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**Front cover:** Heuglin's or Blue Nile patas monkey *Erythrocebus poliophaeus* (Reichenbach, 1862) male from the Beijing Wildlife Park, China. The species is here revalidated by Spartaco Gippoliti (see pages 53-59). Photograph by Jonas Livet..

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# Population Density of *Aotus* cf. *lemurinus* (Primates: Aotidae) in a Subandean Forest Patch on the Eastern Slopes of the Western Andes, Region of Dapa, Yumbo, Valle del Cauca, Colombia

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**Abstract:** Little is known of the demography of night monkeys, *Aotus*. The few studies that have been conducted in specific sites of the Amazon region do not allow for landscape-level inferences, and many of them fail in terms of the basic principles of statistical inference or are inadequate regarding assumptions of the methods used (replication and randomness). Night monkeys in the Colombian Andes inhabit generally fragmented landscapes of differing structure and composition (size, shape, isolation and vegetation types). However, there has been no quantitative diagnosis of their status or any effective monitoring of their populations. We estimated the population density of *Aotus* cf. *lemurinus* in a forest of about 900 ha on the eastern slopes of the Western Cordillera in the department of Valle del Cauca, Colombia, between 1,600 and 2,178 m above sea level. We used the Distance sampling method, with 30 linear transects with a total transect length of 9 km and a survey effort of 98.4 km. Surveys were conducted between 18:00 and 22:00 and between 03:00 and 06:00. The population density was estimated to be 113 individuals/km$^2$, one of the highest reported for the genus. This density could be a crowding effect related to the isolation process or a density compensation because of the reduced abundance of other species that may compete with night monkeys in some niche dimensions. A monitoring programme is needed to determine the trend of this population.

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## Introduction

Habitat loss is one of the most pervasive threats to biodiversity worldwide (Laurence *et al.* 2000). Forest loss causes the extirpation of forest-dependent species, but the viability of populations remaining in forest fragments is often uncertain and highly variable between species and populations (Laurence *et al.* 2002). An understanding of ecological parameters and a species' responses to environmental change is necessary to achieve effective conservation. Population biology theory and conservation management explicitly require accurate estimates of abundance to calculate the minimum sizes of viable populations (Begon *et al.* 2006). These data can be obtained through the estimation of population densities, understood as the number of individuals of a species in an area or habitat (Barrows 2001). Population density varies over time, and it is important that inferences about population trends should not be made based on assessments with limited geographic and temporal variation (Rudran and Duque 2003). It is also necessary to evaluate aspects such as group size and composition, as they are important elements in the dynamics that influence population density as a demographic parameter (Crockett and Eisenberg 1987). Data on density and age and sex composition of a population is important to understand tolerance to the loss or transformation of a species' habitat (Estrada *et al.* 1994, 1996; Cuarón 2000).

The original extent of occurrence of *Aotus lemurinus*, assuming an elevational range of 1,000 m to 3,000 m asl, was about 137,000 km$^2$ (Hernández-Camacho and Cooper 1976; Morales-Jiménez and de la Torre 2008, modified by the authors, taking altitude into account). We estimate that between 2007 and 2012, forests in the species' range were reduced by almost 3,000 km$^2$ (2.2% in five years), and more than 300 forest patches were lost. Forests in 28% of its range (38,700 km$^2$) are highly fragmented—more than 4,700 fragments that vary greatly in size (mean = 523 ha, median = 92 ha, SD = 5,390). More than 72,000 km$^2$ of its range are now largely a matrix of crops and cattle pasture (unpubl. data).

The Dapa region in the department of Valle del Cauca, Colombia, has a total area of 2,409 ha, and in 2007 there was

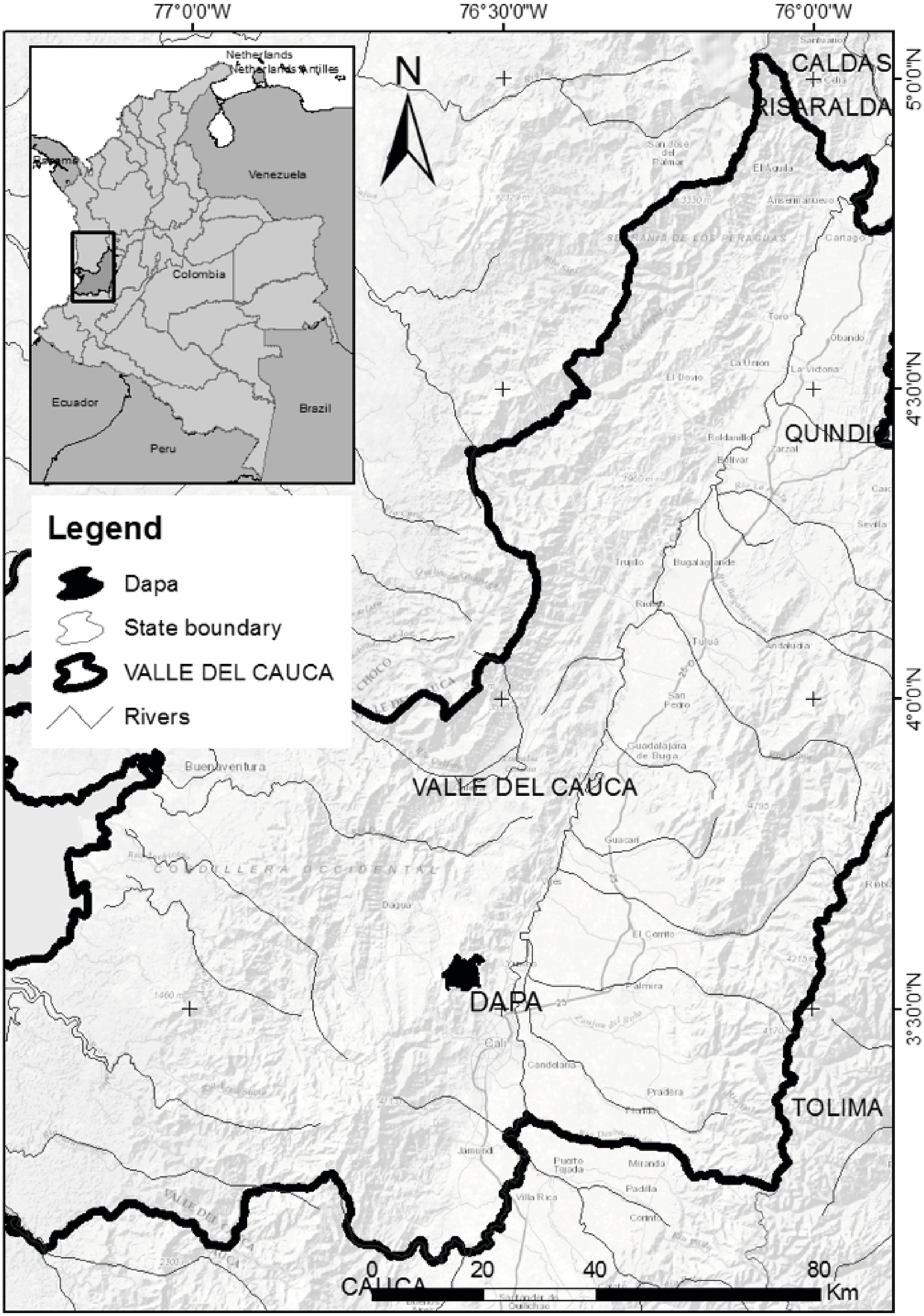

**Figure 1.** Study site.

at least one patch of dense forest of 262 ha, and a further 162 ha of successional vegetation (17% of the total area, although 512 ha of the aerial photograph analyzed was under cloud). By 2012, there was no dense forest remaining. The vegetation was transformed into 454 ha of fragmented forests and 612 ha of successional vegetation (44%). While it is possible that no forest had been lost, the increased degradation and fragmentation were evident.

*Aotus lemurinus* is classified as Vulnerable on the IUCN Red List of Threatened Species (Morales-Jiménez and de la Torre, 2008; Rojas-Diaz *et al.* 2012), and data on its habitat requirements and population numbers are needed for the formulation and implementation of conservation measures (Defler 2003). Here we estimate the population density of *Aotus* cf. *lemurinus* in Dapa, for comparison with density estimates from other regions (Heltne 1977; Green 1978; Rathbun and Gache 1980; Wright 1985; Zunino *et al.* 1985; Aquino and Encarnación 1986a, 1986b, 1988; García and Braza 1989; Stallings *et al.* 1989; Arditi and Placci 1990; Brown and Zunino 1994; Fernandez-Duque *et al.* 2001; Colombia, FIDIC 2007; Hernández and Diaz 2010; Maldonado 2011; Roncancio *et al*. 2012).

The study site is at the limits of the presumed ranges of *A. zonalis* and *A. lemurinus* (Defler 2010). The Andean or lemurine night monkey *A. lemurinus* occurs at higher elevations, above 1,000–1,500 m, whereas the Chocoan night monkey *A. zonalis* occurs in the lowlands to the west. These taxa are sibling species, and we refer to the night monkey in the Dapa region as *Aotus* cf. *lemurinus* pending confirmation of its identity using molecular genetic data.

## Methods

### *Study site*

The Dapa region is on the eastern slopes of the western cordillera near the city of Cali in the Cauca River Valley (3°33'46"N, 76°33'04"W), in the municipality of Yumbo, department of Valle del Cauca. Elevation in this region ranges from 1,000 to 2,200 m asl. The survey was carried out in an area of 2,409 ha. The native vegetation is Tropical Montane Cloud Forest (TMCF). The study was conducted in the forested area of Dapa (Fig. 1). Of a possible study site of about 993 ha, we selected three zones of about 300 ha, each covered largely by cloud forest. Members of the local community had confirmed that night monkeys occurred there, and also informed us that the type of forest was their natural habitat.

### *Data Collection*

We carried out line transect surveys between March and July 2015. We used the Distance sampling method, counting night monkeys (single individuals or groups), and measuring the perpendicular distance from the path with a tape measure between the individual seen or the approximate center of the group and the transect (Buckland *et al*. 2001). We always tried to count the entire group, but usually that is not possible and there is a significant negative relationship between group size and perpendicular distance, and if we use the group mean to estimate the density, this could be an underestimate. To avoid this bias, we use the estimated group size using the regression with respect to group size and perpendicular distances. The distribution of detection distances was then used to build a detection function (detection probability as a function of distance from the transect) (Buckland *et al*. 2001). Transects were surveyed repeatedly to increase sample size for calculating encounter rate. A coefficient of variation (CV) was calculated from encounter rates, detection probabilities and group sizes. The CV was used to calculate a confidence interval.

We set up 30 transects in three blocks (10 in each block) throughout the study area. The total sampling effort was 98.4 km (180 surveys along 30 transects, with an average of six surveys of each transect). Surveys were conducted between 18:00 and 22:00 and between 3:00 and 6:00 based on the active periods of the night monkeys and as such to increase the detection probability. Surveys were carried out for 20 consecutive nights in each area, in each block of 10 transects. Each transect was walked as quietly as possible at an average speed of 0.6 km/h. To keep detectability constant along the transect we tried to walk at a constant speed, and when a group was located, the observers stayed with the group for a maximum of 15 minutes (Peres, 1999). For the majority of the records, however, it was, around three minutes. The night monkeys were located by the red light reflection of the eyes, by the typical click vocalization, and by the noise of them moving in the canopy, and only recorded when clearly identified as night monkeys (Fig. 2) rather other arboreal mammals such as *Potos* or *Bassarycion*.

**Figure 2.** Photograph of *Aotus* cf. *lemurinus* in Dapa. Photo by Armin Hirche, 2015.

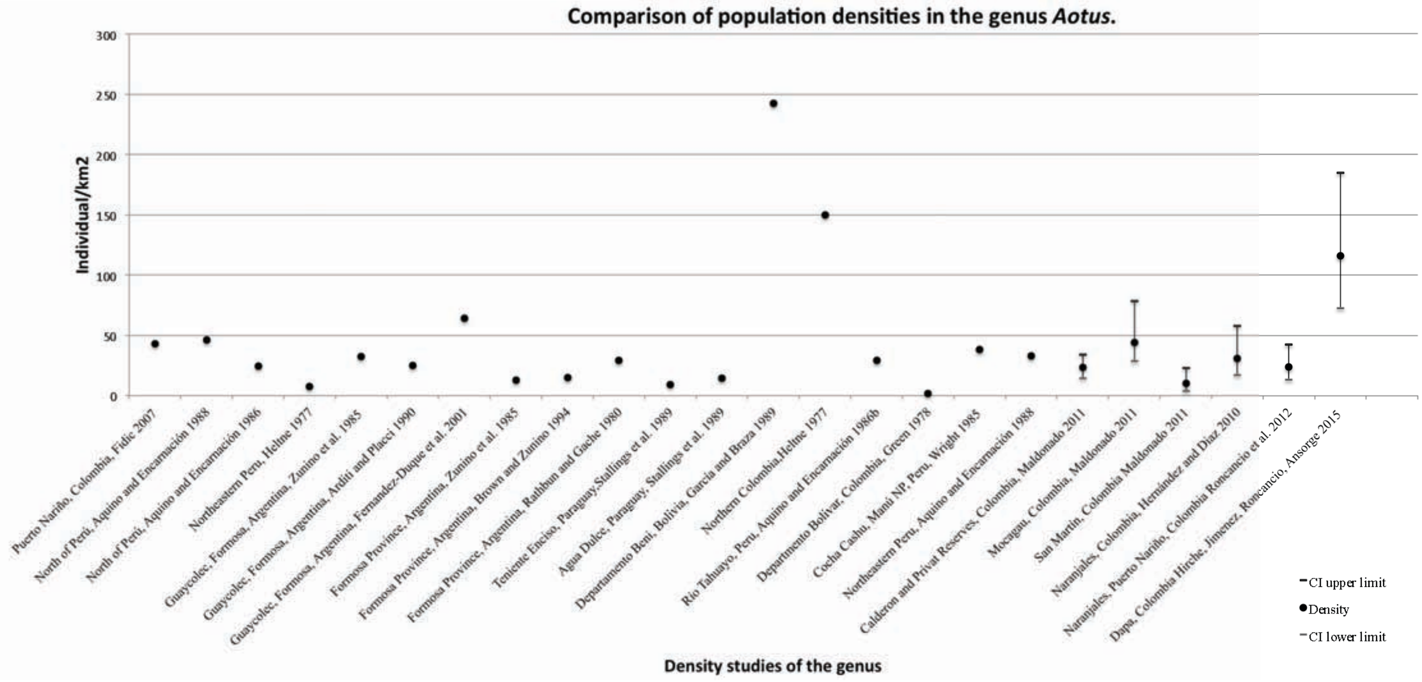

**Figure 3.** Comparison of population densities in the genus *Aotus*.

*Data analyses*

We analyzed data with the program Distance 7.0 (Thomas *et al.* 2009). Detection functions were selected according to the fit between the frequency distribution of detection distances and theoretical models (key and adjustment series) provided by the software Distance. The models that we tested were: half-normal (cosine, hermite polynomial), uniform (cosine, simple polynomial) and hazard rate (cosine, simple polynomial). We chose the model providing the best fit according to the Akaike Information Criterion (Buckland *et al*. 2001). The variance of population densities was empirically calculated as the sum of the sampling variances of encounter rates, the estimate of detection probability, and group size (Buckland *et al.* 2001).

We found a relationship between detection probability and group size. The use of mean group size underestimated population density (Buckland *et al.* 2001). Therefore, we used the expected group size estimated from the regression between group size and detection probability.

We used confidence intervals to compare population density estimates among localities. An overlap of >25% between the confidence intervals of two localities was interpreted as no significant difference in population density (Cumming *et al*. 2007).

## Results

We obtained 59 records of *Aotus* cf. *lemurinus.* The encounter rate was 0.6 groups/km. Recorded group size ranged from one to five individuals. The frequency distribution of perpendicular distances presented a better fit using the Uniform with Cosine expansion series model. The estimated population density of the night monkeys was 113 ind/km$^2$ (95% CI = 70.79 to 180.65) and the estimated group density was 52.4 groups/km$^2$ (95% CI = 33.4 to 82.1), with CV of 23.65 and 22.55, respectively. The average group size was 2.2 individuals (95% CI = 1.9 to 2.5). The most important component of the variance of the density was the encounter rate (74.4%), followed by a probability of detection (16.5%) and by the group size (9%).

## Discussion

The population density of *Aotus* in Dapa was significantly higher than estimates of *Aotus* densities in other localities, which mostly range from 30–40 ind/km$^2$ (Fig. 3). High population densities of primates in forest patches following deforestation have been explained as a crowding effect driven by the reduction and fragmentation of the habitat (Ramos-Fernandez and Wallace 2008). This situation of presumed overpopulation can lead to overexploitation of resources, predation, and reduced survival and birth rates (Milner *et al.* 1999; Begon *et al.* 2006), increased possibility of inbreeding, and possibly a reduction in population size (Estrada and Coates-Estrada 1996; Anzures-Dadda and Manson 2007). This high density could be a temporary situation, depending on the functional connectivity, the population dynamics in isolated conditions, and the viability of the population (Kattan and Álvarez-López 1996; Harcourt and Doherty 2005).

Of the four primates—*Alouatta seniculus*, *Ateles fusciceps* and *Cebus capucinus*, besides *Aotus*—that would have originally occurred in the area (Hernández-Camacho and Cooper 1976), we saw only night monkeys, so the high density of *Aotus* cf. *lemurinus* in this fragment could also result from density compensation (MacArthur *et al.* 1972). It is probable that the local extinction or depletion of other primates or other species that are less tolerant to the reduction and fragmentation of the forest, or synergistic threats such as hunting (Jonsson *et al.* 2006; Arroyo *et al*. 2007) have reduced the competition in some niche dimensions (Hutchinson 1957), providing for an increase in carrying capacity for the population of *Aotus*. This phenomenon has been found for primates in the Amazon and Guiana Shield in areas that are heavily hunted. In places where the ateline population density has been reduced by hunting, the densities of non-hunted mid-sized primates increase (Peres and Dolman 2000; González-Solis *et al*. 2001). The white-footed tamarin (*Saguinus leucopus*) of the eastern slopes of the central Andean region, in the department Antioquia, show a similar pattern in forest fragments without *Ateles hybridus*, *Alouatta seniculus*, and *Cebus versicolor*, while in fragments with the complete primate assemblage densities were significantly smaller (Roncancio *et al*. 2011, in prep.).

In the study of Castaño *et al.* (2010) in the middle Cauca River basin, night monkeys ate the infructescence's of *Cecropia telealba* (Cecropiaceae), and the fruits (syconia) of *Ficus* cf. *maitin* and *Ficus* cf. *palmicida* (Moraceae) (Castaño and Cardona 2005; Castaño *et al.* 2010). *Cecropia telealba* is dominant in Dapa, which might be a factor promoting the high population density we recorded. The evidently high densities in these forest patches emphasize the importance of these habitats for the conservation of these night monkeys, and we have argued for their protection in regional action plans and besides recommended measures to increase connectivity between the fragments and to minimize the negative impact of their degradation due humans exploiting them for their resources.

To accurately determine the conservation status of a species through the analysis of changes in population density, it is necessary to assess habitat type at each site (successional stage, floristic assemblage, and plant phenology) and such as aspects as disturbance and hunting, and to carry out regular surveys to record any trends in population densities and size. For a monitoring programme to be effective we need to be able to detect change, a feature known as statistical power. The statistical power depends on the precision of the estimates of, in this case, population density. If we have a broad sampling error (e.g., coefficient of variation), a type II error (failure to detect change) is probable, with possibly grave consequences regarding management decisions (March and Trenham 2008). Here, the detectable change to this population based on the coefficient of variance is 16.71% two-tailed, or 5.2% one-tailed, with a statistical power of 0.8, and a significance level of 0.05 (Gerrodette 1987, 1991). To improve the analytic power of the distance sampling method, it is necessary to increase the sampling effort, mainly in the number of transects (sample units) since the component that most contributed to the variance was the encounter rate. Considering the threats faced by *Aotus* cf. *lemurinus*, the environmental NGO DapaViva will conduct surveys every three years to monitor their population density, to contribute to informed measures for their conservation.

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# Conservation Action Plan for Ecuadorian Primates: Process and Priorities

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**Abstract:** The 2015 assessment of the conservation status of the Neotropical primates reported that 91 species and subspecies (42.5%) are threatened. This highlights the need to establish priority actions to mitigate the threats caused by human activities and promote the conservation of their populations and habitats. Ecuador is fifth-ranking of the Neotropical countries in terms of primate richness, with 22 taxa, 11 of which are threatened. Ongoing conservation actions need to be improved and new ones need to be designed. In this context, we are drawing up a Conservation Action Plan for the primates of Ecuador, which brings together the main organizations and experts involved in the study of Ecuadorian primates. The plan builds on previous work done by the organizations involved, and will be periodically modified and updated taking into account new information as it is generated. The multidisciplinary approach of this initiative was a key factor in promoting the fulfillment of the goal of this action plan, which is to reduce the extinction risk of the threatened primates in Ecuador, and generate information to properly assess species currently listed as Data Deficient before 2027. This plan is not only important for the information it presents, but also because it is a clear example of what can be achieved when the government, academia and society work together towards the common goal of improving the conservation status of Ecuadorian primates and their habitats.

**Key Words:** assessment, Ecuador, endangered, hotspot, Neotropical primates

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Primates are unique, not only for their diversity, anatomical adaptations, social systems and ecological roles, but also for the threats they face (Garber and Estrada 2009; Estrada *et al*. 2017). An evaluation of the conservation status of the Neotropical primates conducted by the IUCN SSC Primate Specialist Group in 2015, reported 42.5% of threatened primates in the region (total taxa = 214, IUCN SSC in prep.). This emphasizes the need to establish priority actions to diminish the threats and promote the conservation of their populations and habitats, including strategies at the national and regional levels (for example, Jerusalinsky *et al*. 2011, Escarlate-Tavares *et al*. 2016 in Brazil, and Mexico, SEMARNAT 2012).

Ecuador is the fifth country of the region in terms of primate richness, with 22 taxa, 11 of which are categorized as threatened and nine Near Threatened (Table 1) (Tirira 2017). There are ongoing initiatives aiming at improving the conservation status of the primates of Ecuador, such as the project being implemented by the Ministry of Environment that focuses on key species of conservation concern (four of which are primates), and which aims at increasing the efficiency of

**Table 1.** National conservation status of the primate species of Ecuador (Tirira 2017).

| | CR | EN | VU | NT | LC | DD | NE |
|---|---|---|---|---|---|---|---|
| *Cebuella pygmaea pygmaea*[1] | | | x | | | | |
| *Leontocebus lagonotus*[2] | | | | x | | | |
| *Leontocebus nigricollis graellsi*[3] | | | x | | | | |
| *Leontocebus tripartitus*[4] | | | x | | | | |
| *Cebus aequatorialis*[5] | x | | | | | | |
| *Cebus capucinus capucinus* | | x | | | | | |
| *Cebus yuracus*[6] | | | | x | | | |
| *Sapajus macrocephalus*[7] | | | | x | | | |
| *Saimiri cassiquiarensis macrodons*[8] | | | | x | | | |
| *Aotus lemurinus* | | | | | | x | |
| *Aotus vociferans* | | | | x | | | |
| *Cheracebus lucifer*[9] | | | x | | | | |
| *Plecturocebus discolor*[10] | | | | x | | | |
| *Pithecia milleri*[11] | | | | x | | | |
| *Pithecia napensis*[12] | | | | x | | | |
| *Pithecia aequatorialis** | | | | | | | x |
| *Alouatta palliata aequatorialis* | | x | | | | | |
| *Alouatta seniculus seniculus* | | | | x | | | |
| *Ateles belzebuth* | | x | | | | | |
| *Ateles fusciceps fusciceps* | x | | | | | | |
| *Lagothrix lagothricha lagothricha*[13] | | x | | | | | |
| *Lagothrix lagothricha poeppigii*[14] | | x | | | | | |
| Total | 2 | 5 | 4 | 9 | 0 | 1 | 1 |

CR = Critically Endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened, LC = Least Concern, DD = Data Deficient, NE = Not Evaluated. 1. Evaluated as *Callithrix pygmaea*. 2. Evaluated as *Saguinus fuscicollis*. 3. Evaluated as *Saguinus graellsi*. 4. Evaluated as *Saguinus tripartitus*. 5. Evaluated as *Cebus albifrons aequatorialis*. 6. Evaluated as *Cebus albifrons cuscinus*. 7. Evaluated as *Cebus macrocephalus*. 8. Evaluated as *Saimiri sciureus*. 9. Evaluated as *Callicebus lucifer*. 10. Evaluated as *Callicebus discolor*. 11. Evaluated as *Pithecia monachus*. 12. Evaluated as *Pithecia aequatorialis*. 13. Evaluated as *Lagothrix lagotricha* and 14. Evaluated as *Lagothrix poeppigii*. * Included in the primate action plan based on one captive individual found in Enkerido, an indigenous village in the Pastaza province, which is thought to have been captured in Ecuador (Tirira 2017).

protected areas through a landscape management approach. Implementation of the CITES convention and other national laws also aim to protect and reduce the threats facing endangered species; yet no primate-specific strategy has been established for the conservation of this order in the country.

We can better understand the extent of the impact of the anthropogenic activities on the conservation status of the Ecuadorian primates if we consider that Ecuador is the country with the highest population density in South America (approx. 55 inhabitants/km$^2$ [Ecuador, INEC 2015]), and also presents one of the highest deforestation rates in South America, estimated between 70,000 and 190,000 ha per year (FAO 2010; Ecuador, Ministerio del Ambiente 2013). Water availability, flat terrain and fertile soil have been key factors for the increase in agricultural development along the coastal region, which has caused unparalleled levels of deforestation (Buitron 2001; Sierra 2001; Mosandl *et al.* 2008). Furthermore, hunting and traffic of living primates are having detrimental effects on the primate populations of Ecuador, increasing their risk of extinction (de la Torre *et al.* 2007; Dew *et al.* 2003; WCS 2006; Zapata-Ríos 2001; Zapata-Ríos *et al.* 2009; Tirira 2013). This is partly because laws regarding wildlife should be clearer and better enforced. Hunting, possession and trade of primates in the national territory is banned (Decreto Ejecutivo No. 3516), while subsistence hunting and traditional medical use in indigenous territory are allowed (Código Orgánico Integral Penal article 247). In this context, the need to develop a conservation action plan for the primates of Ecuador was an urgent challenge (de la Torre 2012; Jack and Campos 2012).

In mid-2016, we carried out the first meetings to define the timeline, the main stakeholders and institutions that had to be involved in the process of developing this plan, and the potential funding sources. The "Workshop for the Elaboration of the Conservation Action Plan for the Primates of Ecuador" took place from 28–30 November 2016 at the Pontificia Universidad Católica del Ecuador, Quito (see Appendix). This initiative brought together the main organizations and experts involved in the study of Ecuadorian primates. The workshop built upon the information on primate species included in the Red Book of Endangered Mammals of Ecuador (Tirira 2011), updated with information from the specialists working on each species, in order to identify the main threats and gaps of knowledge.

This initiative was supported by the Ministry of Environment of Ecuador, through the project "Landscapes and Wildlife Conservation," of the Global Environmental Facility (GEF), United Nations Development Programme (UNDP), Wildlife Conservation Society (WCS), the Asociación Ecuatoriana de Mastozoología (AEM), Conservation International (CI), Bioparc de Doué la Fontaine, Fundación Mamíferos y Conservación, Universidad San Francisco de Quito (USFQ), and Pontificia Universidad Católica del Ecuador (PUCE).

