dasi* from *A. kandianus*. Tubercles within an hourglass-shaped pattern on the dorsum of *A. dasi* were visible in all (32) specimens that we observed together with *A. kandianus* at the lower part of the Pidurutalagala (PFR). Making detailed observations with a larger sample size on the Peak Wilderness populations of these

TABLE 2. Some ecological parameters of *Adenomus kandianus* from lower Pidurutalagala (PFR), Sri Lanka. (Abbreviations: M, males; F, female; J, juvenile; SVL, snout-to-vent length in mm; WT, weight in g; MHB, major habitat; MIC, microhabitat; CAC, canopy cover; AT, ambient temperature; RH, relative humidity; TE, water temperature; CLO, cloud cover; FW, rapid flowing cold water stream with dense canopy; LUX, light meter; RS, mid of the stream on a rock edge (icovered with green moss close to the water); EL, edge of the stream on leaf litters close to the water).

TABLA 2. *Algunos parámetros ecológicos de* Adenomus kandianus *de Pidurutalagala baja (PFR), Sri Lanka. (Abreviaturas: M, machos; F, hembra, J, juveniles; SVL, la longitud hocico-cloaca en mm; WT, peso en g; MHB, hábitat importante; MIC, microhábitat, CAC, dosel forestal; AT, temperatura ambiente ; HR, humedad relativa, TE, temperatura del agua; CLO, cobertura de nubes; FW, arroyo de corriente rápido de agua fría con dosel denso; LUX, intensidad de luz; RS, parte media de la corriente en una arista de roca (con cubierta de musgo cerca del agua); EL, borde de la corriente sobre las camadas de hojas cerca del agua).*

SEX	SVL, mm	WT, g	MHB	MIC	CAC, %	AT, ˚C	RH, %	TE, ˚C	CLO, %	LUX
M	30.9	2.2	FW	RS	80	26.2	68	17.5	4/8	04.8
M	29.8	2.5	FW	RS	70	25.5	71	17.8	5/8	01.7
M	30.8	2.3	FW	RS	90	25.9	76	17.2	5/8	03.1
M	30.9	2.4	FW	RS	90	25.6	75	18.6	4/8	03.7
M	31.6	2.5	FW	EL	70	24.7	72	16.9	6/8	02.8
M	31.8	2.4	FW	RS	70	25.5	74	17.8	5/8	05.2
M	30.6	2.2	FW	RS	80	24.5	75	17.5	4/8	02.3
M	31.9	2.3	FW	RS	85	24.6	83	18.2	6/8	04.6
M	31.6	2.5	FW	RS	75	26.2	76	18.3	4/8	03.2
F	40.8	3.7	FW	RS	80	25.4	69	17.5	5/8	04.1
F	39.6	3.6	FW	EL	80	25.7	66	18.1	7/8	01.6
F	40.9	3.6	FW	EL	70	24.8	82	17.4	5/8	03.6
F	40.4	3.5	FW	RS	90	25.6	75	18.6	4/8	04.7
J	16.9	1.6	FW	EL	75	26.3	73	17.5	5/8	02.6
J	17.5	1.7	FW	EL	70	25.1	88	17.9	6/8	05.3

two species may help clarify this discrepancy. Given their sympatric distribution and morphological resemblance, it would be important to study the possibility of hybridization between these two species in their natural habitats (see Haddad *et al*. 1994, Riley *et al*. 2003). Alternatively, investigating their secondary sexual characteristics, vocalization patterns, breeding microhabitats, and temporal reproductive dynamics (time of breeding in the year/season and mating period of the day within the reproductive season) may also reveal important conspecific mate selection strategies (Gerhardt 1982, Phelps *et al*. 2006, Ryan and Rand 1999).

At Pidurutalagala (PFR) *A. kandianus* is sympatric with *Duttaphrynus melanostictus* (common toad), *Ramanella palmata* (Parker's ramanella), *Hylarana temporalis* (bronzed frog), *Fejervarya* cf. *greenii* (Sri Lanka frog), *Pseudophilautus alto* (Horton Plains shrub frog), *P. femoralis* (leaf-nesting shrub frog), *P.* cf. *popularis* (Common shrub frog), *P.* cf. *regius* (Polonnaruwa shrub frog), *P. sarasinorum* (Muller's shrub frog), *P. silus* (pug-nosed shrub frog), *Taruga eques* (mountain hourglass tree frog), *Ichthyophis* cf. *glutinosus* and four unidentified *Pseudophilautus* (shrub frog) species in addition to *A. dasi* (Das's dwarf toad).

Habitats around lower Pidurutalagala (PFR) up to 1300 m elevation have been replaced rapidly by human encroachments primarily for tea, agricultural lands and human settlements. Such anthropogenic impacts are exacerbated by the surrounding unplanned agricultural systems that indiscriminate use of broad-spectrum pesticides and inorganic fertilizers. In addition, unsustainable agricultural practices and deformation in the reserve vicinity have resulted in severe soil erosion leading to sedimentation in low-order streams that provide habitats for many species of aquatic and semi-terrestrial fauna. Accumulation of silt and fine substrates in the streambed may destroy interstitial spaces that provide refugia and foraging grounds for amphibians (Stoddard and Hayes 2005, Muenz *et al*. 2006). The large-scale road constructions and reforestation programs with tree species like *Albizia*, *Cupressus*, *Eucalyptus* and *Pinus* lead to soil erosion. Moreover, some areas are now at a risk of land-sliding, and spreading alien invasive floral species.