The workshop included oral presentations, discussion sessions and plenaries of fifteen institutions and researchers, which presented the advances and needs in different study areas. Eighteen talks were given on various topics, including distribution, ecology and conservation status of the Ecuadorian primates, main threats, lessons learned from previous action plans, theoretical and legal bases of animal rights, veterinary procedures, and planning of strategic action plans.

The proposed strategies integrated the vision of the different participants and enabled the identification of priority actions that could significantly contribute towards the goal of effectively decreasing the extinction risk of every primate species by one level of the IUCN ranking, and generating relevant information to properly assess those species listed as Data Deficient before 2027 in Ecuador. To achieve these objectives, we defined the following strategic areas: (1) creation of protected areas and the strengthening of the management of the existing ones; (2) mitigation of human impacts; (3) species management; (4) regulations; (5) research; (6) environmental education; and (7) implementation of conservation strategies. For each of those areas, specific actions where established considering the conservation status and specific threats for each species.

The multidisciplinary approach of this plan will require the internalization of these lines of action into the working agendas of the different institutions involved in primate conservation in Ecuador. The benefits of following the same criteria towards the conservation of the primates of Ecuador are countless, as all efforts will sum for the same objective. Additionally, it will increase the possibility of involving actors that have not been taken into account, and will improve cooperation between organizations.

The Conservation Action Plan for the Primates of Ecuador has been planned for a period of 10 years (until 2027), with an evaluation that will take place in the middle of the process, five years after its approval. The aim of this evaluation is to assess the efficiency of the strategies defined and to consider the need to adapt the objectives and actions as well as to discuss new strategies to promote their implementation. Although the plan will only be official when the Ministry of Environment recognizes it as a public document, updated information on the different species is already being generated and will be included in the plan. Experts are also updating protocols regarding captive population management and rehabilitation to improve those existing and better systematize the procedures.

This plan is important not only for the information it presents and the actions it promotes, but also because it is a clear example of what can be achieved when the government, academia and society work together towards the common goal of improving the conservation status of Ecuadorian primates and their habitats. While the plan contemplates all Ecuadorian primates, it was clear during the workshop that the species inhabiting the coastal region deserve special attention because of the critical situation they are facing, mainly because of habitat fragmentation and isolation, which increase the risk of extinction. Although effectively achieving the main objective of this plan seems ambitious, it brings with it the opportunity of collaboration between institutions, unifying efforts, and increasing efficiency and effectiveness in the implementation of conservation actions. We believe this is the only way to ensure the protection of Ecuador's primates.

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## Appendix 1

Agenda of the "Workshop for the Elaboration of the Conservation Action Plan for the Primates of Ecuador".

### PLAN DE ACCIÓN PARA LA CONSERVACIÓN DE LOS PRIMATES DEL ECUADOR

### Taller de especialistas

**28 a 30 de noviembre de 2016**

**Agenda**

| Hora | Lunes 28 |
|---|---|
| **08:30** | Registro de asistentes. Hall de piso 1, edificio de Biología |
| **09:00** | Inauguración y palabras de bienvenida:<br>● Santiago Burneo (Director de la Escuela de Biología, PUCE)<br>● Santiago Silva (Director Nacional de Biodiversidad, Ministerio del Ambiente del Ecuador)<br>● Luis Suárez (Director de Conservación Internacional-Ecuador)<br>● Víctor Utreras (Coordinador Nacional del Proyecto Paisaje - MAE/PNUD/GEF) |
| **09:20** | Presentación de los asistentes. Modera: Diego G. Tirira |
| **09:45** | Mecánica del taller. Modera: Diego G. Tirira |
| | **Introducción** |
| **09:50** | Conferencia: Una revisión al estado de conocimiento de los primates del Ecuador [**Diego G. Tirira** (Grupo de Estudio de los Primates del Ecuador - GEPE, Asociación Ecuatoriana de Mastozoología - AEM y Fundación Mamíferos y Conservación)] |
| **10:50** | **Receso** |
| **11:20** | Conferencia: Guías de los Planes de Manejo para Especies de UICN [**Stephanie Arellano** (UICN-Sur)] |
| **11:40** | Conferencia: Lecciones aprendidas del Plan de acción para la conservación de los murciélagos del Ecuador [**M. Dolores Proaño & Santiago Burneo** (PUCE)] |
| **12:00** | Conferencia: Planeamiento estratégico para la conservación de los primates en Brasil: avances y desafíos [**Leandro Jerusalinsky** (Ministério do Meio Ambiente, Brasil)] |
| **13:00** | **Almuerzo** |
| | **Sesión normativa y marco legal (matriz código N)** |
| **14:00** | Conferencia: Primates: ¿especies protegidas por la ley? [**Hugo Echeverría** (abogado ambiental, Quito)] |
| **14:20** | Conferencia: Los primates, sujetos del derecho ecuatoriano [**Joan Correa Paredes** (Secretaría Técnica de Cooperación Internacional)] |
| **14:40** | Plenaria y discusión (Matriz código N) |
| **15:40** | **Receso** |
| **16:00** | Plenaria y discusión (Matriz código N) (continuación). Conclusiones |
| **17:30** | **Fin de jornada** |

Ministerio del Ambiente

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Asociación Ecuatoriana de Mastozoología

## PLAN DE ACCIÓN PARA LA CONSERVACIÓN DE LOS PRIMATES DEL ECUADOR

### Taller de especialistas

**28 a 30 de noviembre de 2016**

### Agenda

| **Hora** | **Martes 29** |
|---|---|
| | **Exposiciones** |
| **09:00** | Conferencia: Situación actual de los Primates Mexicanos: Modelos como herramientas de conservación [**Francisca Vidal-García** (Instituto de Ecología A.C., Xalapa, Veracruz, México)] |
| **09:45** | Conferencia: Efectos de la fragmentación en *Cebuella pygmaea* y *Alouatta palliata* [**Stella de la Torre** (GEPE/AEM y Universidad San Francisco de Quito - USFQ)] |
| **10:15** | Conferencia: Estacionalidad en Primates: monitoreo de especies de primates en la Reserva Biológica Colonso Chalupas [**Sara Álvarez Solas** (GEPE/AEM y Universidad Ikiam)] |
| **10:35** | Conferencia: Aspectos taxonómicos y ecológicos de *Cebus aequatorialis* (Primates: Cebidae) en el Ecuador [**María Fernanda Solórzano** (GEPE/AEM y MAE Proyecto Paisaje)] |
| **10:55** | **Receso** |
| **11:30** | Conferencia: Investigación participativa en la conservación de primates: El caso de los parabiólogos de la Reserva Tesoro Escondido y la conservación de *Ateles fusciceps* [**Citlallei Morelos-Juárez** (GEPE/AEM y Fundación Cambugán)] |
| **11:50** | Conferencia: Cacería y conservación de los primates en el Ecuador [**Galo Zapata Ríos** (WCS)] |
| **12:10** | Conferencia: Tráfico de primates nativos en el Ecuador [**Diego G. Tirira** (GEPE/AEM y Fundación Mamíferos y Conservación)] |
| | **Sesión áreas protegidas y prioritarias (código AP) y estudios científicos (código EC)** |
| **12:30** | Formación de grupos de trabajo para la tarde |
| **12:40** | **Almuerzo** |
| **14:00** | Análisis y discusión en grupos de trabajo:<br>Grupo 1: Áreas protegidas y prioritarias para la conservación (matriz código AP). Modera: Diego G. Tirira<br>Grupo 2: Estudios científicos necesarios (matriz código EC). Modera: Stella de la Torre |
| **15:40** | **Receso** |
| **16:00** | Presentación de resultados de grupos de trabajo y conclusiones |
| **17:30** | **Fin de jornada** |

Universidad San Francisco de Quito

WCS Ecuador

Conservación Internacional Ecuador

# PLAN DE ACCIÓN PARA LA CONSERVACIÓN DE LOS PRIMATES DEL ECUADOR

## Taller de especialistas

**28 a 30 de noviembre de 2016**

## Agenda

| Hora | Miércoles 30 |
|---|---|
| | **Exposiciones** |
| **09:30** | Conferencia: Acciones estratégicas para la conservación de los primates Mexicanos [Francisca Vidal-García [**Francisca Vidal-García** (Instituto de Ecología A.C., Xalapa, Veracruz, México)] |
| **10:15** | Conferencia: Retos en la conservación de primates de la Costa ecuatoriana y las posibles soluciones [**Nathalia Fuentes S. & Felipe Alfonso-Cortes** (GEPE/AEM y Proyecto Washu)] |
| **10:35** | Conferencia: Estado de conservación de las poblaciones de *Ateles fusciceps fusciceps* en Flavio Alfaro: adaptación o supervivencia [**Laura Cervera** (GEPE/AEM)] |
| **10:55** | **Receso** |
| **11:30** | Conferencia: Tenencia de primates como mascotas por las comunidades Chachi: estudios de caso e implicaciones para la conservación del críticamente amenazado mono araña de la Costa [**María Isabel Estévez** (GEPE/AEM)] |
| **11:50** | Conferencia: Análisis de primates nativos tratados en el Hospital veterinario de la USFQ [**Andrés Ortega** (USFQ)] |
| | **Sesión educación ambiental (código EA) y control de impactos (código C)** |
| **12:10** | Formación de grupos de trabajo |
| **12:15** | Análisis y discusión en grupos de trabajo:<br>Grupo 1: Educación ambiental (matriz código EA). Modera: Felipe Alfonso-Cortes<br>Grupo 2: Control de impactos (matriz código C). Modera: Diego G. Tirira |
| **13:00** | **Almuerzo** |
| **14:00** | Análisis y discusión en grupos de trabajo (continuación) |
| **15:00** | Presentación de resultados de grupos de trabajo y conclusiones |
| **15:30** | **Receso** |
| | **Sesión planes de manejo (código PM) y otros (código O)** |
| **16:00** | Plenaria y discusión. Modera Diego G. Tirira |
| **17:30** | **Palabras finales y cierre de taller** |

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# Field Data on the Little Known and Endangered *Lepilemur mittermeieri**

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**Abstract:** *Lepilemur mittermeieri* is a very little known sportive lemur of the Ampasindava peninsula of Madagascar, presently regarded as Endangered. It was described in 2006 by Rabarivola *et al*. on the basis of genetic material only, obtained from three individuals collected at the same locality. No observation confidently allocated to the species has been reported since. The objectives of our research were to verify that the sportive lemurs found in forests of the Ampasindava peninsula beyond the type locality of *Lepilemur mittermeieri* belonged to the same species as the type, to provide morphological and behavioral data for populations confidently attributed to *L. mittermeieri* and to obtain for these populations preliminary evaluations of density variations within the peninsula. Our surveys were undertaken in March and April 2014 in remnant forest patches of the western part of the Ampasindava peninsula. Linear transects by night and punctual observations by day were conducted. A total of 54 animals were seen along nine transects situated in four forest patches, two at low altitude and two at high altitude. All animals examined and photographed appeared similar, and the impression was gained that a single taxon was involved. Genetic material collected from one dead specimen proved identical to the type of *L. mittermeieri* which confirmed the identity of the populations we observed. It thus appears that *L. mittermeieri* is indeed the only sportive lemur present on the peninsula and that it occurs in several forest remnants. We endeavored to get evaluations of the density and abundance of the species in the four forest patches we studied. We used KAIs (Kilometric Abundance Indices) to evaluate and compare relative densities, and Buckland's distance sampling method to evaluate absolute densities. The latter suggested a density of 1.9 animals/ha, a result that must, however, be taken with caution.

**Key Words:** *Lepilemur mittermeieri,* Ampasindava peninsula, Madagascar, distance sampling, endangered species

## Introduction

Sportive lemurs (genus *Lepilemur*) are medium-sized, mostly folivorous, forest-dwelling, mostly nocturnal primates, confined, like the rest of the infraorder Lemuriformes, to Madagascar (Wilmet *et al*. 2014). They are placed by most recent authors in the monotypic family Lepilemuridae (Groves 2005; Schwitzer *et al.* 2013). As a genus, the sportive lemurs are widely distributed, in discrete populations, in low and mid-altitude evergreen and deciduous forests of Madagascar (Andriaholinirina *et al*. 2006; Mittermeier *et al*. 2010; Mittermeier 2013; Drösher and Kappeler 2014). The diversity of the genus has only recently been fully appreciated (Schwitzer *et al*. 2013). Until the 1970s, all populations were included in two or one species. Between 1977 and the 1990s seven species were recognised. Groves (2005) recognised eight species. Recent genetic and cytogenetic studies have identified 26 species, with more likely to be discovered (Schwitzer *et al*. 2013). The cryptic character of the now-recognized species, the long ignorance of their identity and the fact that many of them have only been characterised through genetic analyses mean that very few eco-ethological data can be specifically attributed to most of them. Thus, by 2013, data on behaviour and ecology were only available for six of the 26 species (Schwitzer *et al*. 2013). The genus is very homogenous; species are morphologically similar and are not sexually dimorphic. The reproductive cycle of individual species and the social behaviour of individuals are poorly known but some sportive lemurs at least show a seasonal reproductive cycle and individuals appear to

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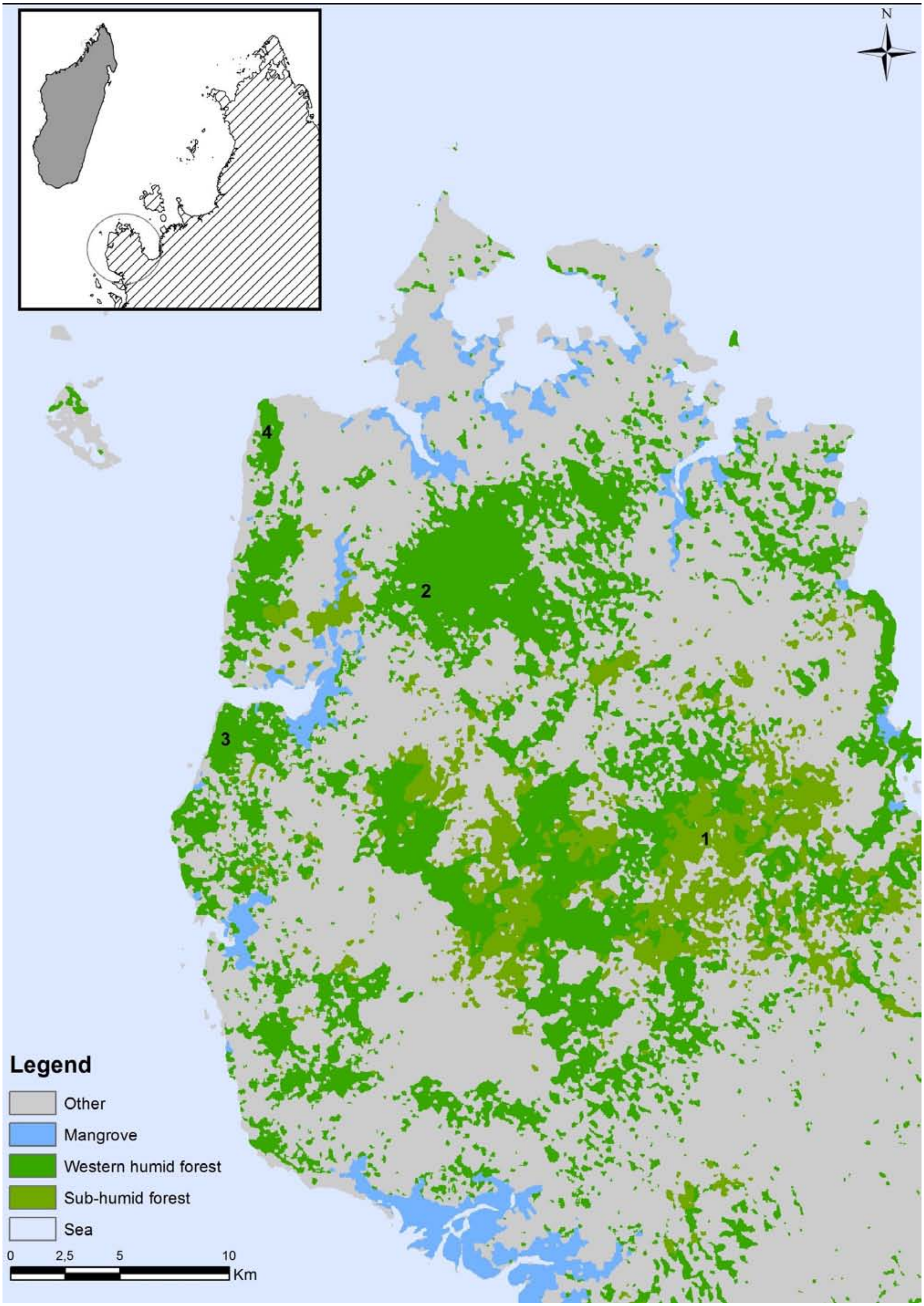


**Figure 1.** Representation of the four sites (numbers) studied on the Ampasindava peninsula in northwest Madagascar. (ArcMap 10.1)

be mostly solitary (Andriaholinirina *et al*. 2006; Dröscher and Kappeler 2014; Thalmann 2001; Zinner *et al*. 2003; Seiler 2012).

Concern for the conservation status of sportive lemurs had long been expressed, in spite of their supposed large range and occasional local abundance, because of the fragmented distributions and severe threats to many isolated populations, risk factors which increase with the current intensification of deforestation and habitat degradation (Ganzhorn *et al*. 2000; Harper *et al*. 2007; Schneider *et al*. 2010). The new understanding of the diversity of the genus has considerably increased this concern as most species are now known to have very small, shrinking and fragmenting ranges and, probably for some of them, small total populations (Schwitzer *et al*. 2013). A 2012 assessment evaluated five species as Critically Endangered, 17 as Endangered, and four as vulnerable. Effective conservation actions are thus urgently needed to preserve viable populations of each species. To define and guide these actions, a minimum understanding of the limits of the area of distribution, of the habitat requirements, and of the behaviour and population size of the target species are required.

Our fieldwork addresses one of the least known, endangered species, *Lepilemur mittermeieri*. *Lepilemur mittermeieri* was described from the Ampasindava peninsula on the basis of tissue samples from three specimens for which karyotypes and mitochondrial cytochrome b DNA sequences were obtained (Rabarivola *et al*. 2006). At the time of the description no indication of presence of the taxon outside of the type locality was known. No morphological description, and no eco-ethological data accompany the description. Mittermeier *et al.* (2010) provided some more information on *Lepilemur mittermeieri*. They suggested that the species was limited to the Ampasidava peninsula and was the only *Lepilemur* on the peninsula. They gave indications on the field appearance of the species, basing their description on unpublished observations by Edward Louis. They did not, however, indicate whether and how it had been ascertained that the animals seen by Louis belonged to the same taxon as the type of *L. mittermeieri*. Recently new data on the abundance of "*L. mittermeieri*" were provided by Ralantoharijaona *et al.* (2014). In this case it is clear that identification rested on geographical probability, not on comparison with the type of the species. No other data appear to have been published on the taxon, which is classified as Endangered (IUCN 2014).

Forest fragmentation proceeds at a fast rate on the Ampasindava peninsula (Ranirison *et al.* 2014), the presumed area of distribution of the species. Measures to help the species may be found to be a priority in the conservation strategy defined for the area in collaboration with the "Managed Resources Protected Areas" project of the UNDP (United Nations Development Programme) and the GEF (Global Environment Fund) (Ranirison *et al.* 2014). Rapid surveys are thus essential to immediately improve our knowledge of the species. The objectives of this first field investigation in several forest patches of the northern part of the Ampasindava peninsula were:

1) to confirm that the sportive lemurs found in forests of the Ampasindava peninsula beyond the type locality of *Lepilemur mittermeieri* belonged to the same species as the type;

2) to provide first data on appearance and measurements of individuals of known genetic identity;

3) to assemble eco-ethological data for populations safely attributed to *L. mittermeieri*, with a first emphasis on forest characteristics in area of occupancy, social behaviour and selection of sleeping sites and fidelity to these sites; and

4) to obtain for populations safely attributed to *L. mittermeieri* preliminary evaluations of density variations in the peninsula.

## Methods

*Study area*

The Ampasindava peninsula is located in northwest Madagascar (Fig. 1), between 13°40'40.0" and 13°40'60.0" latitude and 47°58'40.0" and 47°58'30.0" longitude, in the southwestern part of the Ambanja district, along the Mozambique Channel, and belongs to the Diana region. The peninsula is included in the Sambirano domain, which is characterized by an average yearly precipitation of 2000–2500 mm, most of it (95%) falling during the hot season (Ranirison *et al*. 2014). Humidity level is always high, and the average annual temperature is near 26°C with low seasonal variation. The mean maximum temperature is about 34°C, the mean minimum temperature about 13°C. Because of the topography of the area, the climate of the Sambirano region is more similar to that of the east coast of Madagascar than to that of other areas of the west coast and can be considered as hot and humid/subhumid (Ranirison *et al.* 2014). The forest cover of the peninsula is highly fragmented because of human activities and the remaining forest patches are under varying levels of anthropic pressure and disturbance. Four main types of vegetation can be distinguished in the Ampasindava peninsula: 1) secondary formations (grassland or culture), 2) subhumid forests, 3) dense humid forests and 4) mangroves (Ranirison *et al*. 2014).

We investigated four patches of forest, selected to provide a spectrum of size, location (central or coastal) (Fig. 1) and habitat types. Sites 1 and 2 (Fig. 1) are located on mountains (site 1 on Andranomatavy mountain, site 2 on Ambohimirahavavy mountain) where vegetation is classified as dense humid forest (Ranirinson *et al*. 2014). Their precise locations are respectively 13°40'26.8"S, 47°58'00.3"E and 13°45'54.5"S, 48°05'40.7"E. They can be considered high-elevation sites as the altitude can reach more than 550 m. Sites 3 and 4 (Sorony forest) are at low elevation (no higher than 300 m), near the coast, in subhumid forest (Fig. 1). Their precise locations are respectively 13°43'53.5"S, 47°52'41.2"E and 13°35'46.7"S, 47°53'42.4"E. The sizes of the four forest patches were estimated at 882 ha (site 1), 1683 ha (site 2), 167 ha (site 3) and 168 ha (site 4).

### *Field observations*

Field observations on presence, distribution, appearance and behaviour of sportive lemurs in the Ampasindava peninsula took place in April 2013. Recces were conducted in four patches of forest to confirm the presence of the species. Once presence of sportive lemurs was confirmed in a forest patch, sportive lemur populations were surveyed using a line-transect method (Buckland *et al*. 2001; Quéméré *et al*. 2010; Ibouroi *et al*. 2013; Sabin *et al*. 2013). We conducted a total of nine line transects: 1 in site 1, 3 in site 2, 2 in site 3, and 3 in site 4. The total of line transects and the number per site varied for logistical reasons. The nine line transects represent a total length of 18.45 km. Individual transect lengths varied from 380 m to 1260 m (Table 1). Some transects were set up along existing trails in the forest and we opened new trails for others. Each transect was marked every 20 m by a biodegradable flag. Censuses were conducted at night by three observers walking together and operating on three consecutive nights (two nights for one of the transects). The entire length of the transect was covered each night. Night observations began around 18:00 and lasted for at least 2 hours. During the survey, team members walked slowly along each transect (around 0.5 km/h) and lemurs were detected by their eyeshine reflecting the headlamp and/or by their vocalizations. Once an animal was visually detected, the use of a powerful hand torch allowed us to confirm generic identification. For each observation we recorded GPS point, time, position of the animal on the tree, as well as its location in relation to the transect (perpendicular distance), as described by Buckland *et al*. (2001), Randrianambinina *et al*. (2010) and Meyler *et al*. (2012). During the survey, we also performed focal observations (Altmann 1974) of 1-minute/animal (when it did not move) to collect data on behaviour (Resting/Vigilance/Feeding/Locomotion/Interaction with other animals). Recces were also carried out during the day in order to locate sleeping sites of the species. The observers looked for trees with holes and checked for occupation by sportive lemur. Once a sleeping site was found, we recorded GPS point, elevation, tree height, diameter of the tree at breast height (DBH), height of the sleeping site, classification of the canopy (open/half-open/closed). The tree species involved was provisionally indicated by a vernacular name provided by Malagasy guides, completed when possible by a generic allocation obtained by reference to the key of Schatz (2001). We collected herbarium material to confirm our identification at Tsimbazaza Botanical Garden in Antanananarivo.

Animals encountered during night surveys or sighted during the day in their sleeping sites were examined at close range. We were able to take high quality pictures of seven individuals. Four animals were photographed at roost sites during the day in natural light (camera Fujifilm FinePixe S2950); two were photographed at night with a flash. The seventh individual was a dead sportive lemur that had been recently killed. On this animal we also collected morphometric data and two tissue samples (hair and ear clip). Eco-ethological data on the *Lepilemur* seen were recorded both during night transects and in day searches for roosts.

### *DNA analyses*

In order to relate the animals observed to the type of *L. mittermeieri*, we conducted a DNA analysis on tissue samples obtained from the dead animal found in the study area. We extracted genomic DNA from both tissue samples (the ear clip and hair) using the NucleoSpin Tissue Kit (Macherey-Nagel). A fragment of the 5'-end of the mitochondrial cytochrome b (cytb) marker was amplified using the primers L14723 (Ducroz *et al*. 2001) and H15149 (Kocher *et al*. 1989 modified by Carr and Marshall 1991) in a 25 µl PCR reaction containing final concentrations of 0.2 mM dNTPs, 0.4 µM of each primer, 1.5 mM MgCl2, 0.75 U of Taq DNA polymerase (Platinum, Invitrogen), 1X PCR buffer and 1.5 µl DNA template. The thermal cycler program consisted of an initial denaturation step of 4 min at 94°C, followed by 40 cycles of 30 s at 94°C, 30 s at 49°C and 90 PCR Kit (Macherey-Nagel) and sequenced them on an ABI 3130 Genetic Analyzer (Applied Biosystems) using the BigDye Terminator Cycle Sequencing Kit v.3.1. We checked that the DNA sequences obtained for the two samples were identical. Using Mega v.6.06. (Tamur *et al*. 2013), we calculated genetic pairwise p-distances (proportion of nucleotide sites at which two sequences differ) between our new sequences and each cytochrome b sequence available in GenBank for the genus *Lepilemur*.

### *Abundance evaluation 1. Relative density evaluation*

We calculated a relative index of abundance which permits a rough comparison between the forest patches we investigated, and which will, with due precautions, enable us to compare the peninsular forests with ones we will sample in other areas. For each transect, we calculated a KIA (*Kilometric Index of Abundance*) (Ferry and Frochot 1958; Mathot and Doucet 2006; Poilecot 2009), with:

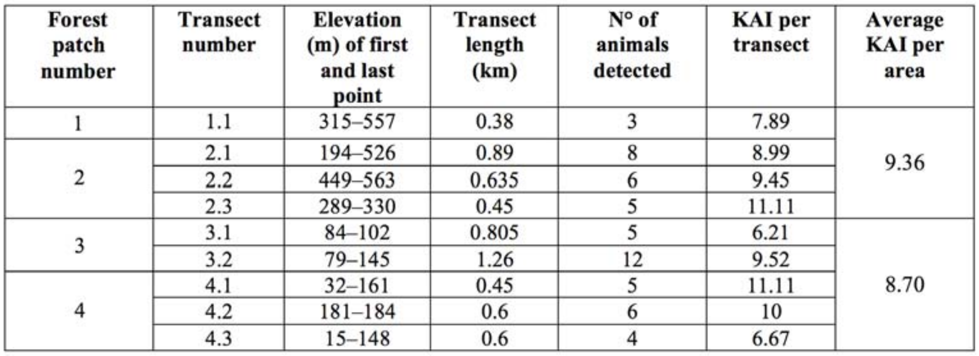
$$KIA = n \div l$$

where $n$ is the number of individuals observed along the transect and $l$ the length of the transect. Each transect was covered three times (twice for one of them). We compared two methods for estimating $n$. One of them is the classical one, which retains the highest number detected on one passage (Ferry and Frochot 1958). It is the best suited for relatively mobile animals such as temperate forest birds, sampled at relatively long intervals. In our case, however, we tried to exploit the small home range and the site fidelity of sportive lemurs as well as the short intervals between our passages.

We combined the results of the three passages on a transect, using precise location to identify successive records of the same animal. This yields of course a higher value for $n$.

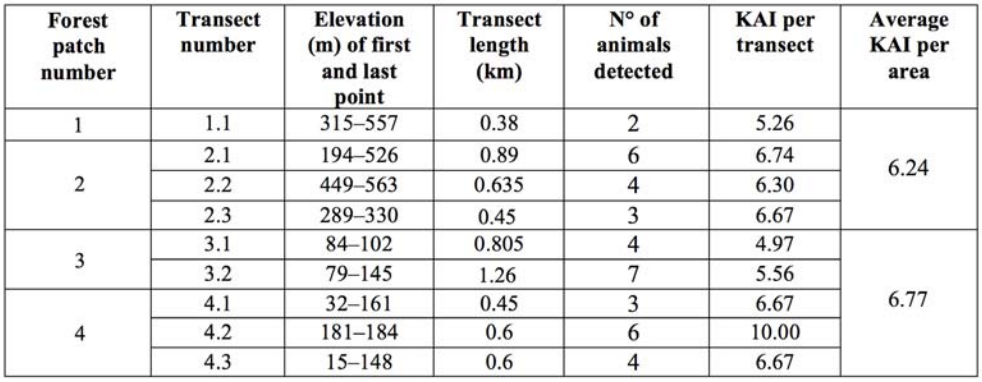
We further calculated KIAs for whole forest patches, by averaging the KIAs obtained for all transects conducted within the patch. For this exercise we combined the two

**Table 1a.** Transect characteristics, number of *Lepilemur* detected by combination of the three passages, KIA (Kilometric Index of Abundance) per transect, average KIA per site at high and low elevation.



| Forest patch number | Transect number | Elevation (m) of first and last point | Transect length (km) | N° of animals detected | KAI per transect | Average KAI per area |
|---|---|---|---|---|---|---|
| 1 | 1.1 | 315–557 | 0.38 | 3 | 7.89 | 9.36 |
| 2 | 2.1 | 194–526 | 0.89 | 8 | 8.99 | |
| | 2.2 | 449–563 | 0.635 | 6 | 9.45 | |
| | 2.3 | 289–330 | 0.45 | 5 | 11.11 | |
| 3 | 3.1 | 84–102 | 0.805 | 5 | 6.21 | 8.70 |
| | 3.2 | 79–145 | 1.26 | 12 | 9.52 | |
| 4 | 4.1 | 32–161 | 0.45 | 5 | 11.11 | |
| | 4.2 | 181–184 | 0.6 | 6 | 10 | |
| | 4.3 | 15–148 | 0.6 | 4 | 6.67 | |

**Table 1b.** Transect characteristics, highest number of *Lepilemur* detected in one passage KIA (Kilometric Index of Abundance) per transect, average KIA per site at high and low elevation.



| Forest patch number | Transect number | Elevation (m) of first and last point | Transect length (km) | N° of animals detected | KAI per transect | Average KAI per area |
|---|---|---|---|---|---|---|
| 1 | 1.1 | 315–557 | 0.38 | 2 | 5.26 | 6.24 |
| 2 | 2.1 | 194–526 | 0.89 | 6 | 6.74 | |
| | 2.2 | 449–563 | 0.635 | 4 | 6.30 | |
| | 2.3 | 289–330 | 0.45 | 3 | 6.67 | |
| 3 | 3.1 | 84–102 | 0.805 | 4 | 4.97 | 6.77 |
| | 3.2 | 79–145 | 1.26 | 7 | 5.56 | |
| 4 | 4.1 | 32–161 | 0.45 | 3 | 6.67 | |
| | 4.2 | 181–184 | 0.6 | 6 | 10.00 | |
| | 4.3 | 15–148 | 0.6 | 4 | 6.67 | |

lowland patches (five transects) on the one hand, the two highland patches (four transects) on the other.

*Abundance evaluation 2. Absolute density evaluation*

We analysed surveys from line transects with distance sampling, a widely used technique for estimating the size or density of populations (Thomas *et al*. 2010; Bouché *et al.* 2012), including lemurs (Quéméré *et al*. 2010; Ibouroi *et al.* 2013; Meyler *et al.* 2012; Axel and Maurer 2011; Salmona *et al.* 2014). We used the Buckland method (Buckland *et al.* 2001) for which the probability of detecting an animal decreases as its distance from the transect increases. This model evaluates the effective strip width (ESW) with a function of detection based on the perpendicular distance of the detected animal to the transect. Several functions can be used, and we tested here four detection models (hazard rate cosine, hazard rate simple polynomial, half-normal cosine and half normal simple polynomial function) and compared them using the Akaike Information Criterion (AIC) and the goodness-of-fit as recommended by Buckland *et al.* (2001). This method is implemented in the DISTANCE 6.0 program and calculates the final density (D) in function of the ESW, the total number of observations (Nt) and the total length of the transects (Lt).

$$D = Nt \div 2.\ ESW.\ Lt$$

The method assumes an even distribution of the target species in the area sampled and an equal probability of detection on each transect. Thus, successive passages on a same transect can be treated in the same way as passages on distinct transects (Buckland *et al.* 2001). Furthermore, all patches were combined as the patch-specific samples were too small to highlight differences between patches. This research complied with protocols approved and adhered to the legal requirement of Madagascar's Association Nationale pour la Gestion des Aires Protégées.

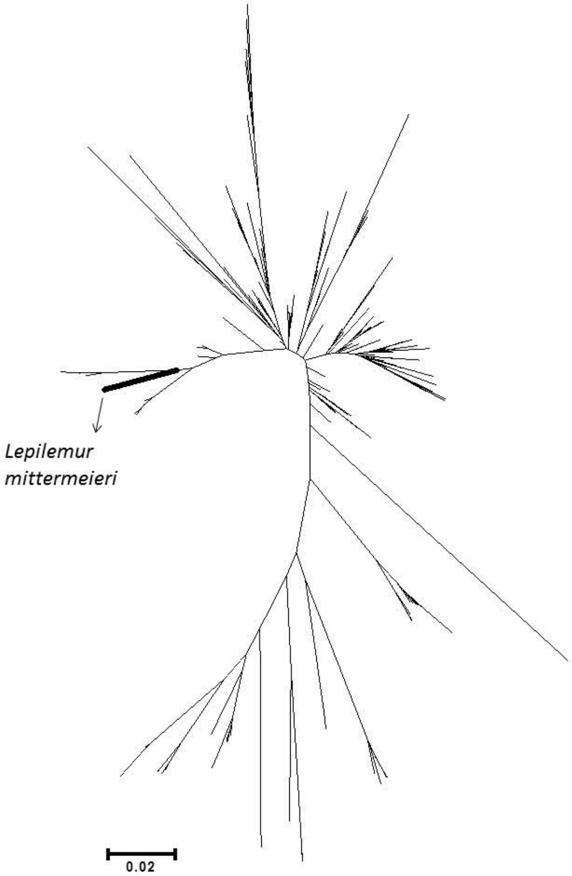


**Figure 2.** Unrooted neighbour-joining tree based on pairwise p-distances among all cytochrome *b* sequences available for the genus *Lepilemur* in GenBank.

## Results

### *Habitat*

All forest patches investigated on the Ampasindava peninsula are multistrata forests in which the tallest trees are 23 to 27 m high. The forests of sites 1 and 2 are on slopes, the upper canopy is more closed and darker than in the other patches, and the lower strata are less dense. The forests of sites 3 and 4 have high densities of small tress and, in places, much bamboo (*Nastus* sp.). Sportive lemurs shared their habitat with other lemur species. Four species, *Eulemur macaco*, *Mirza zaza*, *Avahi unicolor* and *Phaner parienti*, were seen during the course of the study.

### *Sportive lemur sightings*

We found sportive lemurs in every forest patch visited. Between transects, diurnal recces and the finding of one dead animal (13°45'41.6"S, 048°07'14.1 E"), we saw altogether 60 different individuals of sportive lemurs. Seven sleeping sites of *Lepilemur* were found. The majority (5 of 7) of those sleeping sites were located in site 1. Four tree species used as sleeping sites belonged to the family Hamamelidaceae (Table 2). Our observations showed that some animals were using the same sleeping site several nights in a row while others, seen one day were not seen the next day.

### *Morphological description of sportive lemurs observed*

Field descriptions of animals seen and examination of photographs reveal no visible differences between individuals observed within a forest patch nor between those found in the four patches. All animals had a brown back with a dark brown to black midline stripe occasionally present from the head to the lower back, and a lighter grey belly. The tail was usually of the same colour as the back and dark brown to black toward the tips. The face was dark grey and mask-like with a whiter area under the mandible. The spectrum of individual variation did not notably diverge from the description provided by Mittermeier *et al.* (2010), and was not particularly broad for a sportive lemur so that there is no reason to think that more than a single taxon was involved in all our sightings on the peninsula. The finding of the dead animal (male) allowed us to verify pelage coloration in daylight at close range. Head-body length and tail length measured on this individual were 27.6 cm and 26.5 cm, respectively. These morphometric measures are within the size interval given by Mittermeier *et al*. (2010) and Mittermeier (2013).

### *Behaviour of sportive lemurs observed*

We observed pairs of sportive lemurs standing peacefully close together or foraging in the same tree several times. We also observed several bouts of agonistic behaviour which could be interpreted as defence of territory and/or mate.

### *DNA analysis*

The two cytb DNA sequences obtained here for two samples of the same animal (GenBank accession number: BankIt2063930 AB42612496 MG551578) are identical to all three cytb sequences of *Lepilemur mittermeieri* already available in GenBank (Rabarivola *et al*. 2006). Their interspecific p-distances with the other sequences of *Lepilemur* range from 3.9 to 16.6% and therefore, the position of *Lepilemur mittermeieri* is well distinct from the other *Lepilemur* species in the neighbor-joining tree constructed with the cytb marker (Fig. 2).

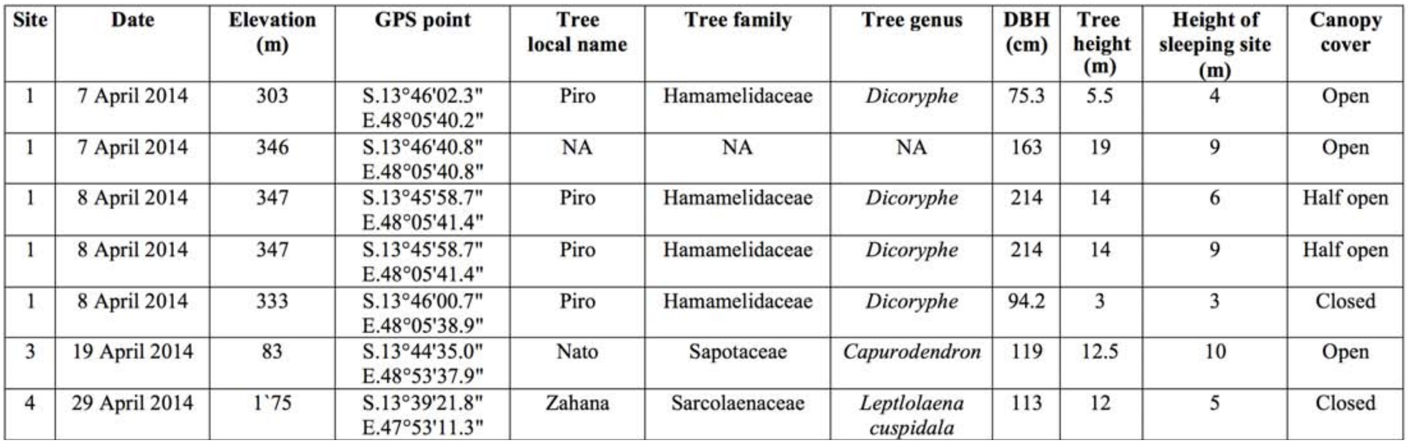
### *Density evaluation 1. Relative density evaluation*

Table 1a and Table 1b summarize the relative abundance data obtained for the nine transects, expressed as KIAs calculated by the two methods. Differences between transects are relatively small in both cases. The average KIAs for sites at high elevation (KIA = 9.36 with our method and KIA= 6.24 with the classical method) and sites at low elevation, (KIA = 8,7 with our method and KIA = 6.77 with the classical method) are also quite similar when our method is used and almost equal when the classical method is used. It thus appears that the density of sportive lemurs in the patches investigated is quite uniform.

### *Density evaluation 2. Absolute density evaluation*

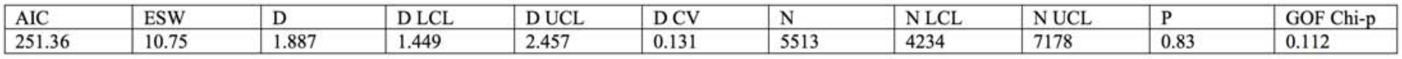
The number of observations per transect and per forest patch is too low to apply with any confidence the distance

**Table 2.** Characteristics of sleeping sites of sportive lemurs, *Lepilemur mittermeieri*, on the Ampasindava peninsula.



| Site | Date | Elevation (m) | GPS point | Tree local name | Tree family | Tree genus | DBH (cm) | Tree height (m) | Height of sleeping site (m) | Canopy cover |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7 April 2014 | 303 | S.13°46'02.3"<br>E.48°05'40.2" | Piro | Hamamelidaceae | *Dicoryphe* | 75.3 | 5.5 | 4 | Open |
| 1 | 7 April 2014 | 346 | S.13°46'40.8"<br>E.48°05'40.8" | NA | NA | NA | 163 | 19 | 9 | Open |
| 1 | 8 April 2014 | 347 | S.13°45'58.7"<br>E.48°05'41.4" | Piro | Hamamelidaceae | *Dicoryphe* | 214 | 14 | 6 | Half open |
| 1 | 8 April 2014 | 347 | S.13°45'58.7"<br>E.48°05'41.4" | Piro | Hamamelidaceae | *Dicoryphe* | 214 | 14 | 9 | Half open |
| 1 | 8 April 2014 | 333 | S.13°46'00.7"<br>E.48°05'38.9" | Piro | Hamamelidaceae | *Dicoryphe* | 94.2 | 3 | 3 | Closed |
| 3 | 19 April 2014 | 83 | S.13°44'35.0"<br>E.48°53'37.9" | Nato | Sapotaceae | *Capurodendron* | 119 | 12.5 | 10 | Open |
| 4 | 29 April 2014 | 1`75 | S.13°39'21.8"<br>E.47°53'11.3" | Zahana | Sarcolaenaceae | *Leptlolaena cuspidala* | 113 | 12 | 5 | Closed |

**Table 3.** Results obtained with DISTANCE; the Akaike Information Criterion (AIC), the Effective Strip Width (ESW), the density (D), the density of individuals analytic lower confidence limit and upper confidence limit (D LCL and D UCL), the density of individuals analytic coefficient of variation (D CV), the total number of animals for the area (N), the number of individuals analytic lower confidence limit and upper confidence limit (N LCL and N UCL), the probability of detection (P) and the Goodness-of-fit chi-square test probability (GOF Chi-p) of the analysis with the DISTANCE Software.



| AIC | ESW | D | D LCL | D UCL | D CV | N | N LCL | N UCL | P | GOF Chi-p |
|---|---|---|---|---|---|---|---|---|---|---|
| 251.36 | 10.75 | 1.887 | 1.449 | 2.457 | 0.131 | 5513 | 4234 | 7178 | 0.83 | 0.112 |

sampling method of Buckland *et al*. (2001). As the relative density is fairly constant over the whole area investigated, however, it appears legitimate to apply the approach to the entire set of data, regarding each passage on a transect as a sample. This yields 69 observations for a total survey effort of 17,010 m. Table 3 summarizes the results obtained with the DISTANCE software. The estimated density is 1.9 animals/ha, with a 95% Confidence Interval situated between 1.5 and 2.5 animals/ha.

## Discussion

This preliminary investigation on the Ampasindava peninsula shows sportive lemurs (genus *Lepilemur*) to be fairly uniformly present in at least some of the remnant forest patches of the peninsula. It also indicates that a single taxon appears to be present on the peninsula. Detailed morphological analysis of seven individuals, and additional observations of about 45 others are consistent with their identification as *L. mittermeieri*. Genetic analysis of one individual has revealed a DNA sequence that corresponds to the sequence regarded as diagnostic of *L. mittermeieri* in the original description of the species. There is thus no reason not to accept that the type of *L. mittermeieri* belongs to the populations we have observed and thus that these can be called *L. mittermeieri*. *Lepilemur mittermeieri* is therefore the species present on the Ampasindava peninsula.

Sportive lemurs were sighted in the same habitat as other lemurs. This cohabitation between several species of lemurs is frequent (Mittermeier *et al.* 2010; Seiler 2012). A notable characteristic of the sportive lemur populations we observed is the relatively low number of sleeping sites discovered compared to the total number of animals observed. This result could be explained by the choice for sleeping sites of high locations or dense tangles of branches instead of tree holes situated at moderate heights, commonly noted for other species (Rasoloharijaona *et al*. 2008; Seiler *et al*. 2013). We also saw several pairs of *L. mittermeieri.* Observation of pairs is rare in *L. sahamalazensis* but has been reported for *L. ruficaudatus* (Zinner *et al*. 2003; Hilgartner 2006) and *L. edwardsi* (Seiler 2012; Thalmann 1998). Our observations, collected during a relatively short time span, could simply reflect a chance coincidence between the mating season and the time of our survey, or it could represent a specific behavioural trait, longer pair-bond, mother and offspring association, animals of either sex associating in relation to food resource availability.

Our figure of estimation with DISTANCE is fairly similar to, but apparently somewhat higher than, the 1.33 animals/ha published by Ralantoharijaona *et al*. (2014). Their results were obtained in 2010 in two forest patches situated in the eastern half of the Ampasindava peninsula. They are analysed with the same algorithm as ours but as their number of observations (26) is even lower than ours and well below the 40 required by DISTANCE, not too much reliance can be placed on a comparison of the two estimates. If the area investigated is representative of all forest areas remaining on the peninsula, estimated at 43,702 ha (Ranirison at al. 2014), the density figures we calculated would correspond for the Ampasindava sportive lemur to a total population of the order of ten thousand animals. This estimate needs however to be taken with extreme caution, as only a very small area has been surveyed and as the distance sampling methodology is of limited reliability.

Additional investigations are still needed to improve our knowledge of this understudied species occurring in fragmented and continuously contracting forest patches. In particular, it is urgent to assemble data on home ranges, sleeping sites, and feeding behaviour of *L. mittermeieri*. The links between these eco-ethological parameters and forest characteristics need to be investigated to ascertain whether forest quality and maturity affect sportive lemurs. Better understanding of habitat use by this species is necessary in order to design guidelines for a conservation strategy in the area. Our preliminary results do confirm that the Ampasindava peninsula must be considered a priority area for Malagasy conservation.

## Acknowledgements

We thank the Ministère de l'Environnement et des Eaux et Forêts and the Madagascar National Parks (MNP) for their permission to conduct this study. We are thankful to the staff of the Department of Paleontology and Biological Anthropology of Antananarivo University for their collaboration and for the field assistance of Simon Razafindramoana. We thank Managed Resources of Protected Area (MRPA) and Missouri Botanical Garden (MBG). We thank Mr. Urbain and Mme Lucie for their precious help and all the field team members; Justin, Cyril and Mr. Parfait Dimbiraza. This field mission was possible thanks to grants and funding from Fondation Leopold III, AEECL, Nature +, Mohamed Bin Zayed Fund, FNRS-FRIA, and Liege University – Gembloux Agro-Bio Tech.

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# A New *Cheirogaleus* (Cheirogaleidae: *Cheirogaleus crossleyi* Group) Species from Southeastern Madagascar

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**Abstract:** A new species in the genus *Cheirogaleus* is described from Ranomafana and Andringitra national parks, Madagascar. Ranomafana National Park is a rainforest situated in a montane region, and Andringitra National Park is comprised of grassland, lowland and highland forests displaying great altitudinal variation. Both parks are known to harbor wide species diversity in flora and fauna. Genetic and morphometric analyses of the samples collected at these localities confirmed that this *Cheirogaleus* lineage represents a new species in the *C. crossleyi* group, and here we elevate it to species status as *Cheirogaleus grovesi*, for the British-Australian biological anthropologist, evolutionary biologist and taxonomist Colin Groves.

**Key Words:** *Cheirogaleus,* dwarf lemur, cryptic species, Madagascar

## Introduction

Dwarf lemurs, genus *Cheirogaleus*, are small, arboreal primates that are opportunistic omnivores subsisting largely on fruit. This genus has the ability to store fat in the tail to survive lean periods during the austral winter (Dausmann *et al*. 2005; Mittermeier *et al.* 2010). Previously unknown species diversity was identified in *Cheirogaleus* through extensive fieldwork coupled with molecular analyses (Lei *et al.* 2014 2015; Frasier *et al.* 2016). Seven new species ("confirmed candidate species" or "CCS"), and four possible new species ("unconfirmed candidate species" or "UCS") were proposed by Lei *et al.* (2014). Elaborating on these publications, we describe here a new *Cheirogaleus* lineage endemic to southeastern Madagascar based on samples collected in and around the national parks of Ranomafana and Andringitra. These two parks are part of the Rainforests of Atsinanana UNESCO World Heritage Site (IUCN Technical Evaluation/UNESCO Designation; <http://whc.unesco.org/en/list/1257>).

Ranomafana National Park, established in 1991, is a rainforest reserve of approximately 43,500 ha located in the Haute Matsiatra and Vatovavy-Fitovinany regions of Madagascar (Wright and Andriamihaja 2002; Gerber *et al.* 2010). The park is largely submontane rainforest and is crisscrossed by at least 29 rivers of varying sizes. The largest of these rivers, the Namorona, runs alongside Route National 25 and bisects the park. Ranomafana is 400–1374 m above sea level, and receives about 2600 mm of rainfall annually (Razafimamonjy 1988; Jenkins *et al.* 1999; Gerber *et al.* 2010). The park is home to rich species diversity, including 13 species of lemur—genera known to be present include *Avahi*, *Cheirogaleus*, *Daubentonia*, *Eulemur*, *Hapalemur*, *Lepilemur*, *Microcebus*, *Prolemur*, *Propithecus*, *and Varecia* (see Wright *et al*. 2012).

The Andringitra area was recognized by early naturalists for its unique geographic and biological characteristics and declared a strict nature reserve in 1927 (Rabetaliana and Schachenmann 1999; Rabetaliana *et al.* 1999). Andringitra National Park was established in 1999 and consists of approximately 31,160 ha of grassland, lowland rainforests, and higher elevation forests, as well as granite outcroppings of Precambrian rock at 500–2600 m above sea level (Rabetaliana *et al.* 1999). Andringitra is home to either 12 or 13 species of lemur—genera known to be present include *Avahi*, *Cheirogaleus*, *Daubentonia*, *Eulemur*, *Hapalemur*, *Lemur*, *Lepilemur*, *Microcebus*, *and Propithecus* (*Varecia* was formerly present but has not been recently reported and may be locally extinct) (Goodman and Rasolonandrasana, 2001; Mittermeier *et al.* 2010). Of these lemurs, the rufous mouse lemur

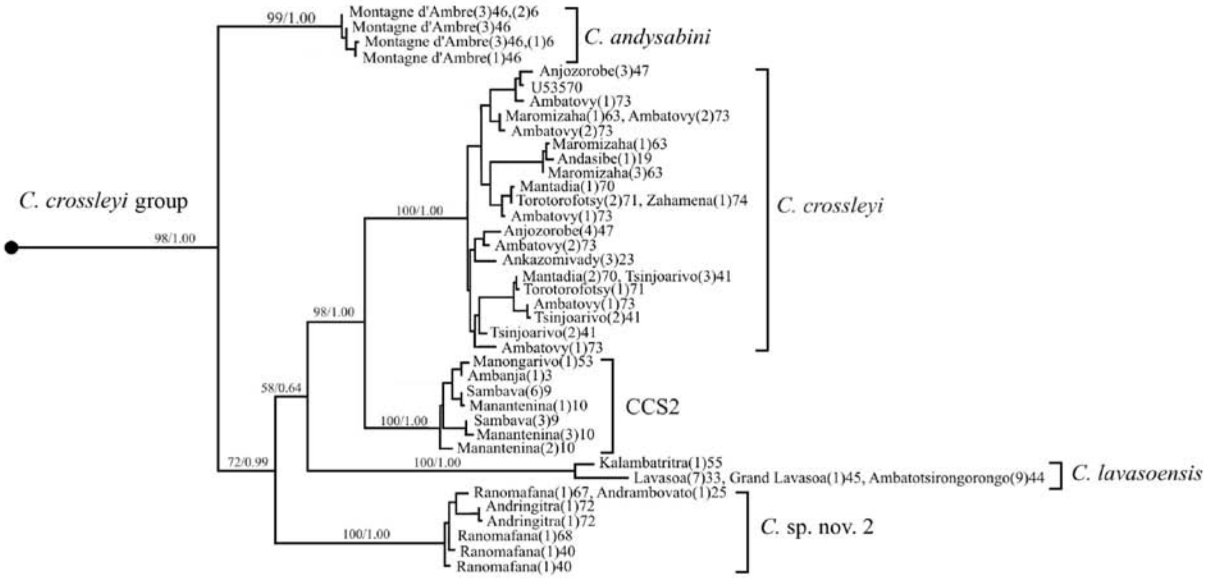

**Figure 1.** Subtree of the phylogenetic relationships between taxa within the *Cheirogaleus crossleyi* group based on cyt*b* sequence data as presented in Lei *et al.* (2014; Fig. 2). Numbers on branches represent maximum likelihood values followed by posterior probability support. Tip labels include locality, followed by number of individuals carrying the haplotype in brackets, then the locality numbers.)

**Figure 2.** Illustration of *C.* sp. nov. 2 and closely related species (Fig. 8 in Lei *et al*. 2014), Illustrations by Stephen D. Nash ©Conservation International. Photographs by Edward E. Louis, Jr. Top left panel represents *C. grovesi*. Top left panel represents a lateral view of *C.* sp nov. 2, top right panel includes all lineages in the *Cheirogaleus crossleyi* group. Bottom photographs are of the holotype of *C.* sp. nov. 2 (TRA8.81) at Andringitra National Park.

(*Microcebus rufus*) is found in the Andringitra area and north along a higher-elevation corridor to Ranomafana National Park, and it is possible that the newly identified *Cheirogaleus* occupies a similar range. The corridor between these areas is within the newly created protected area Corridor Forestier Fandriana-Vondrozo (CoFAV, 2015).