Threats to the unique biodiversity recognized and the challenges to its conservation demand urgent scientific attention together with policy and planning (Amarasinghe and Karunarathna 2010, Helgen

FIG.5. (a) Undisturbed forest area in the gully of lower Pidurutalagala forest reserve; (b) typical habitat of the toad *Adenomus kandianus* with a rapid flowing stream and rock boulders; (c) a male *A. kandianus* on its microhabitat in middle of the stream; (d) lower part of the forest (PFR) with high anthropogenic pressure.

(a) Área de bosque no perturbado en el barranco de parte baja de la Reserva Forestal Pidurutalagala; (b) el hábitat típico del sapo Adenomus kandianus *con una corriente de cauce rápido y cantos rodados; (c) un* A. kandianus *macho en su microhábitat en medio de la corriente; (d) parte inferior del bosque (PFR) con alta presión antropogénica.*

and Groves 2005, Pethiyagoda *et al*. 2007, Pethiyagoda 2012, 2013). Sri Lanka's Environmental Policy framework needs to be strengthened with focus on conservation of threatened species and their habitats. The national Forest Ordinance (FO) and Flora and Fauna Protection Ordinances (FFPO) are two key policy enactments that warrant attention in terms of renovations. Existing policies only afford protection within the protected area boundary, not the overall landscape that enraptures the metacommunity dynamics of concerned species. It is imperative that on-ground conservation actions such as habitat restoration and soil conservation be implemented with a landscape perspective (Woolmer *et al*. 2008).

The potential impacts of habitat management need to be reviewed in the context of the entire watershed and not only simply the local habitat (Frissell *el al*. 1986, Herlihy *et al*. 1998). It is crucial to identify the degraded habitats within these highly sensitive, erosion-prone watersheds and carryout vegetation restoration based on fast-growing naïve species that are congruent with the regional hydrodynamics and soil ecology. As a countermeasure for watershed-scale deformation, soil erosion, and agrochemical contamination, the riparian forests need to be delineated as critical buffer zones (Burke and Gibbons 1995, Semlitsch and Bodie 2003, Willson and Dorcas 2003). It is important to take necessary steps towards conservation of this unique habitat and further exploration in lower part of Pidurutalagala (PFR) will lead to the discovery of many new species of amphibians as well as reptiles.

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FIG.6. Two types of color patterns of *Adenomus dasi* photographed from lower part of the Pidurutalagala Forest Reserve.

Dos tipos de patrón de color en Adenomus dasi *fotografiados en la parte inferior de la Reserva Forestal Pidurutalagala.*

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Appendix 1

Adenomus dasi: Holotype, WHT 2267 (22.2 mm SVL), Moray estate, Rajamally, near Mousakelle, Sri Lanka, 1370 m attitude (06˚48'N, 80˚31'E), collector D. Gabadage 22 July 1997; Paratypes, WHT 2268 (19.1 mm SVL), collector K. Manamendra-Arachchi 16 March 1995, and WHT 2269 (24.4 mm SVL), collectors M.M. Bahir and D. Gabadage 12 March 1997 (all from type locality).

Adenomus kandianus: Holotype, BMNH1947.2.20.63 (29.5 mm SVL), Ceylon, collector G.H.K. Thwaites; BMNH1947.2.20.62 (23.6 mm SVL), Ceylon; DWC 201201001 (32.2 mm SVL), Peak Wilderness Sanctuary, Sri Lanka, 1879 m altitude (06°48'34.16"N, 80°30'19.07"E), collectors L.J.M. Wickramasinghe and D.R. Vidanapathirana 23 October 2009; (31.1 mm SVL), and (40.8 mm SVL), NMSL un-cataloged, Pidurutagala, Sri Lanka, 1400–1600 m altitude (7°00'56.10"–7°01'27.87"N, 80°47'13.97"–80°47'35.70"E), collector A. de Silva on 16 September 2010.

Adenomus kelaartii: WHT 1447 (45.1 mm SVL), Batadombalena, Kuruwita, Sri Lanka, 460 m altitude (06˚47'N, 80˚23'E), collectors M.M. Bahir and D. Gabadage 17 September 1996; WHT 247 (25.1 mm SVL), Koskulana, near Panapola, Sri Lanka, 460 m altitude (06˚24'N, 80˚28'E), collectors K. Manamendra-Arachchi and D. Gabadage 11 July 1993; WHT 1448 (33.6 mm SVL), Morningside, near Rakwana, Sri Lanka, 1060 m attitude (06˚24'N, 80˚38'E), collectors D. Gabadageand M.M. Bahir 5 September 1996.