In 1999, a dwarf lemur from Ranomafana (RANO229) was immobilized to acquire morphometric data and genetic samples, and was determined to be *Cheirogaleus major* (E. E. Louis Jr. pers. comm.). Subsequently, samples from RANO229 were used as an outgroup in multiple genetic studies (Louis *et al.* 2006; Johnson *et al*. 2008). Groeneveld *et al*. (2009) were the first to incorporate this individual into a genetic study specific to *Cheirogaleus*. In this study, using mitochondrial sequence data, they demonstrated that RANO229 (GenBank accession: AY58448) was not *C. major*, but belonged to the *C. crossleyi* group in a subclade with an individual from Andrambovato/Oranjatsy (RMR146). Interestingly, RMR146 morphologically grouped with *C. major*, which the authors attributed to the possibility of hybridization (Groeneveld *et al.* 2009), lending credence to the initial field identification of RANO229. The Ranomafana-Andrambovato subclade inside the *C. crossleyi* group was recovered again in a study with additional Ranomafana samples (MB210, MB217) and morphometric data (Groeneveld *et al*. 2010); RANO229 was not included in this study. Thiele *et al.* (2013) proposed tentative species status for this lineage, identified as *C.* sp. Ranomafana Andrambovato in their analyses, which included MB210, MB217, and RMR146. Building on these works, Lei *et al.* (2014) expanded the genetic dataset for this proposed lineage with the inclusion of additional individuals from Ranomafana, which clustered with individuals from Andringitra National Park (Fig. 1). This Ranomafana-Andringitra clade was designated as *Cheirogaleus* sp. nov. 2 (Lei *et al.* 2014).

Here we describe a new species of dwarf lemur from the Haute Matsiatra region of Madagascar along the CoFAV based on specimens collected in and around the national parks of Ranomafana and Andringitra.

## Methods

### *Sampling and morphology*

See Lei *et al.* (2014) for a comprehensive list of localities and numbers of individuals that were represented in the most recent genus-wide study of *Cheirogaleus*. Here, we will only enumerate those belonging to the *C. crossleyi* group (Table 1). From the focal lineage, *C.* sp. nov. 2, two individuals from Ranomafana National Park and two individuals from Andringitra National Park were immobilized by the field team from the Madagascar Biodiversity Partnership (MBP; Table 2, Fig. 2). Morphometric measurements taken on sedated lemurs were recorded as in Louis *et al*. (2006) and Andriantompohavana *et al.* (2007). All lemurs were released at the point of capture. Interactions with the study subjects abided by Omaha's Henry Doorly Zoo and Aquarium's IACUC (97-001, 12-101), and all collection and export permits were obtained from the appropriate authorities in Madagascar and the United States, respecting the Convention for International Trade in Endangered Species (CITES).

### *Data generation and phylogenetic analyses*

Methods used to identify this new species were presented in the "Methods" section of Lei *et al.* (2014). Briefly, extracted genomic DNA taken from safely immobilized animals was subjected to a series of wet bench and computational analyses (Table 1). The mitochondrial regions analyzed were: Cytochrome *b* (cyt*b*) (Irwin *et al.* 1991); Cytochrome oxidase subunit II (COII) (Adkins and Honeycutt 1994); the displacement loop or control region (D-loop) (Baker *et al.* 1993; Wyner *et al.* 1999); a fragment of the cytochrome oxidase subunit III gene (COIII); NADH-dehydrogenase subunits 3, 4L, and 4 (ND3, ND4L, and ND4); as well as the tRNA$^{Gly}$, tRNA$^{Arg}$, tRNA$^{His}$, tRNA$^{Ser}$, and partial tRNA$^{Leu}$ genes (PAST) (Pastorini *et al*. 2000). Three nuclear loci were also sequenced: alpha fibrinogen intron 4 (FIBA), von Willebrand Factor intron 11 (vWF) and Cystic Fibrosis Transmembrane conductance (CFTR-PAIRB) (Heckman *et al*. 2007; Horvath *et al.* 2008). All genetic data were analyzed using Maximum Likelihood (ML) and Bayesian phylogenetic analyses, and subjected to a battery of tests to examine the strength of the results (Lei *et al*. 2014). Phylogenetic trees were constructed based on these analyses and used to evaluate genetic divergence between lineages (Lei *et al.* 2014). Additionally, a Bayesian species delimitation analysis was performed using the bPTP webserver (http://species.h-its.org; Zhang *et al.* 2013) as in Lei *et al.* (2015). Use of species delimitation methodology without additional corroborative work has acknowledged limitations (Markolf *et al.* 2011). In the case of this *Cheirogaleus* group the bPTP species delimitation is presented as additional evidence of our assertion that this group constitutes a new species.

## Results

### *Morphology*

Morphological data were available for three individuals of *C.* sp. nov. 2: one adult male and one adult female from Andringitra, and one adult female from Ranomafana (Table 3). A juvenile from Ranomafana was excluded from the morphological data. The average weight of *C.* sp. nov. 2 was 0.453 kg.

### *Phylogenetic Analyses*

In the cyt*b* sequence fragments, *C.* sp. nov. 2 differs from its closest genetic relatives in Lei *et al.* (2014) (*C. andysabini*, *C. lavasoensis* and *C. crossleyi*) in genetic distance by 6.3%±0.7%, 8.2%±0.7% and 6.5%±0.7%, respectively (Fig. 1). *Cheirogaleus* sp. nov. 2 is sympatric in the northern part of its range with *C. sibreei* and CCS5, a yet-to-be described species in the *C. major* group. The new species described

**Table 1.** Wild *Cheirogaleus* individuals sampled for this study. IDs correspond to Figure 2 and Figure 5 of Lei *et al.* (2014), except fr the samples from Thiele *et al*. 2013 (denoted at the bottom of the table).

| ID | Species Designation | Location | Latitude | Longitude |
|---|---|---|---|---|
| AMB5.22 | *C. andysabini* | Montagne d'Ambre | -12.52731 | 49.17331 |
| AMB5.23 | *C. andysabini* | Montagne d'Ambre | -12.53017 | 49.17464 |
| AMB5.27 | *C. andysabini* | Montagne d'Ambre | -12.51722 | 49.17950 |
| AMB5.28 | *C. andysabini* | Montagne d'Ambre | -12.47881 | 49.21222 |
| AMB5.29 | *C. andysabini* | Montagne d'Ambre | -12.47922 | 49.21606 |
| AMB5.30 | *C. andysabini* | Montagne d'Ambre | -12.47917 | 49.21597 |
| AMB5.31 | *C. andysabini* | Montagne d'Ambre | -12.51083 | 49.19275 |
| AMB5.32 | *C. andysabini* | Montagne d'Ambre | -12.51242 | 49.18956 |
| AMB5.34 | *C. andysabini* | Montagne d'Ambre | -12.47822 | 49.21717 |
| AMB5.35 | *C. andysabini* | Montagne d'Ambre | -12.49519 | 49.20783 |
| ANJZ1 | *C. crossleyi* | Anjozorobe | -18.47750 | 47.93812 |
| ANJZ2 | *C. crossleyi* | Anjozorobe | -18.47750 | 47.93812 |
| ANJZ3 | *C. crossleyi* | Anjozorobe | -18.47750 | 47.93812 |
| JOZO4.7 | *C. crossleyi* | Anjozorobe | -18.46789 | 47.94131 |
| JOZO4.8 | *C. crossleyi* | Anjozorobe | -18.46789 | 47.94131 |
| JOZO4.9 | *C. crossleyi* | Anjozorobe | -18.46789 | 47.94131 |
| JOZO4.10 | *C. crossleyi* | Anjozorobe | -18.46789 | 47.94131 |
| MIZA16 | *C. crossleyi* | Maromizaha | -18.97375 | 48.46461 |
| MIZA19 | *C. crossleyi* | Maromizaha | -18.97067 | 48.46431 |
| MIZA6.1 | *C. crossleyi* | Maromizaha | -18.95694 | 48.49236 |
| MIZA6.2 | *C. crossleyi* | Maromizaha | -18.95694 | 48.49236 |
| MIZA7.1 | *C. crossleyi* | Maromizaha | -18.95694 | 48.49236 |
| TAD4.10 | *C. crossleyi* | Mantadia | -18.80942 | 48.42731 |
| TAD4.11 | *C. crossleyi* | Mantadia | -18.80942 | 48.42731 |
| TAD4.12 | *C. crossleyi* | Mantadia | -18.80942 | 48.42731 |
| TOR6.2 | *C. crossleyi* | Torotorofotsy | -18.83658 | 48.34719 |
| TORO8.11 | *C. crossleyi* | Torotorofotsy | -18.77044 | 48.42814 |
| TORO8.16 | *C. crossleyi* | Torotorofotsy | -18.76856 | 48.42475 |
| TVY7.12 | *C. crossleyi* | Ambatovy | -18.85086 | 48.29256 |
| TVY7.196B | *C. crossleyi* | Ambatovy | -18.86433 | 48.31136 |
| TVY7.197 | *C. crossleyi* | Ambatovy | -18.86658 | 48.30972 |
| TVY7.199 | *C. crossleyi* | Ambatovy | -18.87294 | 48.305 |
| TVY7.20 | *C. crossleyi* | Ambatovy | -18.84797 | 48.29433 |
| TVY7.200 | *C. crossleyi* | Ambatovy | -18.86883 | 48.30975 |
| TVY7.206 | *C. crossleyi* | Ambatovy | -18.87289 | 48.30453 |
| TVY7.207 | *C. crossleyi* | Ambatovy | -18.87178 | 48.30297 |
| TVY7.22 | *C. crossleyi* | Ambatovy | -18.85017 | 48.292 |
| TVY7.33 | *C. crossleyi* | Ambatovy | -18.85086 | 48.29256 |
| ZAH240 | *C. crossleyi* | Zahamena | -17.48917 | 48.74722 |
| TRA8.81 | *C.* sp. nov. 2 | Andringitra (Ambarongy) | -22.22269 | 47.01889 |
| TRA8.82 | *C.* sp. nov. 2 | Andringitra (Ambarongy) | -22.22292 | 47.0195 |
| RANO229 | *C.* sp. nov. 2 | Ranomafana (Talatakely) | -21.24833 | 47.42406 |
| RANO2.95 | *C.* sp. nov, 2 | Ranomafana (Vatoharanana) | -21.29250 | 47.43842 |

| | | | | |
|---|---|---|---|---|
| KAL7.7 | *C. lavasoensis* | Kalambatritra (Sahalava) | -23.53672 | 46.5335 |
| GAR8 | CCS2* | Manongarivo | -14.02369 | 48.27233 |
| **Thiele *et al.* 2013 Samples** | | | | |
| KC505933 | *C. lavasoensis* | Petit Lavasoa | -25.0809 | 46.7622 |
| KC505934 | *C. lavasoensis* | Petit Lavasoa | -25.0809 | 46.7622 |
| KC505935 | *C. lavasoensis* | Petit Lavasoa | -25.0809 | 46.7622 |
| KC505936 | *C. lavasoensis* | Petit Lavasoa | -25.0809 | 46.7622 |
| KC505937 | *C. lavasoensis* | Petit Lavasoa | -25.0809 | 46.7622 |
| KC505938 | *C. lavasoensis* | Petit Lavasoa | -25.0809 | 46.7622 |
| KC505939 | *C. lavasoensis* | Petit Lavasoa | -25.0809 | 46.7622 |
| KC505940 | *C. lavasoensis* | Ambatotsirongorongo | -25.0780 | 46.7824 |
| KC505941 | *C. lavasoensis* | Ambatotsirongorongo | -25.0780 | 46.7824 |
| KC505942 | *C. lavasoensis* | Ambatotsirongorongo | -25.0780 | 46.7824 |
| KC505943 | *C. lavasoensis* | Ambatotsirongorongo | -25.0780 | 46.7824 |
| KC505944 | *C. lavasoensis* | Ambatotsirongorongo | -25.0780 | 46.7824 |
| KC505945 | *C. lavasoensis* | Ambatotsirongorongo | -25.0780 | 46.7824 |
| KC505946 | *C. lavasoensis* | Ambatotsirongorongo | -25.0780 | 46.7824 |
| KC505947 | *C. lavasoensis* | Ambatotsirongorongo | -25.0780 | 46.7824 |
| KC505948 | *C. lavasoensis* | Ambatotsirongorongo | -25.0780 | 46.7824 |
| KC505949 | *C. lavasoensis* | Grand Lavasoa | -25.0891 | 46.7447 |
| **Groeneveld *et al.* 2009, 2010 Samples** | | | | |
| EU825359 | *C.* sp. nov. 2 | Andrambovato (Oranjatsy) | -21.4959 | 47.4018 |
| GQ243488 | *C.* sp. nov 2 | Ranomafana (Talatakely) | -21.2639 | 47.4189 |
| GQ243489 | *C.* sp. nov. 2 | Ranomafana (Talatakely) | -21.2639 | 47.4189 |
| EU825360 | *C. andysabini* | Montagne d'Ambre | -12.4748 | 49.2185 |
| EU825361 | *C. andysabini* | Montagne d'Ambre | -12.4748 | 49.2185 |
| EU825362 | *C. andysabini* | Montagne d'Ambre | -12.4748 | 49.2185 |
| EU825348 | CCS2* | Sambava | -14.3994 | 50.1739 |
| EU825349 | CCS2* | Sambava | -14.3994 | 50.1739 |
| EU825350 | CCS2* | Sambava | -14.3994 | 50.1739 |
| EU825351 | CCS2* | Sambava | -14.3994 | 50.1739 |
| EU825352 | CCS2* | Sambava | -14.3994 | 50.1739 |
| EU825353 | CCS2* | Sambava | -14.3994 | 50.1739 |
| EU825354 | CCS2* | Manantenina | -14.4910 | 49.8115 |
| EU825355 | CCS2* | Manantenina | -14.4910 | 49.8115 |
| EU825356 | CCS2* | Manantenina | -14.4910 | 49.8115 |
| EU825357 | CCS2* | Manantenina | -14.4910 | 49.8115 |
| EU825358 | CCS2* | Manantenina | -14.4910 | 49.8115 |
| EU825363 | CCS2* | Ambanja/Beandroana | -13.7030 | 48.5046 |
| EU825364 | CCS2* | Sambava | -14.3994 | 50.1739 |
| EU825365 | CCS2* | Sambava | -14.3994 | 50.1739 |
| EU825366 | CCS2* | Sambava | -14.3994 | 50.1739 |
| EU825367 | CCS2* | Manantenina | -14.4910 | 49.8115 |
| GQ243481 | *C. crossleyi* | Tsinjoarivo/Vatateza | -19.7208 | 47.8569 |
| GQ243482 | *C. crossleyi* | Tsinjoarivo/Vatateza | -19.7208 | 47.8569 |

| | | | | |
|---|---|---|---|---|
| GQ243483 | *C. crossleyi* | Tsinjoarivo/Vatateza | -19.7208 | 47.8569 |
| GQ243484 | *C. crossleyi* | Tsinjoarivo/Vatateza | -19.7208 | 47.8569 |
| GQ243485 | *C. crossleyi* | Tsinjoarivo/Vatateza | -19.7208 | 47.8569 |
| GQ243486 | *C. crossleyi* | Tsinjoarivo/Vatateza | -19.7208 | 47.8569 |
| GQ243487 | *C. crossleyi* | Tsinjoarivo/Vatateza | -19.7208 | 47.8569 |
| EU825368 | *C. crossleyi* | Ankazomivady | -20.7800 | 47.1820 |
| EU825369 | *C. crossleyi* | Ankazomivady | -20.7800 | 47.1820 |
| EU825370 | *C. crossleyi* | Ankazomivady | -20.7800 | 47.1820 |
| * CCS designations 2 and 6 are from Lei *et al*. 2014 | | | | |

**Table 2.** List of dwarf lemurs, *Cheirogaleus* sp. nov. 2, from Ranomafana and Andringitra examined during this study using acronyms TRA and RANO to designate sites (see Table. 1). Catalog and tissue accession numbers from the Museum of Texas Tech University (TTU-M).

| ID No. | Catalog No. | Tissue No. | Sex | Microchip ID | Weight (kg) | GPS | | Sampling Date |
|---|---|---|---|---|---|---|---|---|
| TRA8.81 | TTU-M 118807 | TK 129245 | Male | 47317E2474 | 0.404 | -22.22269 | 47.01889 | 11/16/2008 |
| TRA8.82 | TTU-M 118809 | TK 129247 | Female | 4734461007 | 0.406 | -22.22292 | 47.01950 | 11/18/2008 |
| RANO2.95 | TTU-M 118808 | TK 129246 | Female | N/A | 0.550 | -21.29250 | 47.43842 | 02/11/2002 |
| RANO229 | | | Female | N/A | 0.268 | -21.24833 | 47.42406 | 11/01/1999 |

Note: RANO229 is a juvenile.

**Table 3.** Ranomafana/Haute Masiatra dwarf lemurs, *Cheirogaleus grovesi*, examined in this study.

| Class | No. | W (kg) | HC (cm) | BL (cm) | TL (cm) | ML (mm) | MW (mm) | F-Tb (cm) | F-LD (cm) | F-Hd (cm) | F-UR (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Male | 1 | 0.404±0.000 | 7.0±0.0 | 17.1±0.0 | 27.7±0.0 | 20.0±0.0 | 21.5±0.0 | 1.0±0.0 | 1.6±0.0 | 3.2±0.0 | 4.5±0.0 |
| Female | 2 | 0.478±0.102 | 6.0±0.2 | 21.6±4.0 | 29.7±1.0 | 19.0±0.0 | 20.0±0.0 | 1.2±0.0 | 1.5±0.0 | 3.9±0.2 | 5.1±0.1 |
| Total | 3 | 0.453±0.084 | 6.3±0.6 | 20.1±3.8 | 29.0±1.4 | 19.5±0.7 | 20.8±1.0 | 1.1±0.1 | 1.5±0.2 | 3.6±0.4 | 4.9±0.3 |

Note: W: weight; HC: head crown, HW: head width, BL: body length, TL: tail length, ML: muzzle length, MW: muzzle width, Forelimb F-Tb: thumb length, F-LD: longest digit length, F-Hd: hand length, F-UR: ulna/radius length.

**Table 3.** Continued.

| Class | F-H (cm) | H-Tb (cm) | H-LD (cm) | H-Ft (cm) | H-T (cm) | H-F (cm) | UC (mm) | LC (mm) | TeL-R (mm) | TeW-R (mm) | TeL-L (mm) | TeW_L (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Male | 3.6±0.0 | 2.0±0.0 | 1.8±0.0 | 5.6±0.0 | 5.5±0.0 | 6.1±0.0 | 5.0±0.0 | 3.2±0.0 | 14.5±0.0 | 8.6±0.0 | 14.0±0.0 | 8.2±0.0 |
| Female | 4.1±0.8 | 1.8±0.4 | 1.6±0.1 | 5.9±0.2 | 5.6±0.7 | 5.1±0.8 | 4.0±0.0 | 3.0±0.7 | NA | NA | NA | NA |
| Total | 3.9±0.7 | 1.9±0.3 | 1.7±0.2 | 5.8±0.2 | 5.6±0.5 | 5.4±0.8 | 4.5±0.7 | 3.1±0.5 | NA | NA | NA | NA |

Note: F-H: humerus length, hindlimb H-Tb: thumb length, H-LD: longest digit length, H-Ft: foot length, H-T: tibia length, H-F: femur length, UC: upper canine length, LC: lower canine length, TeL-R: right testis length, TeW-R: right testis width, TeL-L: left testis length, TeW-L: left testis width.

here differs from these two lineages by a genetic distance of 13.1%±0.9%, and 11.0%±0.8%, respectively (See Lei *et al.* 2014, Appendix II(g) for cyt*b* genetic distance data). Additional analyses using D-loop, COII, and PAST mitochondrial gene regions resulted in *C.* sp. nov. 2 segregating as a distinct lineage with a high degree of confidence (posterior probabilities equal to 1.00, with a single individual from Ranomafana scoring 89/0.99; Figs. 2–4 in Lei *et al*. 2014). These results were supported by analyses of three nuclear loci (CFTR-PAIRB, FIBA, vWF), with posterior probability in support of an independent lineage at 0.98 in a phylogenetic analysis including the CCS2 specimen from Kalambatritra, another possible, though as yet unconfirmed, new species in the *C. crossleyi* group known from multiple individuals on the northeastern (Sambava, Manantenina) and northwestern (Ambanja/Beandroana, Manongarivo) coasts (Figs. 5–6 in Lei *et al.* 2014). Use of the CCS2 specimens in the analysis significantly increased support, from 0.55 to 0.98, for the independence of the *C.* sp. nov. 2 lineage, likely because a more accurate picture of the genetic diversity within *C. crossleyi* was possible with the inclusion of a larger number of closely related species.

The population aggregate analysis (PAA) results are congruent with those presented in Lei *et al.* (2014). We obtained a Bayesian PTP support value of 0.96 indicating an excellent probability of the likelihood that *C.* sp. nov. 2 is a species based on the given dataset.

## Discussion

Several new *Cheirogaleus* species were recently described via genetic analyses by Lei *et al.* (2014, 2015) and Frasier *et al.* (2016). Yet, there is still evidence of additional undescribed diversity in dwarf lemurs, in particular within the *C. crossleyi* group.

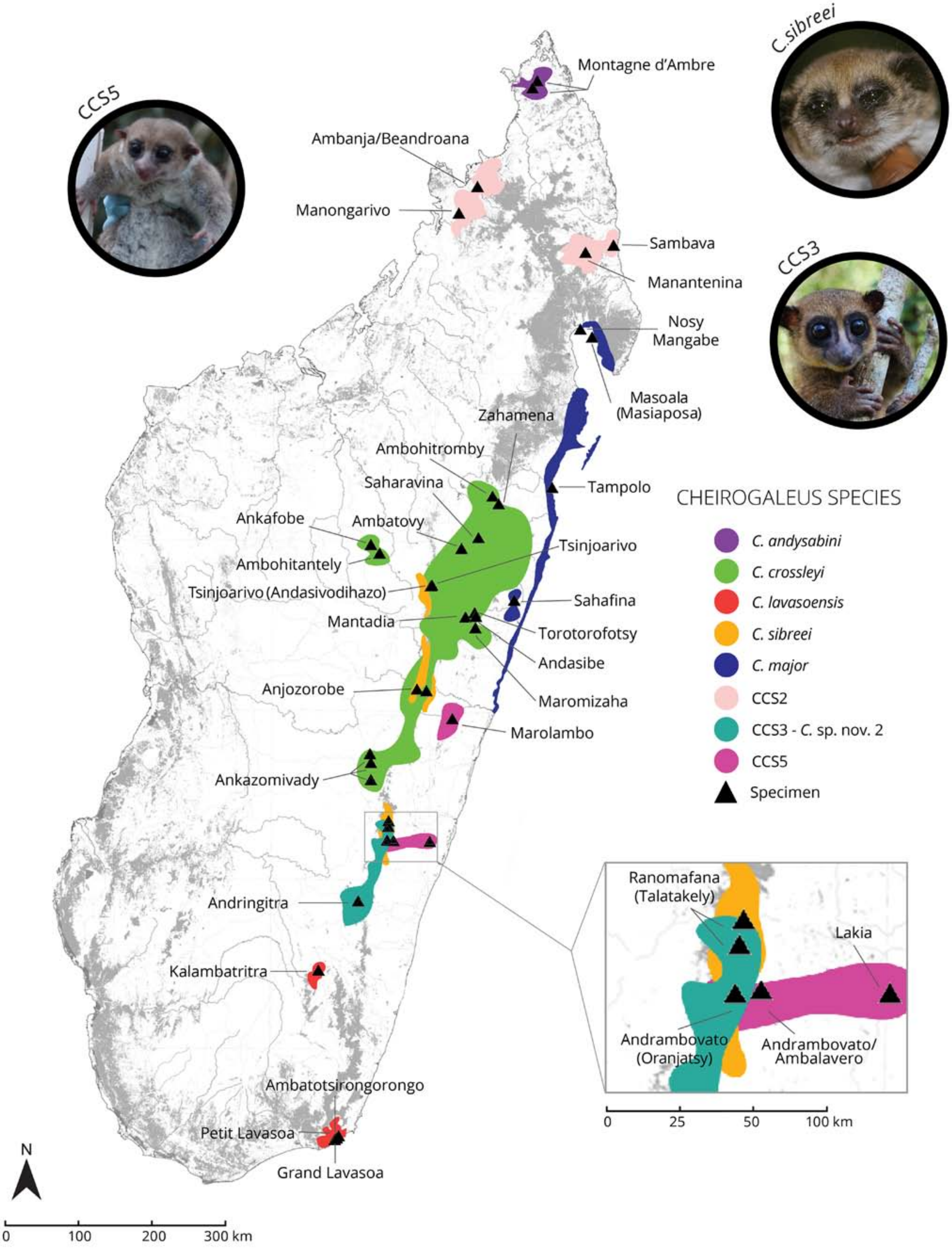

**Figure 3.** Map of Madagascar with the ranges of *C.* sp. nov. 2 and other species in the *C. crossleyi* group: *C. andysabini*, *C. crossleyi*, *C. lavasoensis*, and CCS2. Map also includes lineages of other *Cheirogaleus* species groups that are partially sympatric, *C. sibreei* and CCS5. Additionally, *C. major* is included with the newly reported population at Sahafina. Photographs are provided to show the distinct phenotypic differences between sympatric lineages.

Lei *et al.* (2014) described the range of *C. crossleyi* as extending from Zahamena in the northeast south to Tsinjoarivo. Fecal samples collected since 2014 indicate a larger range for this species than previously suspected. *Cheirogaleus crossleyi* populations have now been identified as far north and west as the Ambohitantely National Park, as well as at the nearby community-run Ankafobe Reserve about 110 km northwest of Antananarivo. Additional populations were identified some 80 km north and east of this location near Lac Aloatra and Ambatondrazaka at the sites of Ambohitromby and Saharavina. Historical sources support this larger range. The naturalist Alfred Grandidier collected the type specimen of *C. crossleyi*, now in the collection of the Harvard Museum of Comparative Zoology (MCZ 44952), near Lac Aloatra in the late 19th century. These remaining animals are isolated in surviving forests, and are likely not contiguous with populations located farther east and south. This population fragmentation and isolation is consistent with that found across the species' extended range (Andriaholinirina *et al*. 2014). *Cheirogaleus crossleyi* populations were also sampled at three sites around Ankazomivady, farther southwest than previously observed. Taken together, these additional samples indicate a greater range than previously known for *C. crossleyi.* Additional sites are being identified not just for *C. crossleyi*, but other *Cheirogaleus* lineages. A population of *C. major* was recently identified at Sahafina and confirmed with mitochondrial DNA (D-loop) sequenced from fecal samples. The presence of this population is being reported here for the first time (Fig. 3).

Here, we present a description of a new species, identified as *C*. sp. nov. 2 (CCS3) within the *C. crossleyi* group by Lei *et al.* (2014), the range of which extends from Ranomafana to Andringitra national parks, and is supported by morphological and genetic data. Sufficient mitochondrial genetic divergence was observed to warrant elevation of this population as a new species (Table 2). Additional evidence used in elevating this population to species status was its geographic isolation from other genetically close populations of *Cheirogaleus*, *C. andysabini*, *C. lavasoensis* and *C. crossleyi*. Geographic isolation should not be the sole consideration for diagnosing a new species, but should be considered as one piece of evidence alongside other factors. In this case other factors include genetic divergence, size, pelage variation, and habitat elevation (Fig. 3; Table 2; Table 3).

Individuals of *C.* sp. nov. 2 are considerably larger (0.18 kg on average) than *C. sibreei* individuals, a lineage with which they share the northern part of their range. It is unlikely that these two species are ecologically sympatric, as *C. sibreei* is found from 1128–1660 m above sea level while *C*. sp. nov. 2 are found at 754–999 m. The distribution of *C*. sp. nov. 2 also partly overlaps with the CCS5 lineage, a cryptic species within the *C. major* group identified at a lower altitudinal range (85–763 m), for which no morphological data are currently available (Lei *et al.* 2014). *Cheirogaleus* sp. nov. 2 is notably larger than other lineages within the *C. crossleyi* species group, to which it belongs (Table 2; Table 3; Lei *et al*. 2014, Table 4). *Cheirogaleus* sp. nov. 2 individuals are as much as 0.11 kg heavier and approximately 5 cm longer than other species in the *C. crossleyi* group.

## Conservation Status

The conservation status of this species is unknown, although its presence in two national parks and a protected corridor indicates that it is possibly more secure than lemur species that are not resident in protected areas. Anthropogenic deforestation is a threat across Madagascar, and national parks are not immune to this threat. It is unknown if this species is hunted for bush meat, but this is certainly a possibility. Additional research is necessary to determine the conservation status of this species, so that protective measures can be taken to ensure the future of the lineage. The continuing identification of new primate species in Madagascar's remaining wild places highlights the need to protect this habitat from additional disturbance by human encroachment.

## Groves', Andringitra, or Haute Matsiatra Dwarf Lemur

### *Cheirogaleus grovesi*

Formerly ***Cheirogaleus* sp. nov. 2**, also CCS3/Crossleyi D (Lei *et al*. 2014), also *Cheirogaleus* sp. Ranomafana Andrambovato (Thiele *et al.* 2013).

**Holotype.** TRA8.81 (TTU-M 118807/K 129245); adult male; Permit number 239/08; 4 x 2.0 mm biopsies from ear pinna and 0.3 cc of whole blood; stored and curated at Museum of Texas Tech University (MTTU) Genetic Resources Collection, Natural Sciences Research Laboratory (NSRL); we placed a microchip subcutaneously between the scapulae and recorded as 47317E2474; collected by Edward E. Louis, Jr., Jean Richard Rakotonomenjanahary, and Jean Claude Randriamanana on 16 November 2008.

**Paratypes.** RANO2.95, RANO229 (juvenile); TRA8.82; RMR146, MB210, MB217

**Type locality.** Madagascar: Fianarantsoa Province, Haute Matsiatra Region, Andringitra National Park, S22.222694, E47.018889 at 763 m above sea level.

**Measurements of holotype.** Measurements recorded in field catalog: body length 17.1 cm; tail length 27.7 cm; head crown 7.0 cm; mass 404 g.

**Description.** The dorsum, limbs, and head are rufous-brown. The areas around the orbits are brownish-black, with a white patch proximal to the fleshy part of the nose in the inter-ocular space. The pelage on the ventral surface of the mandible is white, which continues onto the rufous-grey pelage of the ventrum.

**Diagnosis.** *Cheirogaleus grovesi* can be distinguished from *C. andysabini*, *C. crossleyi*, *C. lavasoensis* and CCS2 by 10, 9, 18 and 12 diagnostic characters in the cyt*b* gene, respectively (Appendix II (k); Lei *et al*. 2014). *C.* species nov. 2 has six diagnostic sites in the cyt*b* sequence fragment such as G, G, C, G, C and C at the positions of 123, 432, 693, 918, 1078 and 1083, respectively, which differentiate *C.* species nov. 2 from all other *Cheirogaleus* species. Despite being geographically close to CCS5 and *C. sibreei*, *C. grovesi* is distinct by six and 31 diagnostic characters from CCS5 and *C. sibreei*, respectively, while CCS5 is clustered in the *C. major* subgroup. An average weight of 0.410 kg was greater than all other members of the *C. crossleyi* species group, which has an average weight of less than 0.33 kg. *Cheirogaleus grovesi* is larger than *C. crossleyi*. Blackish-brown fur around eyes, rufous brown fur on dorsum, limbs, and head, venter is a mix of grey and rufous brown fur.

**Distribution.** *Cheirogaleus grovesi* is known from the national parks of Ranomafana and Andringitra, as well as surrounding areas, and likely occupies a fragmented range between the two parks across the Haute Matsiatra region of Madagascar. Observed at 754–999 m above sea level (Fig. 3).

**Etymology.** This species is named for the late British-Australian biological anthropologist, Professor Colin Groves (1942-2017), in recognition of his more than forty years of work in the fields of primatology, evolutionary biology, morphological analysis, mammalian taxonomy and associated disciplines. Professor Groves embodied the true spirit of collaboration. His fastidious research on historical collections incorporated the work of those that preceded him, which he combined with the efforts of his contemporaries, creating compositions that span hundreds of years of scientific exploration. At the time of his passing, Professor Groves was widely regarded as the greatest living primate taxonomist.

**Vernacular Names.** Groves', Andringitra, or Haute Matsiatra dwarf lemur.

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# The Conservation Status of Two Threatened Primates in the Korup Region, Southwest Cameroon

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**Abstract:** Primary users of wildlife have only rarely been considered in determining the status of threatened species. There is no recent information on the status of *Piliocolobus preussi* (Critically Endangered) and *Cercocebus torquatus* (Vulnerable) in southwestern Cameroon. This study documents the status of both primates using data collected in Korup National Park (KNP), Banyang-Mbo Wildlife Sanctuary (BMWS), and Nkwende-Hills (NHFR), Nta-Ali (NAFR) and Rumpi-Hills (RHFR) forest reserves, referred to as the Korup region (KR). The study area is an important portion of both species' ranges in the West Africa Biodiversity Hotspot. We were specifically interested in confirming the presence/absence of each species per site, identifying threats, evaluating trends in abundance and, using the International Union for the Conservation of Nature (IUCN) classification categories and criteria in assessing the conservation status for both species. We interviewed 178 hunters from 31 peripheral villages, and collected data on 286.9 km of recce walks in the Korup region. Statistical comparisons of mean perceptions of hunters showed *P. preussi* to be significantly present in KNP (88.9%), but not in NHFR (65.6%) and BMWS (57.7%), and *C. torquatus* to be significantly present in NHFR (100%) and BMWS (96.7%), but not in KNP (77.8%). According to 54.9% and 53.9% of the hunters interviewed, poaching is the main threat to the respective species. Habitat loss is also important. Data from the last ten years shows a proportional decline in relative abundance of 83.4% and 53.4% for *P. preussi* and *C. torquatus*, respectively. We suspect a decline in the extent of occurrence and/or habitat quality in the Korup Region. In order to ensure awareness of the needs for their conservation, we recommend that *C. torquatus* be classified as Endangered (A2bc), and *P. preussi* be maintained as Critically Endangered (A2bc) because of the estimated declines of $\geq$50% and 80%, respectively, based on encounter rate, and suspected decline in the extent of occurrence and habitat quality.

**Keywords:** Conservation status, hunters' interviews, Korup Region, Cameroon, red-capped mangabey, Preuss's red colobus, threatened species

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## Introduction

In 2002, the Convention on Biological Diversity, recognizing its impact on human well-being, adopted the target of achieving a significant reduction in the current rate of biodiversity loss (UNEP 2002). However, despite growing investment in nature conservation, and a global increase in the area under protection since 2002, key habitats for threatened species are still not adequately protected (UN 2010), leading to the observed extinction of species.

Cameroon's forests are essential for the conservation of African biodiversity (Doumenge *et al.* 2001), and those of the Korup Region are especially important, not only in Africa (Oates *et al*. 2004), but also globally (Myers *et al*. 2000). These forests along the Cameroonian-Nigerian border represent the largest remaining tracts in the entire West African Biodiversity Hotspot (Myers *et al.* 2000). With 15 species, eight of them diurnal, they are of special importance for the conservation of African primates (Waltert *et al.* 2002). In spite of the conservation measures that have been developed in West Africa, poaching there and throughout the Congo basin, and particularly in Cameroon, remains the biggest threat to more than 80 species and subspecies of mammals, including 17 primates (WWF 2008). Large-scale habitat conversion for industrial oil palm plantations is also imminent (IUCN 2010; Kupsh *et al.* 2014).

These threats have grown and intensified, and there are fewer primates now than ever before (Mittermeier *et al.*

2005). Relatively low population densities of primates, paired with intensive hunting (Photo 1) beyond sustainable rates of extraction, have been observed since the 1990s (Pollard 1997; Usongo 1997). To inform of threats to primates worldwide, the Species Survival Commission (SSC) of IUCN regularly updates information on their status through the Red List. No recent information exists, however, on the status of two of the most threatened large primates occurring in the Korup Region of southwest Cameroon and Ebo National Park of Littoral Cameroon: Preuss's red colobus *Piliocolobus preussi*[1] (CR A2cd) and the red-capped mangabey *Cercocebus torquatus* (VU A2cd) (IUCN 2010). These have been classified as such due to assumed declines of 80% and 30% in their abundance over the past three generations, as well as being continually impacted by overexploitation in the bushmeat trade (Linder, 2008; IUCN 2010). Older reports also reveal that both species face imminent local extinction (Waltert *et al.* 2002). In the study area, little consideration has been given to the use of information from the primary users of wildlife in determining the status of a species; however, local hunters have a vast knowledge of their abundance, distribution and threats in the forests where they hunt. Here we report on data collected from interviews of hunters and from surveys on hunter trails to help determine the status of *P. preussi* and *C. torquatus* in the Korup region.

## Methods

### *The Korup region*

The Korup region is the core of the ranges of *Piliocolobus preussi* and *Cercocebus torquatus* in the Gulf of Guinea forests (Waltert *et al.* 2002; Willcox and Nambu 2007; Linder 2008; Oates *et al.* 2008). Red-capped mangabeys range patchily from southwest Nigeria, west of the Niger River, through the southwest of Cameroon and Equatorial Guinea, to Gabon and south Congo (Ehardt 2013). Preuss's red colobus is believed to have had a similar range in the past, from the Cross River in Nigeria south to the Ebo Forest, just north of the Sanaga River (Butynski and Kingdon 2013). Its range today is largely restricted to the Korup Region. In 2001 it was recorded in the Ebo National Park, in the littoral region of Cameroon (Dowsett-Lemaire and Dowsett 2001).

The Korup region is in the southwest of Cameroon, from 05°36'32.9" to 09°10'50.1"N and from 05°14'50.0" to 08°42'44.8"E, in UTM Zone 32N. It encloses five protected areas—the Korup National Park (126,000 ha), Nkwende Hills Forest Reserve (40,982 ha), Rumpi Hills Forest Reserve (45,675 ha), Nta-Ali Forest Reserve (27,835 ha) and the Banyang-Mbo Wildlife Sanctuary (66,220 ha) (Fig. 1). Korup National Park (KNP) is situated within the Ndian and Manyu divisions, and the northeastern part of the park is continuous with the Nkwende Hills Forest Reserve (NHFR). It lies to the West of Nguti − Mamfe road and the base of these hills is in Mgbegati village. Part of Nkwende Hill extends to Okoroba village at 705 m above sea level, with rock faces commonly called "chimpanzee stone," alleged to be a refuge for chimpanzees. The Nta-Ali Forest Reserve (NAFR) is located in the Manyu division and the Rumpi Hills Forest Reserve is in the Ndian division. Lastly, the Banyang-Mbo Wildlife Sanctuary (BMWS) is situated between Kupe-Manengouba and Manyu divisions. The forest around the sanctuary has been converted into secondary vegetation due to logging and agricultural activities around surrounding villages. Intact primary forests, however, can still be found in the higher elevations in Nkwende Hills Forest Reserve (Ndeh *et al.* 2002) and around Mount Rata in the Rumpi Hills Forest Reserve (Fomete and Tchanou 1998). Nta-Ali Forest Reserve is a relatively degraded forest and has recently been reclassified as Forest Management Unit 11-006 (Cameroon, MINEF 2002). In this study, 31 villages were selected, all close to these protected areas. Details on climate, geological conditions, topography, vegetation and fauna are found in the management plans of the protected areas (Cameroon, MINEF 2001, 2002; Ndeh *et al.* 2002; Cameroon, MINFOF 2008).

Because most of the villages around these PAs are remote and inaccessible, they tend to be quite small (Vabi 1999). They are headed by chiefs assisted by regent chiefs. Local institutions involved in wildlife conservation issues are the Forest Management Committees, Ekpe Society, and the traditional council.

**Photo 1.** Carcass of a red-capped mangabey in Osselle village (periphery of Nkwende hills forest reserve).

### *Data collection*

From August to October 2011 and April to September 2012, data were collected by addressing questionnaires to 178 resident male bushmeat hunters, all of whom agreed to be interviewed. We gave preference to hunters who hunted primates, and asked questions on presence/absence (P/A), sites where they occurred, and threats faced by both species. Informal discussions and observations were also noted. Before

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[1] Taxonomy follows Groves (2007).

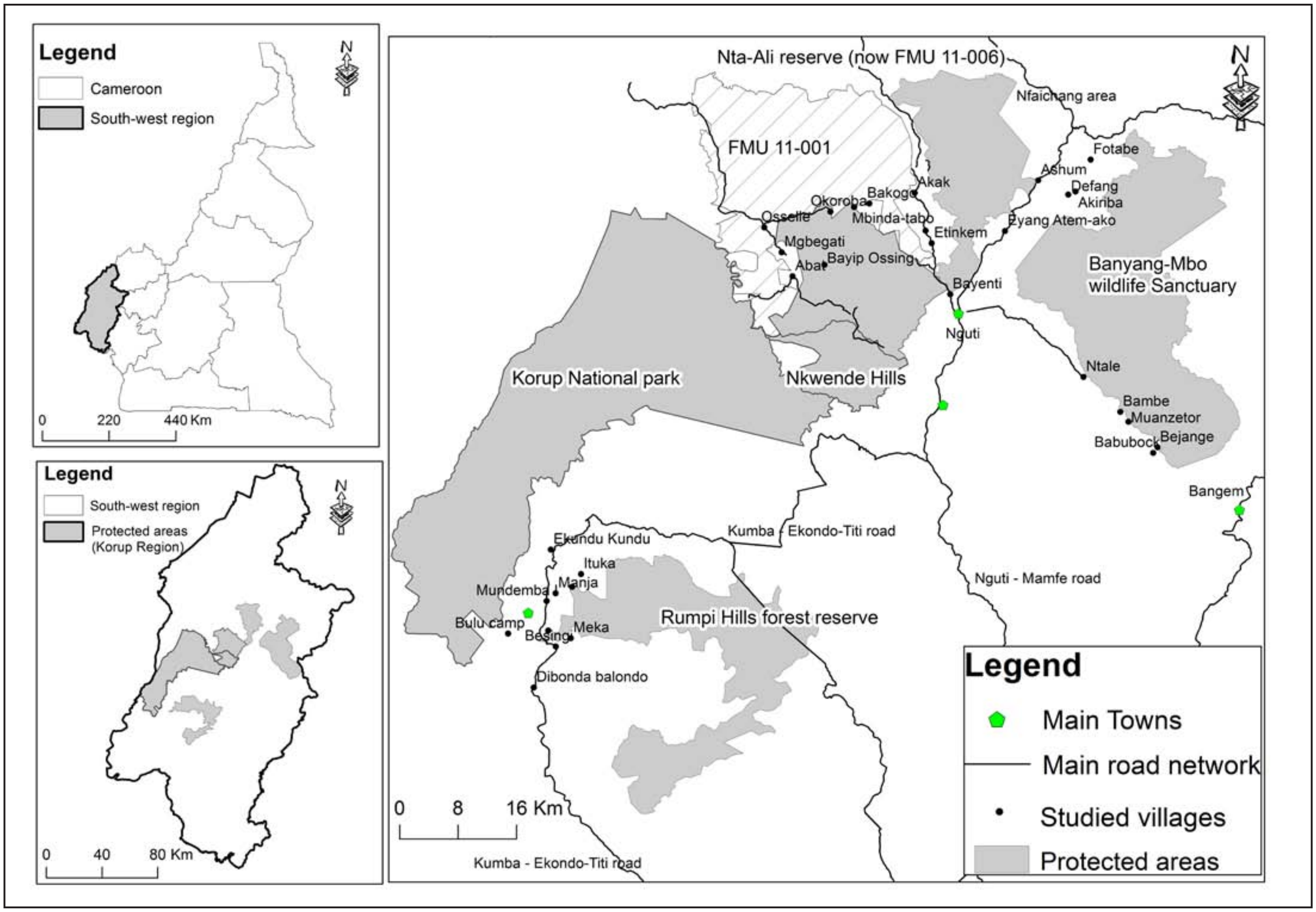

**Figure 1.** Study area.

interviews, we showed them pictures of each of the primates. If the hunter recognised the species, we asked them for the local name and a brief description of the species behavior to ensure correct identification. Guided by hunters, we also visited sites where both species had been observed recently. We walked a total of 286.9 km of hunter trails along sites where the species were recently observed, noting direct observation and indirect evidence (calls) of the primates, and signs of human activities (hunter camps [Photo 2], gun cartridge shells, traps, gunshots, hunter tracks, etc.).

*Data analysis*

Presence/absence, opinions on trends in abundance, and records of both species were evaluated based on the strength of the statistical differences between the mean proportions of hunter's opinions. Kruskal-Wallis Analysis of Variance (ANOVA) was used to compare perceptions between protected areas; Mann-Whitney U and Wald-Wolfowitz Runs Tests were used to compare the hunters' opinions in the protected areas. No correction factor was applied to the p-values for paired tests. Alpha levels were set at 0.05 (95%).

For each site, when the mean proportion of opinions of presence was greater than or equal to 50% and significantly higher than the mean proportion of opinions of absence, the species was considered "present." When the difference was not significant, the species was considered as "could be present." When the mean proportion of absence opinions was greater than 50% and significantly higher or not than

**Photo 2.** One of the many hunter camps and local guns used during hunting expeditions.

presence opinions, the species was considered as "could be absent." Temporal trends were based on the statistical differences between hunters opinions on P/A status 30 years ago and P/A status today, and categorized as either "significant decline," "suspected decline," "probable decline," "or stable" on a trend map.

Encounter rates (ER = number of group sightings and vocalizations/km) were computed for both species per site and used as an index for evaluating trends according to IUCN species classification criteria (IUCN 2011). Here, declines are measured over a period of 10 years or three generations (criteria A) using an index of abundance appropriate to the taxon (e.g. ER for primates as in Waltert *et al.* 2002; Flinkerbusch 2011), which can be used to satisfy criteria A2b. Suspected changes in ER of both species were estimated by comparing current ER with those recorded 10 years ago in all sites where data were available despite the difference between both survey approaches (present and historical) used in the same sites.

## Results

### *Red-capped mangabey: Presence/absence and trend of abundance*

Using a Wald-Wolfowitz Runs Test (Table 1), we found that the number of hunters indicating presence was significantly higher than those indicating the absence of *C. torquatus* in Nkwende Hills Forest Reserve and Banyang-Mbo Wildlife Sanctuary. Although more hunters indicated that red-capped mangabeys were present in Korup National Park (77.8%) and Nta-Ali Forest Reserve (73.5%) than those who indicated they were absent, the difference was not statistically significant. For the Rumpi Hills Forest Reserve the number of hunters indicating that the mangabeys were absent was significantly higher than the number who said they were present. According to hunters, therefore, *C. torquatus* is present in the Nkwende Hills Forest Reserve and the Banyang-Mbo Wildlife Sanctuary, could be present in Korup National Park and Nta-Ali Forest Reserve, and could be absent from the Rumpi Hills Forest Reserve. Perceptions of hunters on the presence of *C. torquatus* 30 years ago reveal that the species was previously abundant in Nkwende Hills Forest Reserve and Korup National Park, and to a lesser extent in Banyang-Mbo Wildlife Sanctuary and Nta-Ali Forest Reserve, but was already very scarce or near extinction in the Rumpi Hills Forest Reserve (Fig. 2).

### *Preuss's red colobus: Presence/absence and trend of abundance*

According to Table 1, we found that the number of hunters indicating presence was significantly higher than those indicating the absence of *P. preussi* in Korup National Park. Although more hunters indicated that Preuss's red colobus were present in the Nkwende Hills Forest Reserve (65.6%) and Banyang-Mbo Wildlife Sanctuary (58.7%) than those who indicated they were absent, the differences were not statistically significant. In Nta-Ali Forest Reserve and the Rumpi Hills Forest Reserve the number of hunters indicating that *P. preussi* was absent was higher (70.6% and 64.7%) than the number who said they were present, but the differences were not significant. According to the hunters, therefore, *P. preussi* is present in Korup National Park, could be present in the Nkwende Hills Forest Reserve and Banyang-Mbo Wildlife Sanctuary, and could be absent in the Rumpi Hills Forest Reserve and Nta-Ali Forest Reserve. Perceptions of hunters on the presence status of *P. preussi* 30 years ago reveal that the species was previously abundant in the Nkwende Hills Forest Reserve and Korup National Park and, to lesser extent in Banyang-Mbo Wildlife Sanctuary and Nta-Ali Forest Reserve, but was already very scarce or near extinction in the Rumpi Hills Forest Reserve (Fig. 3).

### *Hunters' perceptions on the sites of location of both species*

The main site where both species can be encountered is Korup National Park as revealed by 34.4% and 35.3% of all interviewed hunters for *P. preussi* and *C. torquatus*, respectively (Fig. 4). Other sites where both species can be encountered, according to hunters, include Banyang-Mbo Wildlife

**Table 1.** Confirmation of hunters on P/A of *Cercocebus torquatus* and *Piliocolobus preussi* in the study area.

| Species | Site | Proportion of presence opinion | Proportion of absence opinion | Z-value | *p*- value |
|---|---|---|---|---|---|
| *Cercocebus torquatus** | NHFR (61) | 100 | 0 | -3.33 | 0.000 |
| | BMWS (60) | 96.7 | 3.3 | -3.88 | 0.000 |
| | KNP (9) | 77.8 | 22.2 | -0.76 | 0.445 |
| | NAFR (34) | 73.5 | 26.5 | 1.34 | 0.179 |
| | RHFR (14) | 14.3 | 85.7 | -2.81 | 0.016 |
| *Piliocolobus preussi*** | NHFR (61) | 65.6 | 34.4 | 2.24 | 0.065 |
| | BMWS (60) | 58.7 | 41.3 | 0.88 | 0.377 |
| | KNP (9) | 88.9 | 11.1 | 2.165 | 0.030 |
| | NAFR (34) | 29.4 | 70.6 | -1.46 | 0.143 |
| | RHFR (14) | 35.3 | 64.7 | -1.28 | 0.200 |

* hunters' opinions compared using Wald-Wolfowitz Runs Test: ** hunters' opinions compared using Mann-Witney U Test. NHFR = Nkwende Hills Forest Reserve; BMWS = Banyang-Mbo Wildlife Sanctuary; KNP = Korup National Park; NAFR = Nta-Ali Forest Reserve; RHFR = Rumpi Hills Forest Reserve. In parentheses: the sample size or the number of hunters interviewed around each protected area.

Sanctuary, the Nkwende Hills Forest Reserve and the Forest Management Unit (FMU) 11-001.

*Encounter rates compared with those 10 years ago*

Over 286.9 km covered, *P. preussi* was encountered only in Korup National Park (ER = 0.02 groups/km), while *C. torquatus* was encountered in Korup National Park (ER = 0.01 groups/km), Banyang-Mbo Wildlife Sanctuary (ER = 0.03 groups/km) and Nkwende Hills Forest Reserve (ER = 0.05 groups/km).

*Cercocebus torquatus* is suspected to have undergone a decline in ER of 97.7% in Banyang-Mbo Wildlife Sanctuary, between 2000 and 2012 (Table 2). In Korup National Park, from 2001−2003 to 2012, the species' trend has been stable. In the Nkwende Hills Forest Reserve, the negative but minor change suggests that the species is stable or fluctuating. Nta-Ali Forest Reserve showed a decline of 100%.

The ER of *P. preussi* has declined by 66.7% in Korup National Park (Table 2). The species was not encountered in previous surveys of Banyang-Mbo Wildlife Sanctuary and the Nta-Ali Forest Reserve. It is believed absent in the Nkwende Hills Forest Reserve, suggesting an estimated decline of 100% (Table 2).

Altogether, in the Korup region, *P. preussi* has undergone a mean decline of 83.4% and *C. torquatus* has undergone a mean decline of 53.4%. Based on the perceptions of hunters, ER, and field observations, we also suspect a decline in the extent of occurrence and or habitat quality of both species in the Korup region.

*Threats to the red-capped mangabey and Preuss's red colobus in the Korup region*

Our data reveal that overhunting, habitat destruction, trapping, disease, predation, and hunting with dogs are the main threats to both species. There are significant differences between the hunters' perceptions on threats to *C. torquatus* and *P. preussi* (Kruskal-Wallis ANOVA: H (7, N = 40) = 25.469; $p < 0.00$). Hunting is the main threat for *C. torquatus* and *P. preussi* according to 53.9% and 54.9% of the hunters, respectively, ranking significantly higher than habitat destruction for *C. torquatus* (Z = -2.68; $p = 0.007$) and *P. preussi* (Z = -2.68; $p = 0.007$). In general, overhunting was significantly higher than other threats in all sites ($p < 0.05$).

Habitat destruction is the second most salient threat according to 29.8% and 28.7% of hunters for *C. torquatus* and *P. preussi*, respectively.

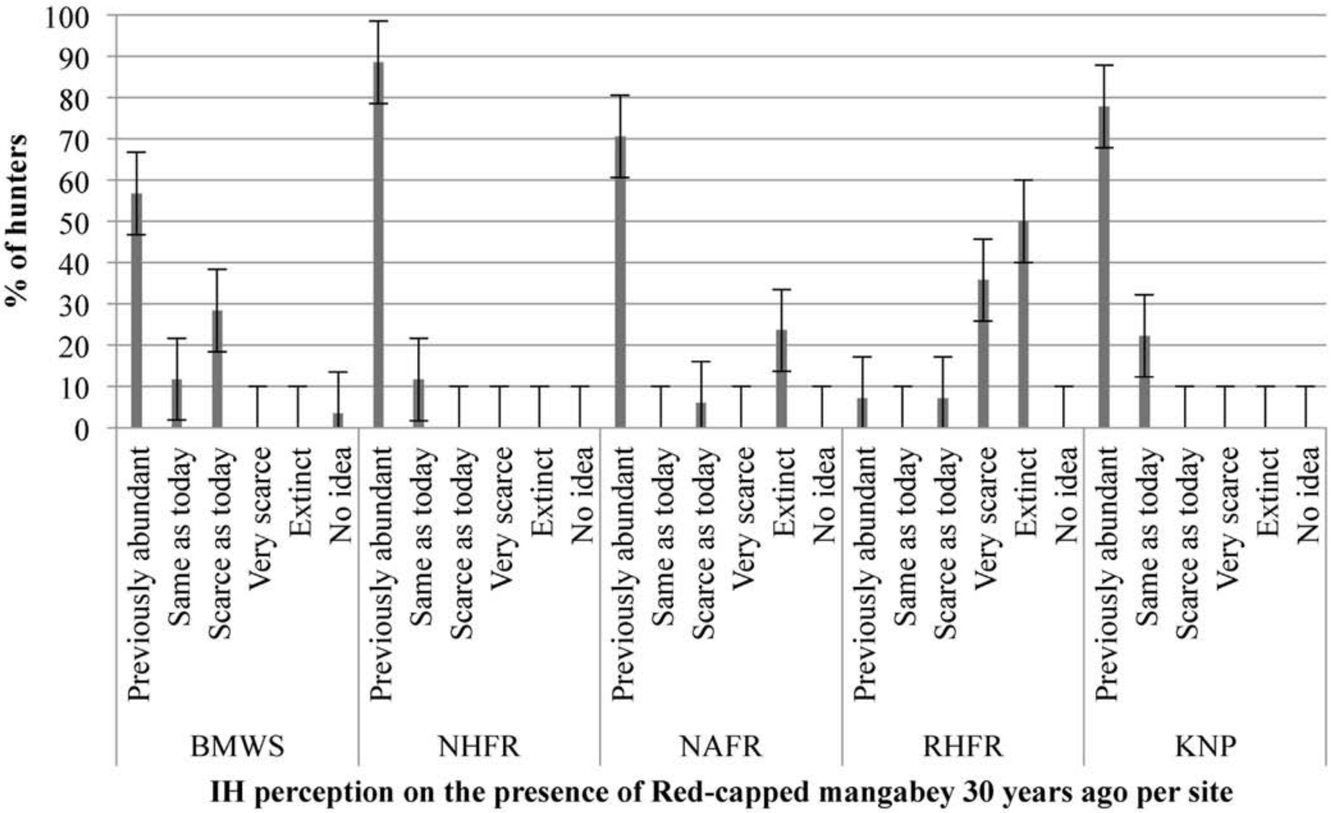

**Figure 2.** Perception of hunters on the trend of abundance of red-capped mangabey in the Korup region. KNP = Korup National Park; BMWS = Banyang-Mbo Wildlife Sanctuary; NHFR = Nkwende Hills Forest Reserve; NAFR = Nta-Ali Forest Reserve; RHFR = Rumpi Hills Forest Reserve. The error bars represent the standard error of the mean.

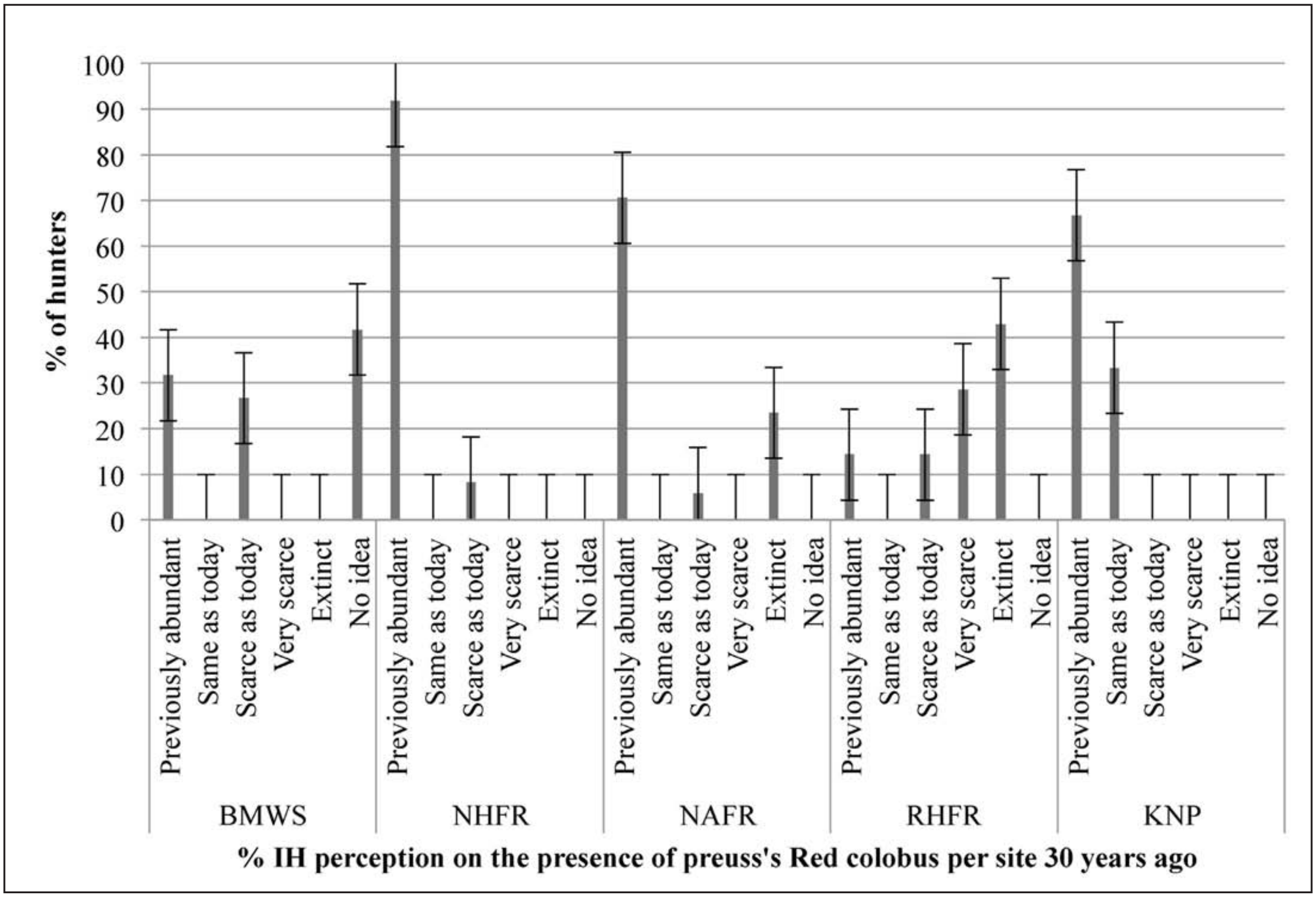

**Figure 3.** Perception of hunters on the trend of abundance of Preuss's red Colobus in the Korup region. KNP = Korup National Park; BMWS = Banyang-Mbo Wildlife Sanctuary; NHFR = Nkwende Hills Forest Reserve; NAFR = Nta-Ali Forest Reserve; RHFR = Rumpi Hills Forest Reserve. The error bars represent the standard error of the mean.

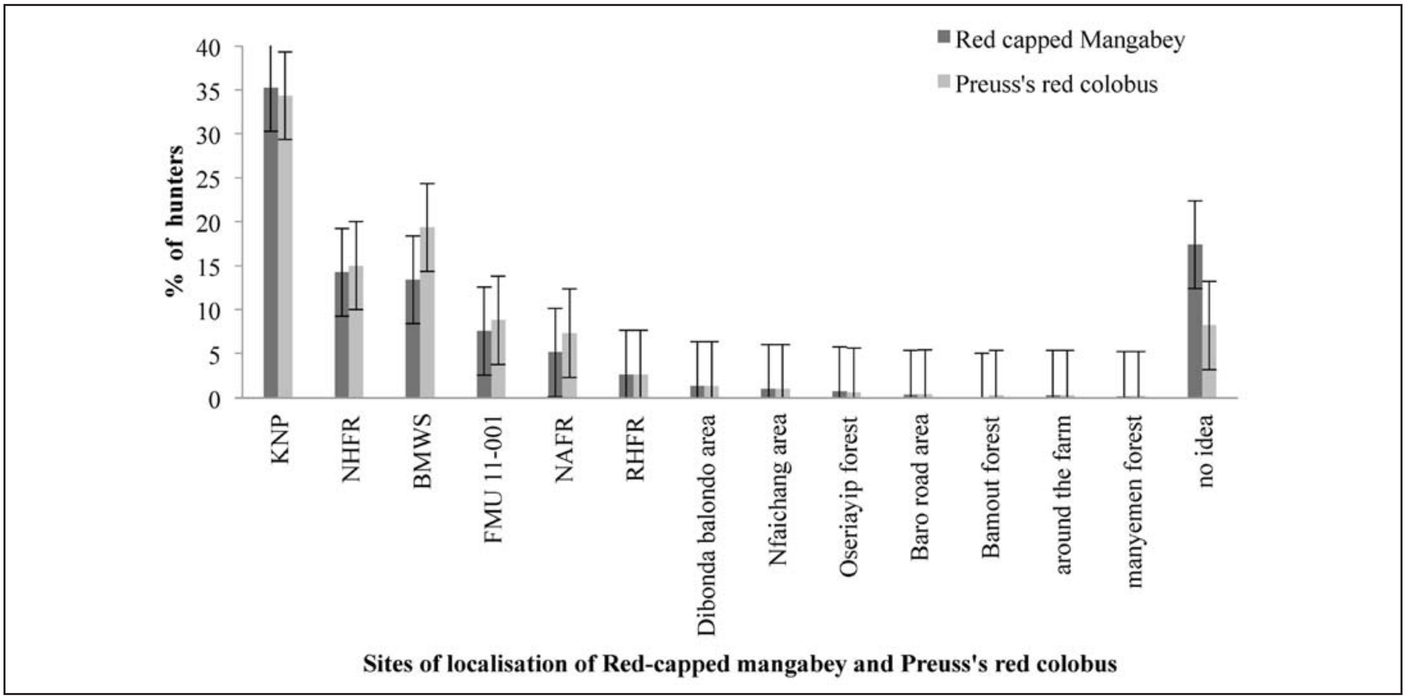

**Figure 4.** Perception of hunters on the possible sites of localisation of both species in the Korup region. KNP = Korup National Park; BMWS = Banyang-Mbo Wildlife Sanctuary; NHFR = Nkwende Hills Forest Reserve; NAFR = Nta-Ali Forest Reserve; RHFR = Rumpi Hills Forest Reserve. The error bars represent the standard error of the mean.

In the study area, high ER for human activities were recorded in all sites except in Korup National Park where it was relatively lower. Accordingly, negative, but low, correlation coefficients were recorded between ER of human activities and ER of *C. torquatus* and *P. preussi* per site (Table 3).

## Discussion

### *Presence/absence and trends in abundance of red-capped mangabey and Preuss's red colobus*

Information from hunters' perceptions (Figs. 5 and 6), and ER (Fig. 7), suggest that *C. torquatus* has declined significantly in the Rumpi Hills Forest Reserve, and is probably declining in Nta-Ali Forest Reserve. It is suspected that remaining populations of the species in Nta-Ali Forest Reserve may have crossed to the hilly areas of Banyang-Mbo Wildlife Sanctuary. The species abundance is also suspected to have declined in Korup National Park. In the Nkwende Hills Forest Reserve and Banyang-Mbo Wildlife Sanctuary, its abundance is probably stable, but low (Fig. 8). Both Banyang-Mbo Wildlife Sanctuary and the Nkwende Hills Forest Reserve may have served as important sites for remaining fragmented groups of this species. Between 1999 and 2002, a bushmeat market survey indicated relatively low offtakes for *C. torquatus* in the Banyang-Mbo area (Willcox and Nambu 2007). This suggests that the species was then already rare, or that the remaining population had been fragmented by excessive hunting. Oates (2011) confirmed that the species occurs in Banyang-Mbo Wildlife Sanctuary and Korup National Park, although management and anti-poaching systems are ineffective. The decreasing occurrence of the species in Korup National Park is of major concern, and ongoing threats may force fragmented populations into nearby forests such as the Nkwende Hills Forest Reserve. Populations in these areas are unlikely to survive, however, if the threats persist.

Regarding *P. preussi*, hunters perceive that it has declined significantly in the Rumpi Hills Forest Reserve and Nta-Ali Forest Reserve, and is probably declining in the Nkwende Hills Forest Reserve, and is suspected to have declined in Banyang-Mbo Wildlife Sanctuary (Figs. 9 and 10). The same conclusion is supported by encounter rate during our surveys (Fig. 11). The species is probably stable only in Korup National Park (Fig. 12). Willcox and Nambu (2007) recorded no carcasses of *P. preussi* around the Banyang-Mbo area between 1999 and 2002. Korup National Park remains the primary area where this species can still be encountered. Oates (2011) attributes declines in Korup National Park to ineffective anti-poaching systems. In the Nkwende Hills Forest Reserve, this

**Table 2.** Classification of *C. torquatus* and *P. preussi* using ER according to IUCN (2011) species classification criteria.

| Zone | Species | Source | Survey period | ER ≥ 10 years ago | ER today | Change | % Change | Status | % Decline (IUCN) | IUCN category |
|---|---|---|---|---|---|---|---|---|---|---|
| KNP | *C. torquatus* | Dunn and Okon (2003) | 2001−2003 | 0.01 | 0.01 | 0.00 | 0.00 | Stable | 53.43 | EN A2b |
| BMWS | | Nchanji (2002) | 2002 | 1.32 | 0.03 | - 1.29 | 97.72 | Decline | | |
| NHFR | | Forboseh *et al.* (2007) | 2002−2003 | 0.06 | 0.05 | - 0.01 | 16.66 | Decline | | |
| NAFR | | Waltert *et al.* (2002) | 1999−2002 | 0.23 | 0.00 | - 0.03 | 100.00 | Decline | | |
| KNP | *P. preussi* | Dunn and Okon (2003) | 2001−2003 | 0.06 | 0.02 | - 0.04 | 66.70 | Decline | 83.40 | CR A2b |
| BMWS | | Nchanji (2002) | 1999−2002 | 0.00 | 0.00 | 0.00 | 0.00 | Absent | | |
| NHFR | | Waltert *et al.* (2002) | 1999−2002 | 0.01 | 0.00 | -0.01 | 100.00 | Decline | | |
| NAFR | | Waltert *et al.* (2002) | 1999−2002 | 0.00 | 0.00 | 0.00 | 0.00 | Absent | | |

% Change = [(ER today – ER 10 years ago)/ER 10 years ago] * 100. KNP = Korup National Park; BMWS = Banyang-Mbo Wildlife Sanctuary; NHFR = Nkwende Hills Forest Reserve; NAFR = Nta-Ali Forest Reserve. There is no previous or recent data on ER for either species for the Rumpi Hills Forest Reserve. Data for NAFR are from surveys located very close to the reserves and in the support zone of KNP for *P. preussi* in NHFR.

**Table 3.** Encounter rates and correlations between ER of human activities and ER for both species.

| Zone | Survey effort (km) | ER *C. torquatus* | ER *P. preussi* | ER Human activities | Correlation between ER for human activities and for *C. torquatus* | Correlation between ER for human activities and for *P. preussi* |
|---|---|---|---|---|---|---|
| KNP | 124.23 | 0.01±0.04 | 0.02±0.06 | 0.46±1.19 | 0.00 | -0.12 |
| BMWS | 55.11 | 0.03±0.09 | 0 | 2.36±0.68 | -0.26 | 0.00 |
| NHFR | 36.58 | 0.05±0.17 | 0 | 4.23±2.65 | -0.46 | 0.00 |
| NAFR | 70.99 | 0 | 0 | 2.07±0.88 | 0.00 | 0.00 |

KNP = Korup National Park; BMWS Banyang-Mbo Wildlife Sanctuary; NHFR = Nkwende Hills Forest Reserve; NAFR = Nta-Ali Forest Reserve. ER = Encounter rate (number of groups encountered per kilometer). Human activities = cartridges, harvesting of NTFPs, trapping and illegal timber exploitation.

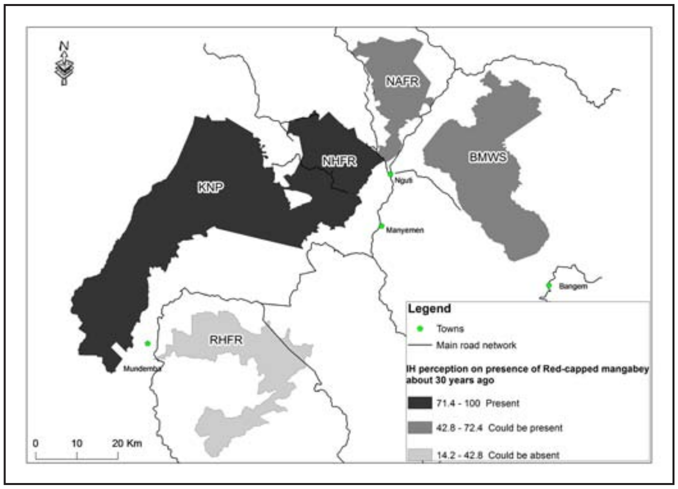

**Figure 5.** Hunters perception on the presence of red-capped mangabey 30 years ago.

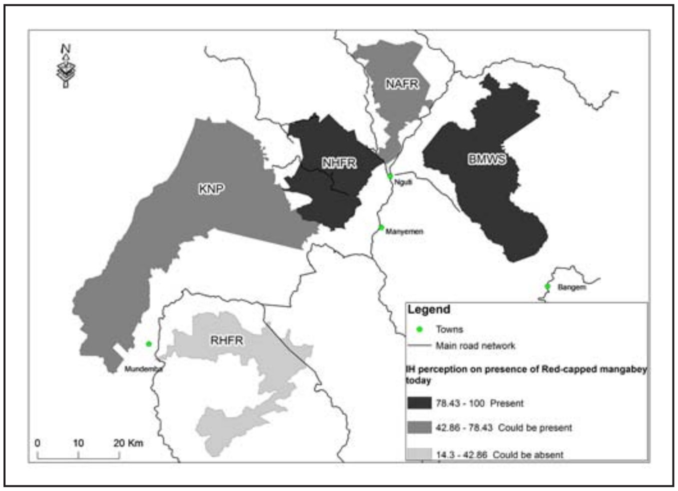

**Figure 6.** Hunters perception on the presence of red-capped mangabey today.

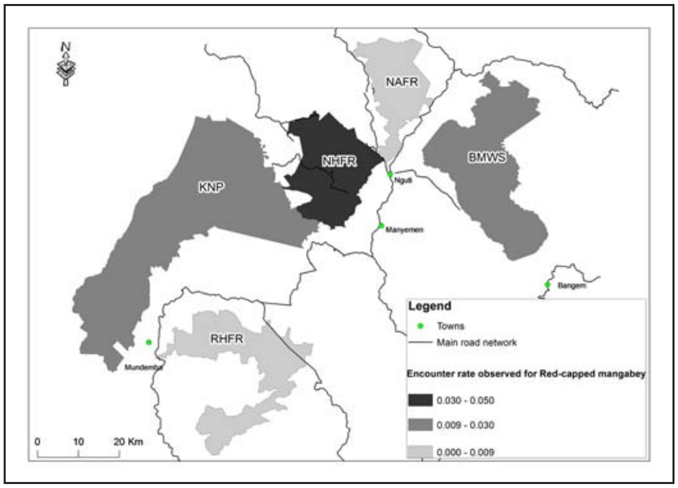

**Figure 7.** Relative abundance of red-capped mangabey today.

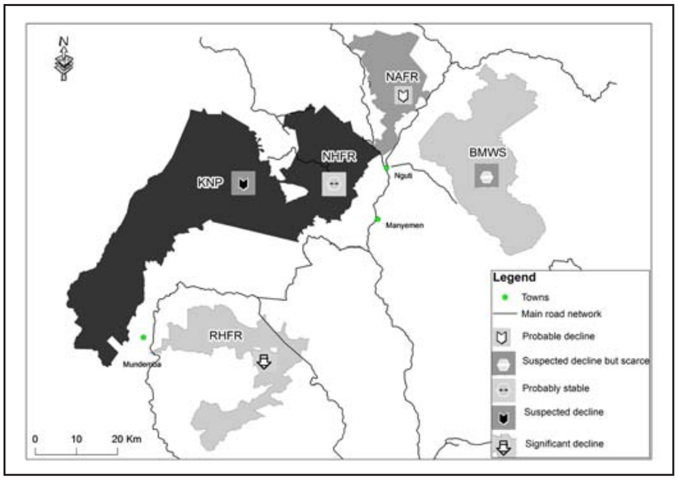

**Figure 8.** Temporal changes in red-capped mangabey abundance based on hunters perceptions.

species has probably declined because of its vulnerability to hunting and habitat disturbance (Oates 2011).

Loss of primate diversity, especially in high priority conservation areas, has already been discussed (Myers *et al.* 2000). *Piliocolobus preussi* was for long known to occur primarily in Korup National Park (Struhsaker 2005), but the species has been documented to occur in the proposed Ebo National Park, Littoral, Cameroon (Dowsett-Lemaire and Dowsett 2001). If it begins to decline in these main strongholds, it is probable that it may go extinct in the wild. However, it is not only *P. preussi* that is threatened in these high priority conservation areas. Some hunters still have the opinion (not significant) that the species can be encountered in NHFR and BMWS even though, if nothing is done to enhance the effective management of these protected areas, both species may become very rare or even go extinct in the near future. A recent survey of wildlife uses around the Nkwende Hills Forest Reserve, Korup National Park and Banyang-Mbo Wildlife Sanctuary confirmed that *P. preussi* and *C. torquatus* are very scarce and represent only 1.8% and 0.8% of mammals used for food, medicines and income (Aghomo 2011). Similarly, recent wildlife surveys in FMU 11005, Korup National Park, Banyang-Mbo Wildlife Sanctuary and the proposed concession for the development of oil palm plantations by Herakles Farms confirm that both *P. preussi* and *C. torquatus* are uncommon in these areas (Bobo *et al.* 2013, 2014a, 2014b; Kupsh *et al.* 2014).

### *Occurrence of red-capped mangabey and Preuss's red colobus*

Aside from Korup National Park, few hunters confirm that Banyang-Mbo Wildlife Sanctuary and the Nkwende Hills Forest Reserve are sites where both species can be found (though not significant). Forest Management Unit (FMU) 11-001, located between Korup National Park and the Nkwende Hills Forest Reserve (see Fig. 1), may also temporarily contain the species (see also Usongo 1995), but logging will certainly destroy the habitats preferred by both species, while facilitating access of these areas to poachers (Waltert *et al.* 2002).

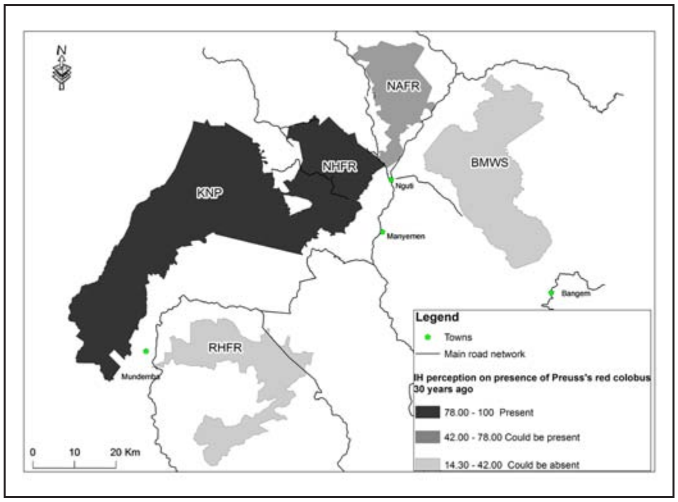

**Figure 9.** Hunters perception on the presence of Preuss's red colobus 30 years ago.

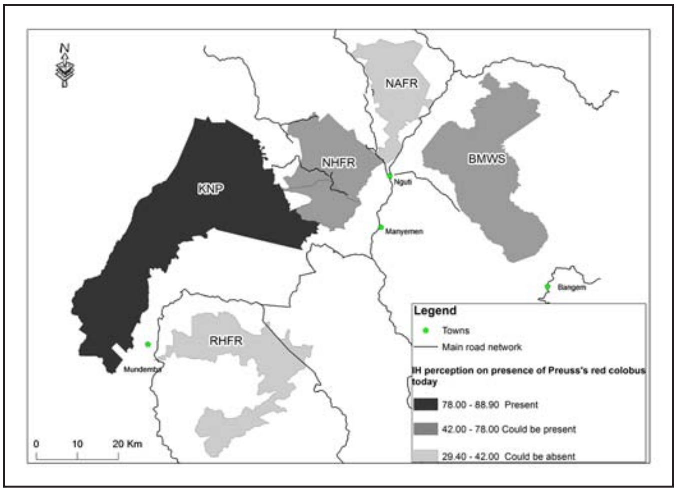

**Figure 10.** Hunters perception on the presence of Preuss's red colobus today.

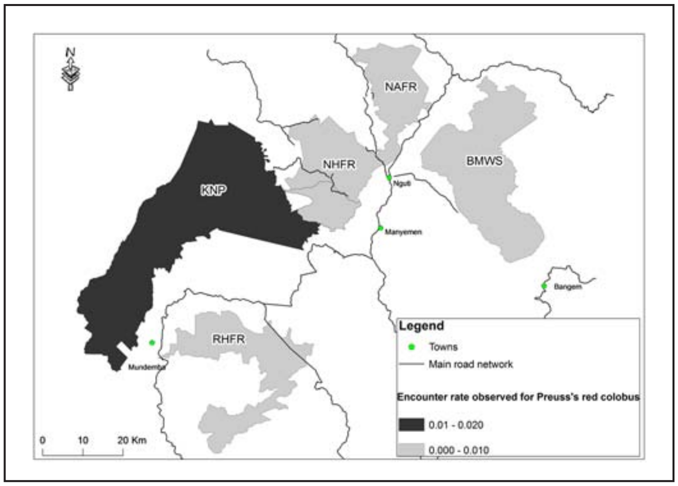

**Figure 11.** Relative abundance of Preuss's red colobus today.

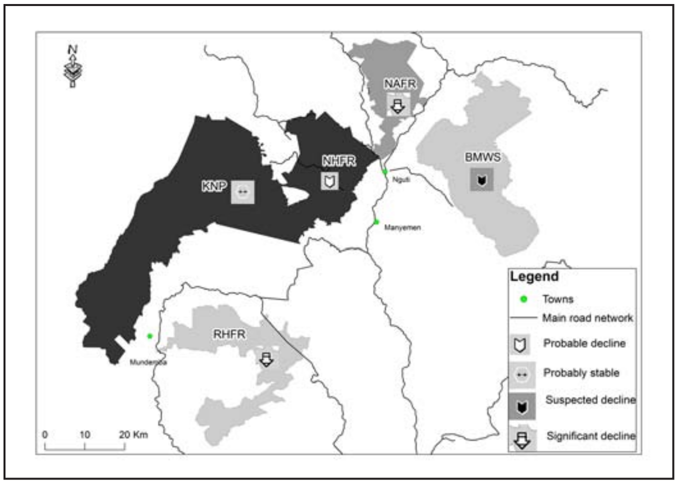

**Figure 12.** Temporal changes in Preuss's red colobus abundance based on hunters perceptions.

*Estimation of suspected changes in ER of red-capped mangabey and Preuss's red colobus*

The situation of *C. torquatus* in Banyang-Mbo Wildlife Sanctuary is explained by the fact that estimated offtakes between 1999 and 2002 (Willcox and Nambu 2007) were very high for a species already vulnerable (125 kg/person/year). In Korup National Park, an ER of 0.01 group/km was recorded in 2004–2005 (Linder 2008). The former suggests a stable ER for *C. torquatus* in the area over time. The negative but low change recorded in the Nkwende Hills Forest Reserve suggests that it may still harbor this species thanks to the inaccessible nature of many parts of the reserve and its strategic position at the northeast of Korup National Park (Ndeh *et al.* 2002). The sharp decline in abundance of *C. torquatus* recorded in Nta-Ali Forest Reserve is likely a result of the degraded nature of the reserve and intensive human activities there. In addition, the reserve was recently converted into a logging unit (FMU 11006) which may further threaten the species (see also Waltert *et al.* 2002); giving more reason to infer/suspect a decline in the extent of occurrence and habitat quality of the species in the Korup region.

For *P. preussi*, a lower ER of 0.05 group/km was already recorded in 2004–2005 in Korup National Park (Linder 2008). Meanwhile, no groups at all were encountered in Banyang-Mbo Wildlife Sanctuary and Nta-Ali Forest Reserve in 2001 or 2012, implying that the species is very scarce or has even disappeared from the area. In Nta-Ali Forest Reserve, *P. preussi* was listed as a species still to be confirmed (MINEF 2001). Nonetheless, hunters continue to believe that individuals can still be found occasionally, but not significantly, especially in BMWS. Similarly, in the Nkwende Hills Forest Reserve, a serious decline was recorded for the species implying that the species may be very scarce or even locally extinct.

The mean percentage declines in ER estimated for *P. preussi* and *C. torquatus* satisfy categories CR A2b and EN A2b, respectively (IUCN 2011) for the range of both species in the study area.

From the information provided by the hunters, and the recent conversion of Nta-Ali Forest Reserve into a logging

**Photo 3.** Active snare trap installed by hunters (non-selective harvesting of ground species including red-capped mangabey).

**Photo 4.** Locally affordable cartridge shells used by primate hunters.

concession, we also suspect/infer a decline in the Extent of Occurrence and/or habitat quality in the Korup region, and especially in the Rumpi Hills Forest Reserve and Nta-Ali Forest Reserve (criterion c of IUCN species classification criteria).

*Threats to red-capped mangabey and Preuss's red colobus*

In many tropical forests, hunting for bushmeat is the primary threat to large vertebrates (Fa *et al.* 2002). The alarm bells for threats to wildlife have already rung in previous IUCN publications (Lee *et al.* 1988). In the Korup region, overhunting is the main threat to the survival of the remaining groups of both species (as in IUCN 2008), while habitat destruction is a second order threat. Additionally, trapping is regarded as a growing threat to *C. torquatus* in the study area, because individuals of this species spend most of their time on the ground, hence increasing the possibility of being caught in traps (Photo 3). In the study area, poaching is a result of the lack of regulation of community hunting practices, of the readily available and cheap gun cartridges (Photo 4), and little to no restrictions or effective taboos on hunting for either of the two species (Bobo *et al.* 2012). Habitat destruction is manifested by agricultural expansion (forest clearing and large-scale industrial plantations), and logging, especially around forest reserves. In the study area, both species are easily hunted because of their large size and the fact that they both live in large groups (see also Isaac and Cowlishaw 2004). As in many areas, unrestricted human activities have an overall negative influence on the abundance of both species.

For an effective management of both species, it is recommended that:

- *C. torquatus* be reclassified from VU (A2cd) to EN (A2bc)
- *P. preussi* should be maintained as a critically endangered species;
- Hunting primates with dogs should be considered as a paramount risk to red-capped mangabey;
- At the local level, both species should urgently be reclassified from Class C (species partially protected, their capture or killing are regulated) to Class A (species integrally protected and prohibited from hunting).
- Studies on species/area relationship should be conducted to define clearly the current Area of Occupancy and Extent of Occurrence for both species in the Korup region.
- The conservation importance of hilly and remote areas should be determined in order to create protected areas that are not easily accessible by poachers;
- Guidelines for the use of national or regional Red List categories for species with wide ranges should be developed by IUCN;
- The use of local knowledge could be explored in studying the status of species particularly at this point in time where conservation efforts and research results are disappointing (especially for scarce species).

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# The Mount Kenya Potto is a Subspecies of the Eastern Potto *Perodicticus ibeanus*

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**Abstract:** The Mount Kenya potto is currently considered a subspecies of the western potto (i.e., *Perodicticus potto stockleyi*). We argue that the Mount Kenya potto is a subspecies of the eastern potto (i.e., *Perodicticus ibeanus stockleyi*). This subspecies has not been observed alive for 79 years, and is assessed on the 2017 Red List as Critically Endangered (Possibly Extinct). We indicate priority field sites in which to search for *P. i. stockleyi*.

**Résumé:** Le potto du Mont Kenya est actuellement considéré comme une sous-espèce du potto occidental (c-à-d. *Perodicticus potto stockleyi*). La présente étude suggère que le potto du Mont Kenya est une sous-espèce du potto oriental (c-à-d. *Perodicticus ibeanus stockleyi*). Cette sous-espèce n'a plus été observée vivante depuis 79 ans. En tant que telle, elle a été évaluée comme En danger critique (peut être Éteinte) sur la Liste Rouge 2017. Cet article présente des sites de terrain prioritaires pour la recherche de *P. i. stockleyi.*

**Keywords:** Aberdare, biogeography, conservation, primates, taxonomy

## Potto Taxonomy

The pottos, genus *Perodicticus* Bennett, 1831, are small (*c*. 1.5 kg), arboreal, quiet (no loud call), highly cryptic, nocturnal primates, endemic to the moist forests of tropical Africa, from southeast Senegal (perhaps The Gambia) eastwards to central Kenya (Fig. 1). The taxonomic arrangement of *Perodicticus* is not yet resolved. For many years, the genus was regarded as monotypic (for example, Jenkins 1987; Groves 2001, 2005; Grubb *et al*. 2003; Butynski and De Jong 2007; Butynski 2013; Pimley and Bearder 2013). Several authors (for example, Groves 2001; Grubb *et al*. 2003), however, suggested that further study might show that *Perodicticus* contains several species. Subsequent detailed morphological study (dentition, cranium, post-cranium, body size, and pelage) by Stump (2005) and Ravosa (2007), together with mtDNA data provided by Roos *et al.* (2004) and Pozzi *et al*. (2015), yield convincing evidence for at least three species of *Perodicticus*: the western potto *P. potto* (Müller, 1776), the eastern potto *P. ibeanus* Thomas, 1910, and the central potto *P. edwardsi* Bouvier, 1879. Oates (2011), Nekaris (2013), Oates *et al*. (2016), De Jong *et al*. (2017), Svensson and Pimley (2017), and Svensson *et al*. (2017) all follow the three-species concept for *Perodicticus*.

## Taxonomic Position of the Mount Kenya Potto

Butynski and De Jong (2007), who treated *Perodicticus* as a monotypic genus, reviewed the taxonomy and biogeography of the potto *Perodicticus potto*, and described a new subspecies—the Mount Kenya potto *Perodicticus potto stockleyi* Butynski and De Jong, 2007 (Fig. 2). This subspecies is known from only one specimen, collected by Lt.-Col. Charles Hugh Stockley in 1938, at 1,830 m above sea level (asl) on Mount Kenya, central Kenya. The holotype (MK-24) resides at the National Museums of Kenya, Nairobi, Kenya.

The elevation of *ibeanus* to species level means that the taxonomic position of *stockleyi* needs to be reassessed. Nekaris (2013) and Oates *et al.* (2016) accepted the three-species concept for *Perodicticus*, but retained *stockleyi* as a subspecies of *P. potto*. Geographically, however, *stockleyi* is much closer to *P. ibeanus* (*c*. 195 km) than to *P. potto* (*c*. 3,450 km) (Fig. 1). The large geographic range (i.e., extent of occurrence) of *P. edwardsi* (*c*. 2,430,000 km²) lies between that of *P. potto* and *P. ibeanus*. In addition, like *P. ibeanus*, but unlike most *P. potto* and most *P. edwardsi*, the pelage of *stockleyi* is very woolly and rippled, and has a dark russet 'saddle' over the shoulders with guard hairs that are heavily frosted silver-grey, although the saddle is not as obvious as for *P. i. ibeanus*

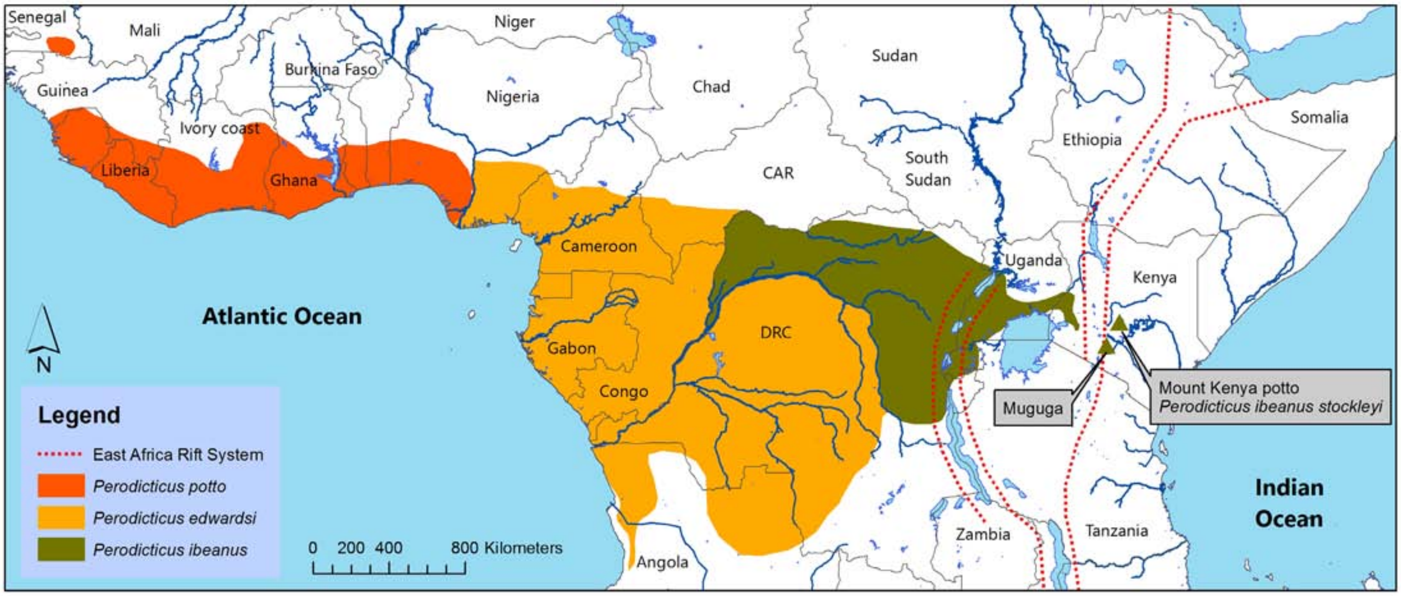

**Figure 1.** Geographic range of the three species of *Perodicticus*, type locality for the Mount Kenya potto *Perodicticus ibeanus stockleyi*, and location of Muguga. Based on Butynski and De Jong (2007), Oates (2011), De Jong *et al*. (2017), Svensson and Pimley (2017), and Svensson *et al*. (2017).

(see Figs. 4–7 in Butynski and De Jong 2007). It appears, therefore, that *stockleyi* is a subspecies of *P. ibeanus*, not of *P. potto.* As such, there are two subspecies for *P. ibeanus*: eastern potto *P. i. ibeanus* and Mount Kenya potto *P. i. stockleyi*. With this taxonomic change, the geographic distribution of *P. ibeanus* (Fig. 1) is as follows:

*P. i. ibeanus* – Democratic Republic of Congo (DRC) from the left (east) bank of the Ubangi River south to the right (north) bank of the Congo River, south along the right (east) bank of the Lualaba River to the Lulindi River, east to the Itombwe Mountains (Baraka) and northwest corner of Lake Tanganyika, then northeast through northwest Burundi, Rwanda, southwest and south Uganda, to the Kakamega, Nandi, and Mau Forests of southwest Kenya. The geographic range (i.e., 'extent of occurrence') is *c*. 850,000 km² (Butynski and De Jong 2007).

*P. i. stockleyi* – Known only from one site at 1,830 m asl on Mount Kenya, central Kenya.

## Should *stockleyi* be Elevated to Species Status?

Although *stockleyi* is here designated as a subspecies, it should be noted that the single specimen available is not only phenotypically (i.e., diagnosably) distinct from the large number of *Perodicticus* specimens available, it is also (almost certainly) geographically (i.e., reproductively) isolated from other *Perodicticus* (both by the Eastern Rift Valley and by a distance thought to be at least 175 km). As such, under the 'Phylogenetic Species Concept' (Cracraft 1983; Groves 2001, 2004, 2012; Cotterill *et al*. 2014; Rylands and Mittermeier 2014), this taxon should be considered a species, *Perodicticus stockleyi.* We believe, however, that species designation at this time is premature given (1) that only one specimen is available and, therefore, we do not know anything about the extent of variation of phenotypic characters present in the population of *Perodicticus* on Mount Kenya (and, apparently, also on the Aberdares Range), and (2) the need for additional field time in support of our contention that this population of *Perodicticus* is indeed isolated.

## Conservation Status of *Perodicticus ibeanus stockleyi*

It appears that *P. i. stockleyi* occurs at low density and/or has a highly localized distribution—or is extinct. Several primate surveys since 2001 in forests >1,050 m asl on and in the vicinity of Mount Kenya and the Aberdare Range have failed to reveal evidence of this subspecies (Butynski 1999; Butynski and De Jong 2007). As such, 10 years after being described, *P. i. stockleyi* appears on the 2017 IUCN Red List as Critically Endangered (Possibly Extinct) (Butynski and De Jong 2017).

The main threats to the long-term survival of *P. i. stockleyi* include habitat degradation, fragmentation, and loss, particularly from expanding, intensive, agriculture and settlement (Butynski and De Jong 2007, 2017). The cause of these threats is the rapidly growing human population (doubling every 20–25 years) in the region of Mount Kenya and the Aberdare Range. These two large blocks of forest are under great pressure. There, most of the mid-altitude (transition) and much of the montane forest has already been destroyed (Butynski and De Jong 2014).

## Where to Search for *Perodicticus ibeanus stockleyi*

Many areas of highland moist forest (>1,300 mm mean annual rainfall) east of the Eastern (Gregory) Rift Valley have not been surveyed for *P. i. stockleyi*. Most forest lies within Mount Kenya National Park and Aberdare National Park, and in the many contiguous or nearby forest reserves. The degree of protection received by these forests, however, varies greatly—as does the level of past exploitation and damage. Since *P. ibeanus* can persist in successional and secondary forest, and is often found on forest edge close to human habitation, chances are that *P. i. stockleyi* occurs in this region. Future surveys to locate *P. i. stockleyi* should be conducted in the wettest forest of the Mount Kenya and the Aberdare Range region up to 2,300 m asl (the known altitudinal range for *P. ibeanus* is 600–2,300 m asl and the range of mean annual rainfall is 1,300–1,900 mm; Butynski and De Jong 2007), with a focus on moist forest at 1,500–2,100 m asl (the *P. i. stockleyi* holotype was collected at 1,830 m asl).

More specifically, on Mount Kenya, there are small areas of moist forest to as low as 1,800 m asl on the southwest slope along the lower reaches of the Thego River and Sagana River, and to as low as 1,500 m asl on the southeast slope, west of the villages of Kirege, Chuka, Kiini, and Mutindwa. Off the northeast flank of Mount Kenya, moist forest is present at 1,400 m asl in Meru Forest and as low as 1,050 m asl in Ngaia Forest at the north end of the Nyambeni Range.

On the Aberdare Range, only small areas of moist forest remain, confined to the extreme south end of the range at about 1,800–2,100 m asl. Forty-eight years ago, on 29 April 1969, Peirce (1972, 1975, pers. comm.) obtained one potto collected in Ndiya Village, Muguga Estate, about 30 km northwest of Nairobi (*c*. 2,100 m asl; *c*. 1,300 mm mean annual rainfall) on the south end of the Aberdares Range. This is the only other record (and first published record) for potto east of the Eastern Rift Valley. This specimen no longer exists; obtained for a parasitological study, it was neither described nor photographed. It is likely that this was *P. i. stockleyi* Butynski and De Jong 2007. Today, the forests nearest to Muguga are Gacuthi Forest, Bama Forest, and Gatamaiyo Forest Reserve. These forests should be searched for potto.

Being small, nocturnal, cryptic, and lacking a loud call, *P. ibeanus* is a difficult primate to detect, particularly if at low density. At some sites, the encounter rate with *P. ibeanus* during nocturnal primate surveys (using torchlight to elicit tapetal reflection) is as low as 0.02/h. It is recommended, therefore, that sites of a few square kilometers be searched at night for >50 h before concluding, with some confidence, that *P. ibeanus* is not present (Butynski and De Jong 2007).

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**Figure 2.** The Mount Kenya potto *Perodicticus ibeanus stockleyi.* Drawing by Stephen D. Nash from photographs and detailed written descriptions of the holotype. Reproduced from Butynski and De Jong (2007).

Muguga Estate in 1969, Jean-Pierre d'Huart for the French version of the abstract, and Stephen D. Nash for the drawing of *P. i. stockleyi*.

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# On the Taxonomy of *Erythrocebus* with a Re-evaluation of *Erythrocebus poliophaeus* (Reichenbach, 1862) from the Blue Nile Region of Sudan and Ethiopia

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**Abstract:** *Erythrocebus* taxonomy has been dormant for almost a century now, with the consequent costs in our understanding of the biology of the genus and for the conservation of these remarkable monkeys. New data on the distribution and physical appearance of patas monkeys in Ethiopia, together with a review of the old taxonomic literature, allows to us disentangle some questions concerning the taxonomy of *Erythrocebus* in northeast Africa. Specifically, I resurrect *Erythrocebus poliophaeus* (Reichenbach, 1862) as a valid species that is found along the Blue Nile Valley at the extreme northeastern portion of the range of the genus. The still little-known, but certainly limited, extent of the range of the species is a cause for conservation concern, but it may be that *Erythrocebus poliophaeus* could serve as a flagship species for conservation in the biologically rich Western Ethiopian Escarpment region and adjoining Sudan. The proposed common English names for the new species are Heuglin's patas monkey (Heuglin was the famous German explorer who discovered it) or the Blue Nile patas monkey.

**Keywords:** Benshangul Gumuz State, Ethiopia, Sudan, Primates, Cercopithecidae, patas monkey, taxonomy

## Introduction

Schwarz (1927) carried out the last taxonomic revision of *Erythrocebus* Trouessart ninety years ago. His arrangement of *Erythrocebus* as a monotypic genus, with three subspecies—*patas* (Schreber, 1774), *pyrrhonotus* (Hemprich and Ehrenberg, 1829), and *baumstarki* Matschie, 1905)—was widely adopted. Dekeyeser (1950) subsequently added the subspecies *villiersi* from the Air Massif, Niger. As already critically noted by Allen (1925), previous taxonomic decisions regarding *Erythrocebus* were often based on single specimens of unknown origin or only on immature individuals; yet, as argued by that author, this does not mean that some of the historically described taxa are not valid. Nearly one century later, this taxonomic problem has still to be resolved, and this is not an isolated case as far as most large African mammals are concerned (Gippoliti and Carpaneto 1995). In 1971, Pierre Dandelot remarked on the confusion in African primatology regarding species and subspecies, and that taxonomists, "at the risk of being treated as 'splitters' by the advocates of simplification," should recognize a greater diversity than was customary at the time. This is just one more taxonomic question which could possibly be answered by applying modern (molecular) methods to available museum collections, integrated by the study of photographic materials of patas monkeys from known localities (cf. De Jong and Butynski 2010).

Groves (2001) and Grubb *et al.* (2003) did not recognize subspecific taxa in *Erythrocebus*, retaining just one species, *E. patas*; this probably reflects more the scarcity of hypodigms in museums than any satisfaction with this taxonomic arrangement. Given the huge distributional range of *Erythrocebus*, it seems unlikely that the current monotypic classification describes the diversity of the genus correctly, all the more since other savannah dwelling African primate genera, such as *Papio* and *Chlorocebus*, comprise multiple species.

*Erythrocebus* taxonomy was also probably negatively affected by an overemphasis on the nose color (black or white). Awareness of nose color changes due to age or physiology (Loy 1974) and belief in a clinal variation from the black nose of true patas to the white nose of eastern *pyrrhonotus* (Schwarz 1960, cited as a pers. comm. in Hill 1966) combined initially to instill confusion, which subsequently resulted in disinterest in the issue.

## Conservation Implications

Until recently, *Erythrocebus patas*, assessed in 2008 as a monotypic genus with no subspecies, was classified as Least Concern on the IUCN Red List of Threatened Species (Kingdon *et al.* 2017), undoubtedly the result of the deficient current taxonomy, the ample geographic range and the scarcity of research. Further, savannah primate species are generally believed to be less at risk than forest primates, but this is clearly an oversimplification that may be encouraged by an excessively-lumped alpha taxonomy (Gippoliti *et al.* 2017). Where the species has received attention, as in Kenya, it has been found to have suffered an historical range decline of about 50% (De Jong *et al.* 2008). The taxon *baumstarki* of northeastern Tanzania may well be in need of more research and conservation efforts (De Jong *et al.* 2009), but subspecies of widespread savannah primates have never received much attention—part of the 'subspecies problem' in conservation (Gippoliti and Amori 2007). The unique recognized species is listed in Appendix II of CITES, and international trade is thus allowed regardless of possible conservation problems among cryptic taxonomic units. *Erythrocebus patas* was reassessed in 2016 as 'Near Threatened' on the IUCN Red List, and the conservation status of the three subspecies recognized by Schwarz (1927) were assessed for the first time, with the following results: *patas* – 'Near Threatened'; *baumstarki* – 'Critically Endangered'; and *pyrrhonotus* – 'Vulnerable' (Y. A. de Jong and T. M. Butynski 2016, unpubl.).

## Historical Background to *Erythrocebus* taxonomy

At the beginning of the 20th century, the number of recognized species in the genus *Erythrocebus* ranged from one to 12 (Pocock 1907; Elliot 1913; Matschie 1912). When Pocock subsumed all East African patas monkeys into the subspecies *pyrrhonotus* Hemprich and Ehrenberg, 1829, he did it admittedly on the basis of very few specimens, and most were of unclear provenance (Pocock 1907: 745). On the basis of intraspecific variability, as found in two adult males from the same locality belonging to *Erythrocebus whitei* Hollister, 1910, Allen found it reasonable to follow Pocock's proposal (Allen 1925). Although it is possible that here Allen was not aware that minor differences could be due to the different social status of adult males (adult harem-living males and younger solitary males), he was certainly right in stating that, considering the poor materials at hand, "it is hardly probable that the three forms recognized by Matschie from Togoland will all prove tenable, or that there are two good forms in the Uele drainage of the Upper Congo or that the form from that region is really sufficiently different from *pyrrhonotus* of the Upper Nile region to require a special name" (Allen 1925: 429). He was, however, surely not right regarding his last point, given that the type locality of *pyrrhonotus*, Darfur and Kordofan (Sudan), is isolated from most of the other members of what are supposedly the same subspecies by formidable barriers to the east such as the White and Blue Niles or even the Rift Valley.

In the account of *Erythrocebus patas* by Isbell (2013) in a recent major treatise on African mammals, Kenyan patas monkeys serve to describe the characters of *Erythrocebus patas pyrrhonotus*. The author evidently followed the taxonomic account proposed by Pocock (1907) and Schwarz (1927), but the hypothesis that a name proposed for the patas monkey of Kordofan applies to a Kenyan patas should be tested if we wish to avoid further confusion in an already chaotic issue. Anchoring a name to its type locality seems a particularly valuable action if we want to disentangle decades of 'taxonomic inertia' and excessive lumping. Particularly as concerns the eastern part of the range, the presence of important river barriers (cf. Cotterill 2003) such as the two Nile rivers has been completely overlooked in assessing *Erythrocebus* taxonomy. Setzer (1956), for example, found that his unique Darfur specimen was much paler compared to other Sudanese specimens. Koch (1969) was aware of the extensive variability existing among Sudanese *Erythrocebus* and thought that a taxonomic revision was overdue. Given this, and after observing photos of patas monkeys from Southern Kordofan, it seems reasonable to restrict usage of *pyrrhonotus* at the subspecific level to the Darfur-Kordofan population west of the Nile, as also implied by Koch (1969). Hopefully, the validity of the proposed taxa for East African patas monkeys (*baumstarki* Matschie; *formosus* Elliot, 1909; *whitei* Hollister, 1910; and *albosignatus* Matschie, 1912) should be assessed by a thorough taxonomic revision that should also use molecular genetic analyses. Although museum materials remain scarce, with the ultimate goal of attracting more attention to the alpha taxonomy of the genus *Erythrocebus*, I here review the taxonomic literature on the genus and, with the help of recent literature and photos of wild patas monkeys, re-evaluate an old, forgotten species from the northern-eastern margin of the distribution of the genus in Sudan and Ethiopia.

## Taxonomy of *Erythrocebus* in Ethiopia

Historical records of *Erythrocebus* in Ethiopia indicate two geographic clusters (Yalden *et al.* 1977): one in the northwest and one in the southwest, apparently separated by the Blue Nile gorge. A uniquely dark form of patas monkey has been recently reported from Western Ethiopia (Yirga *et al.* 2010), and precisely two groups were encountered at almost the same time at 9°48.5'N, 34°42.6'E in agricultural lands around the Garabiche/Songa woodlands and at 9°53.76'N, 34°40.27'E near bamboo forest along the main road to Assosa and its adjacent cultivation sites—Bambesi Woreda (Benshangul Gumuz National Regional State). Two photos show features of the adult male, especially the long dark-gray/black fur on the withers that extends to the upper forelimbs, the black facial mask with a black nose, and ventral parts that are pinkish rather than pure white, and these clearly distinguish patas in the study site (Fig. 1) from other *Erythrocebus* seen

**Figure 1.** *Erythrocebus poliophaeus* (Reichenbach, 1862) from western Ethiopia (from Yirga *et al*. 2010).

elsewhere in East Africa and even in southwest Ethiopia (Fig. 2). A photo of an adult male near the Alatish National Park, not far from the village of Gelego (12°13'N, 35°53'E) (Heckel *et al.* 2007), perfectly agrees with the above, and both have the characters described for *poliophaeus* Reichenbach, 1862 (Fig. 3), of which *albigenus* Elliot, 1909, is certainly a junior synonym. In his description of *albigenus* (one adult captive male, type locality unknown but "somewhere in Sudan"), Elliot remarked that the face and nose were black, lacking a band between ear and eye, and the shoulder covered with very long black hairs annulated with cream color; he remarked also on the very long, mane-like hair on the hind neck and shoulders (Elliot 1909, 1913). The photos from Yirga *et al.* (2010) also show the species in an atypical habitat for the genus (close to bamboo forest). We might postulate that this species survived an arid period in a montane refugium in western Ethiopia.

Although *poliophaeus* is *de facto* unstudied in its natural range, the observations of Loy (1974) regarding changes in color of the faces in female *Erythrocebus* from Ethiopia must be referred to this taxon (and certainly not to *E. patas sensu strictu*, as supposed by Isbell 2013), as confirmed by Loy's remark that "our Ethiopian adult males are problematical with their black noses" (Loy 1974: 255). This can be further confirmed by comparing photos of adult females in Loy (1974: plate 1) with those from Nigeria in the study of Palmer *et al.* (1981: 375), which found ontogenetic changes in nose color but never observed dark facial skin in their patas

**Figure 2.** The typical patas monkeys from Gambela National Park, provisionally referable to *Erythrocebus pyrrhonotus formosus* Elliot, 1909. Courtesy of Ludwig Siege.

**Figure 3.** Adult male *Erythrocebus poliophaeus*, Beijing Zoo. Courtesy of Jonas Livet.

monkeys, which certainly belong to a different species. The skull of the holotype of *albigenus* is quite distinctive according to Elliot (1913), but this obviously requires the study of much more material.

Butler (1966) reported on the distribution of patas monkeys along the Dinder and Blue Nile in Sennar (Sudan) from 13°N and 33°E. Patas monkeys were reported for the Dinder National Park in Sudan (Happold 1966 and pers. comm. 2017) without much detail, and for the southern tip of the Alatish National Park in Ethiopia (Mengesha and Bekele 2008).

Photographs provided by Jonas Livet (pers. comm.) indicate that pure breeding groups of *poliophaeus* are housed in the zoos of Beijing (China) (Fig. 3), Al Ain (Dubai), and Kuwait. Patas monkeys in Ethiopia or Sudan are evidently still being commercially traded. The species may be hunted for medical purposes in the Kafta-Humera District, Tigray National Regional State, specifically Hlet-Coca sub-district in Northern Ethiopia, about 560 km to the west of Mekelle (Tigray, Ethiopia) (Yirga *et al.* 2011), but these records await confirmation.

Considering the geographic separation and distinctive external appearance, I have no hesitation in considering *poliophaeus* to be a distinct species. Its closest taxon in appearance seems to be *baumstarki*, for which species' status is also warranted. The recognition of these patas monkeys as species, highlights the need for field surveys to assess their geographic range and conservation status in both Ethiopia and Sudan.

*Erythrocebus poliophaeus* (Reichenbach, 1862)

Heuglin's or Blue Nile patas monkey

Syn.*Cercopithecus poliophaeus* Reichenbach, 1862
 *Cercopithecus poliolophus* Heuglin, 1877, renaming of *poliophaeus*
 *Erythrocebus albigenus* Elliot, 1909

The lectotype of *E. poliophaeus* is a young male in the Vienna Natural History Museum, NMW 743/ST 1567. Four-year-old male, skull, skeleton, mounted: Fazoglo, Africa (Reichenbach 1862); T.v. Heuglin leg. et vend. (AV 1856/III/1 *Cercopithecus poliophaeus*) (Ellenberger 2010) (Fig. 5).

The holotype of *E. albigenus* is an adult male, Natural History Museum London 1908.6.15.1, skin and skull. Captive at Giza Zoo, Cairo, and originating from "Anglo-Egyptian Sudan."

Geographic distribution. Available records refer to this species in Ethiopia as very scarce. Heuglin (1857) was the first to report patas monkeys from the then Wochni District (= Uahni 12°40'N, 36°42'E), but only a century later Blower (1968) added two more records, 30 km south of Metemma (12°45'N, 36°10'E; northern known limit), and 5 km east of

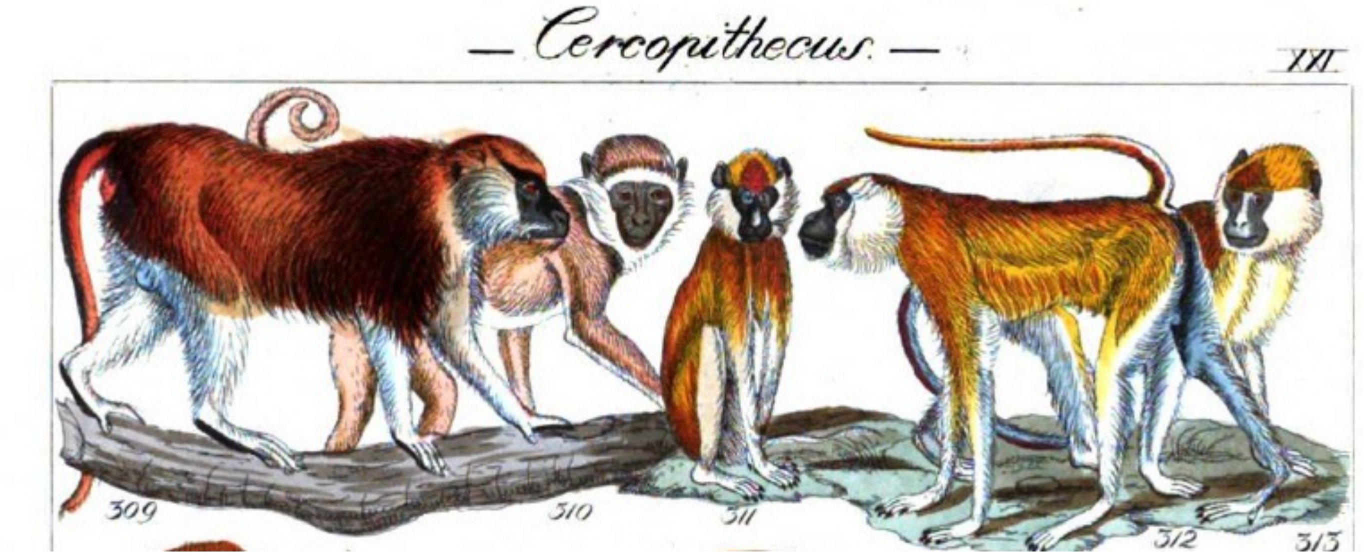

**Figure 4.** *Erythrocebus poliophaeus* as figured by Reichenbach (1862) number 309. Incidentally, figures 311 to 313 show *E. pyrrhonotus* from Sudan.

**Figure 5.** Lectotype of *Erythrocebus poliophaeus* (Reichenbach, 1862) in the Vienna Natural History Museum. Courtesy of the Vienna Natural History Museum.

Gubba (11°15'N, 35°17'E). The data and photographs of Yirga *et al.* (2010) are critical to assessing the southern limit of *E. poliophaeus* in Bambesi Woreda (Benshangul Gumuz State), well south of the Blue Nile at 9°48.5'N, 34°42.6'E and at 9°53.76'N, 34°40.27'E. As patas monkeys tend to be lowland dwellers, up to 1000 m above sea level (Assosa/Bambesi has an altitude of 1400−1600 m asl), it is postulated that there is an altitude barrier between *Erythrocebus poliophaeus* in Benishangul and the Gambela *Erythrocebus* taxon, as, in the Oromiya region along the Sudanese border, between Benishangul and Gambela, the Ethiopian highlands stretch up to the Sudanese border reaching higher elevations (Fig. 6).

### *Erythrocebus pyrrhonotus formosus* Elliot, 1909

The scanty photographic material available (Fig. 2) indicates a different taxon of red monkey in southwest Ethiopia, in Gambela National Park (Fig. 6). This may be ascribed to the taxon *formosus* Elliot, 1909, described from "Uganda", and is here provisionally treated as a subspecies of *pyrrhonotus*. It is clearly much less blackish than *poliophaeus*, and has a black band from eye to ear that is absent in *poliophaeus*. The nose is white in adult males. This is probably the species found over most of Uganda. A better knowledge of phylogeographic structure among the various forms of white-nosed patas of East Africa is urgently needed.

## Conclusions

As anticipated by Allen (1925), some of the named forms of *Erythrocebus* could be valid taxa if more evidence came to light. The main aim of the article was to revive interest in the topic and highlight some conservation priorities in East Africa. A species first described over 150 years ago is re-evaluated; it is known from the Blue Nile basin in western Ethiopia and adjoining Sudan, and separated from another *Erythrocebus* taxon by the Sudd swampy region in Sudan and the Ethiopian highlands, which stretch up to the Sudanese border north of Gambela. It is an obvious focus for further research and conservation. Monkeys of the genus *Erythrocebus* are potential flagships for important African ecosystems, and may well be at greater risk than is generally believed.

The western Ethiopian escarpment flora has received due scientific attention only in this century, and a number of new endemic species have been discovered in Benshangul Gumuz in recent years (Sebsebe Demissew *et al.* 2005). A revised taxonomy of the genus *Erythrocebus* is also fundamental to analyze the available data concerning the natural history and biology of the different taxa. With the recognition of the Heuglin or Blue Nile patas monkeys *Erythrocebus poliophaeus* we have now two taxa with a black face and nose (at least in the adult male)—the other being *Erythrocebus baumstarki*—at the fringe of the genus's range in East Africa, and possibly representing ancient surviving lineages that have been

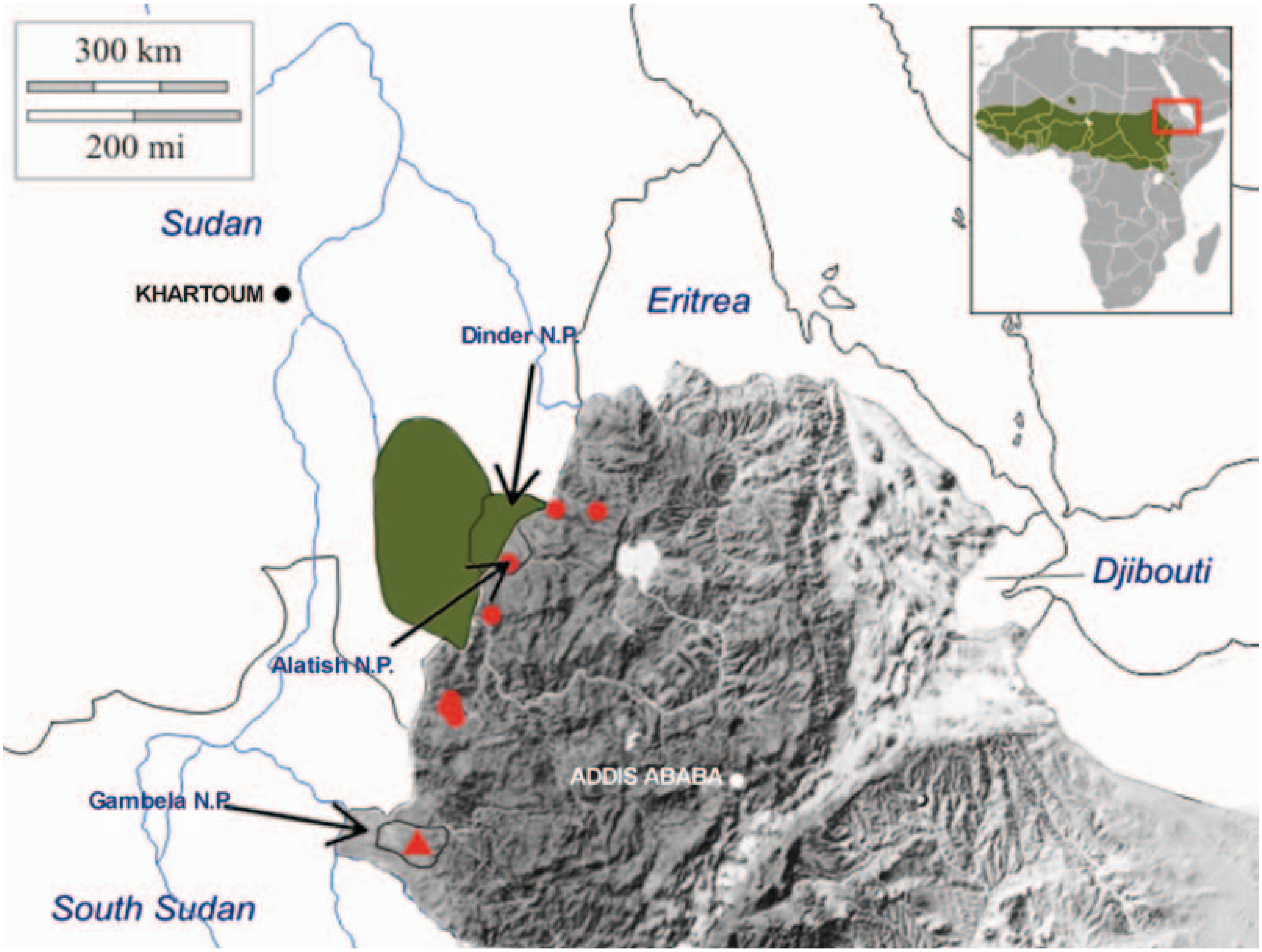

**Figure 6.** Approximate distribution of *Erythrocebus* in Ethiopia and East Sudan. Green = approximate distribution of *Erythrocebus poliophaeus* in Sudan according Butler (1966); red dots = Ethiopian records of *E. poliophaeus*; red triangle = approximate distribution of *Erythrocebus pyrrhonotus formosus* Elliot, 1909, in southwest Ethiopia. Insert; the entire range of the genus *Erythrocebus*.

supplanted by a white-nosed species elsewhere in East Africa that is provisionally referred as *Erythrocebus pyrrhonotus*, with *E. p. formosus* and a number of other subspecies occurring over its range.

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# Two New Tarsier Species (Tarsiidae, Primates) and the Biogeography of Sulawesi, Indonesia

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**Abstract:** We name two new tarsier species from the northern peninsula of Sulawesi. In doing so, we examine the biogeography of Sulawesi and remove the implausibly disjunct distribution of *Tarsius tarsier*. This brings tarsier taxonomy into better accordance with the known geological history of Sulawesi and with the known regions of biological endemism on Sulawesi and the surrounding island chains that harbor portions of the Sulawesi biota. The union of these two data sets, geological and biological, became a predictive model of biogeography, and was dubbed the Hybrid Biogeographic Hypothesis for Sulawesi. By naming these species, which were already believed to be taxonomically distinct, tarsier taxonomy better concords with that hypothesis and recent genetic studies. Our findings bring greater clarity to the conservation crisis facing the region.

**Keywords:** Biodiversity, bioacoustics, cryptic species, duet call, Manado form, Gorontalo form, Libuo form, taxonomy

## Introduction

Groves and Shekelle (2010) reviewed and revised tarsier taxonomy. In place of Hill's (1955) familiar taxonomy with three species, *Tarsius tarsier* (= *spectrum*), *T. bancanus*, and *T. syrichta*, they recognized three genera: *Tarsius*, *Cephalopachus*, and *Carlito*, respectively. They argued this change was warranted for several reasons: (1) genetic evidence indicated that each of Hill's species was likely to have originated by the middle Miocene or earlier; (2) variation among Hill's species was both under-appreciated and unrecognized; and (3) the increasing number of recognized taxa of extant tarsiers, particularly numerous cryptic sibling taxa from Sulawesi, was creating an unwieldy classification. In this revision, they also restricted the senior taxon of the genus *Tarsius*, *T. tarsier*, to the island of Selayar, and resurrected *T. fuscus* for the Makassar form of the southwest peninsula. This taxonomy left *T. tarsier* with an implausibly disjunct distribution, including Selayar Island off the southwest peninsula, the northern peninsula beyond Tinombo, and the southeast peninsula. Our current work addresses two populations of tarsiers (Tarsiidae, Primates) north of the range of *Tarsius wallacei.*

### ***Tarsius spectrumgurskyae*** sp. nov.

**Holotype:** Museum Zoologicum Bogoriense (MZB), Cibinong, Indonesia, 3269, adult male, collected by Mohari in August 1908.

**Type locality:** Manado, North Sulawesi

**Hypodigms:** (1) MZB: 3264, 3266, 3269, 6596 (Manado), skins and skulls; 6593 (Mapanget, Minahasa), skin and skull; 6594 (Tondano, Tonsea Lama, Manado), skin and skull. (2) BMNH 1897.1.2.1-2 (Rurukan), skins and skulls; 1897.1.2.1 (Manado), skin; 1939.1322-3 (Minahasa), skins. (3) MZB 5017 (Manado), skull only. (4) USNM 217559 (Manembo Nembo), skin and skull; 83967 (Rurukan), skin and skull; 219454 (Rano Rano), skin and skull. (5) AMNH 196479, 196480, 196481, 196482, 196483, 196484, 196485, 196486 (Rurukan) and 196487, 196488 (Klabat).

**Etymology:** Gursky's spectral tarsier. This species is named in honor of Dr. Sharon Gursky, who has dedicated most of her professional life to studying the behavioral ecology of this species. Most of her work on this species was published using a taxonomy that is now superseded, in which

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†Colin P. Groves 1942-2017

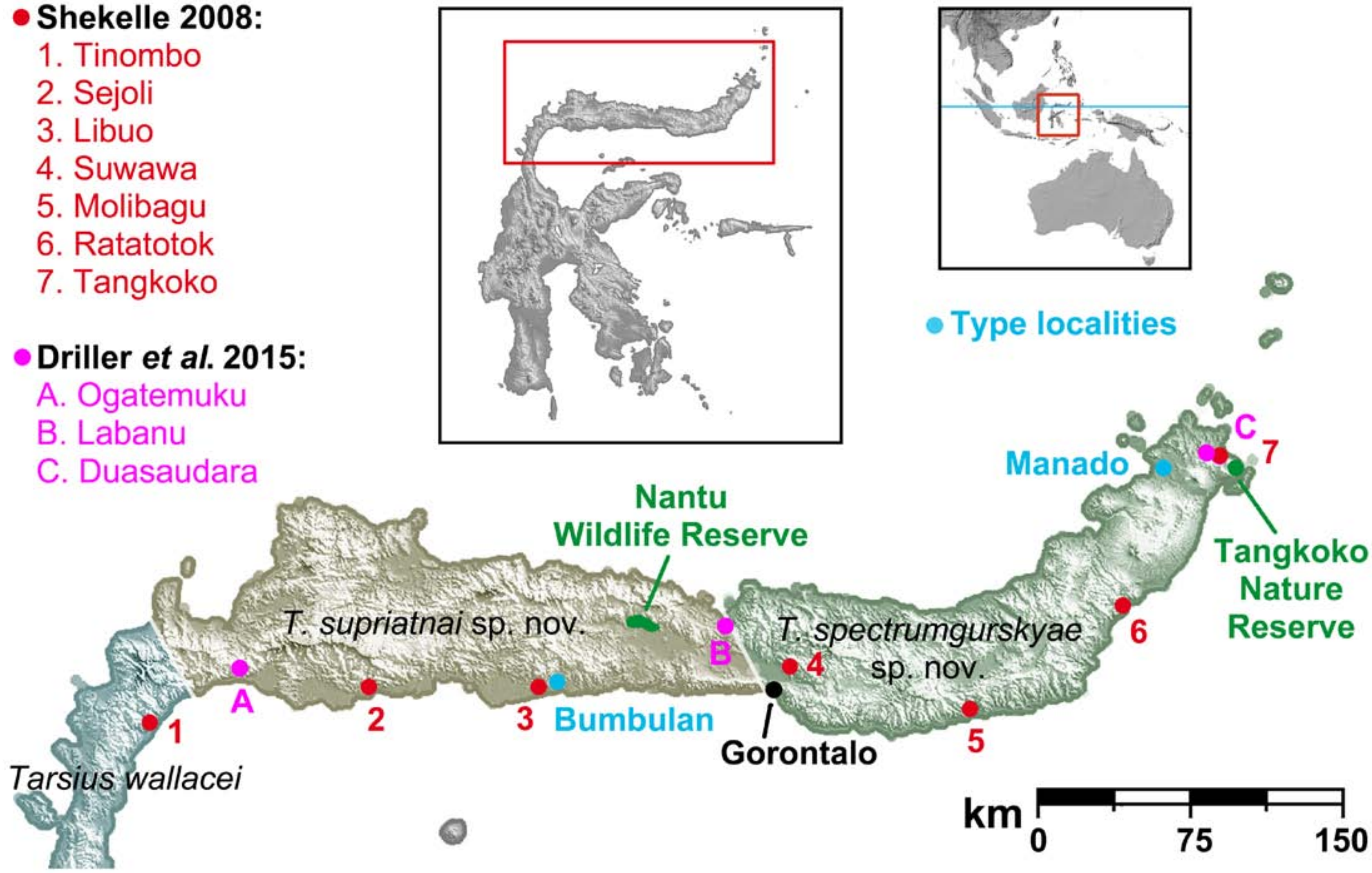


**Figure 1.** The Northern Peninsula of Sulawesi, Indonesia, showing type localities, species distributions, sampling points of Shekelle (2008) and Driller *et al.* (2015), and two key protected areas.

her population was classified as *Tarsius spectrum*. Ongoing reclassification, therefore, created an unfortunate disconnect between the species name used in her publications, and the most up-to-date taxonomic revision. Thus, by naming this species *Tarsius spectrumgurskyae*, it forever links the names *Tarsius* and *spectrum* with the population of animals that she studied.

**Local Name:** Tangkasi, Wusing

**Distribution:** Field surveys have identified the diagnostic call of this species from Tangkoko in the north to Suwawa, on the western edge of Dumoga-Bone National Park (Fig. 1). Field surveys also found this acoustic form at Ratatotok (and nearby Basaan) and Molibagu (Shekelle 2008), as well as at Labanu and Duasaudara (Driller *et al.* 2015). These data imply that this species shares a zone of endemism with two macaque species, *Macaca nigra* and *M. nigrescens* (see Evans *et al*. 2003).

**Field work:** MacKinnon and MacKinnon (1980), Niemitz *et al*. (1991), Gursky (1994, 1995, 1997, 1998a, 1998b, 1998c, 2000a, 2000b, 2000c, 2002a, 2002b, 2002c, 2003), Shekelle *et al.* (1997), Nietsch and Kopp (1998), Nietsch (1999), Shekelle (2003, 2008), Driller *et al.* (2015).

**Diagnosis:** As with many species of Eastern Tarsier, the clearest field diagnosis of living specimens is from a spectrogram of its duet call or through playback tests (Figs. 2 and 3). As there is no known case of sympatry among extant tarsiers, the best diagnosis of museum and other deceased specimens is by provenance, or genetic analysis, although some diagnostic morphological characters are indicated.

**Morphology:** Resembling *T. supriatnai* n. sp. and *T. pelengensis*, and contrasting with other species of the genus in the prominent brown patches on the thigh (they are lighter, yellower, in *T. wallacei* and *T. dentatus*, and inconspicuous or absent in other species); resembling *T. supriatnai* n. sp. and *T. fuscus*, and contrasting with other species, in the presence of a tail pencil that is both long and black; resembling *T. supriatnai* n. sp. and *T. wallacei* in the prominence of the white postauricular spot, and in the comparative sparseness of the hair on the tarsus (not, however, as sparse as in *T. sangirensis*); resembling *T. supriatnai* n. sp. alone in the prominence and white color of the hair on the sides of the upper lip, the prominent black eye rims, the dark color of the tarsus hair, the general partial fusion of pads on the manus, the long posterior portion of the auditory bulla, broad palate, narrow upper molars, strongly convex nasal tip, and the presence of a noticeable diastema between $I^2$ and $C^1$. Differs from *T. supriatnai* n. sp. and all other species in the genus in the small size of the prominent bare spot at the base of the ear, and the comparatively short hindfoot and, especially, middle finger length relative to the (large) head-and-body length.

**Vocalizations:** the duet call of this species is fully diagnostic in spectrographic analysis and by playback tests, and is described below (Figs. 2 and 3).

**Genetics:** Shekelle *et al.* (2008, 2010) found their small genetic data set to be broadly consistent with the hypothesis that acoustic forms are distinct species, but did not find the Manado form to constitute a single monophyletic clade. More recently, Driller *et al.* (2015), using more genetic evidence, found support for the separation of *T. spectrumgurskyae* and dated its divergence at 0.3 mya.

### Description

**Morphology:** Surveys of wild populations indicate that body weight and tail length are within the range of several other species of *Tarsius*: body weight (female 95−119 g, n = 24; male 104−126 g, n = 11), tail length (female = 213−268 mm, n = 22; male = 220−258 mm, n = 9) (data from Shekelle 2003). Surveys of museum specimens indicate the posterior portion of the auditory bulla is long; the palate is broad; upper molars are narrow; the nasal tip is strongly convex; there is a noticeable diastema between $I^2$ and $C^1$. The tail pencil is long, thick and black; the thigh is browner than the body; the white patch on the sides of the upper lip is conspicuous; the bare spot at the base of ear is present, tending to be small; the tarsal hair is of medium length, and fairly dark. *Tarsius spectrumgurskyae* is large, but smaller than *T. dentatus* and overlaps the ranges of the small species such as *T. fuscus*, so that size is not diagnostic; the auditory bulla is comparatively short, despite the length of its posterior portion; toothrows are fairly long, but variable; pelage is grey-buff like most mainland Sulawesi tarsiers (*T. fuscus* the exception); usually noticeably browner on the thigh; the tail is comparatively short, 121−210% of head and body; the black paranasal spot is well-marked; the eye-rim is usually conspicuously black. Thenar and first interdigital pads usually partly (incompletely) fused. Cranial and external proportions overlap with those of other northern and central species, but dental proportions do not (Groves 2003) (refer to Figs. 4 and 5, Table 1).

**Vocalizations:** The Manado form was originally described by MacKinnon and MacKinnon (1980), and further examined by Niemitz *et al.* (1991), Shekelle *et al.* (1997), Nietsch and Kopp (1998), Nietsch (1999), and Shekelle (2003, 2008). More recently, Yi *et al.* (2014) found that the Manado and Gorontalo forms are easily separable with quantitative analysis. The duet begins with a series of synchronized female and male notes. The duet often begins with a female note, but pre-duet calling makes this difficult to determine with certainty. Male calls are chevron-shaped chirps that rise from ~6 kHz to ~13 kHz, and then descend to less than 6 kHz. The duration of each note is ~0.2 seconds. The female phrase is a series of ~9−15 notes, which are far more varied in terms of frequency, frequency modulation, and duration, than are those of the male. The duration of the female phrase varies, but

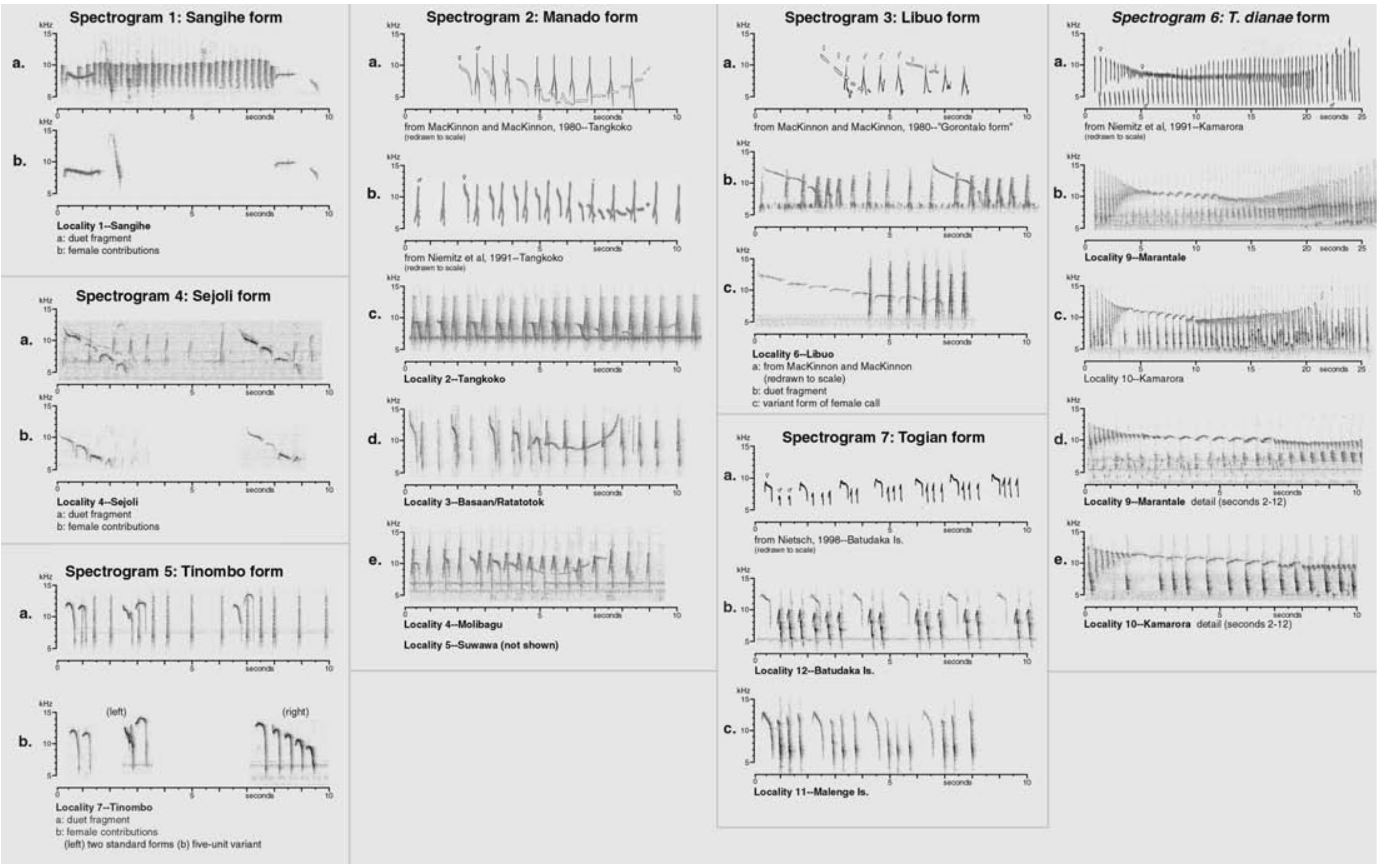
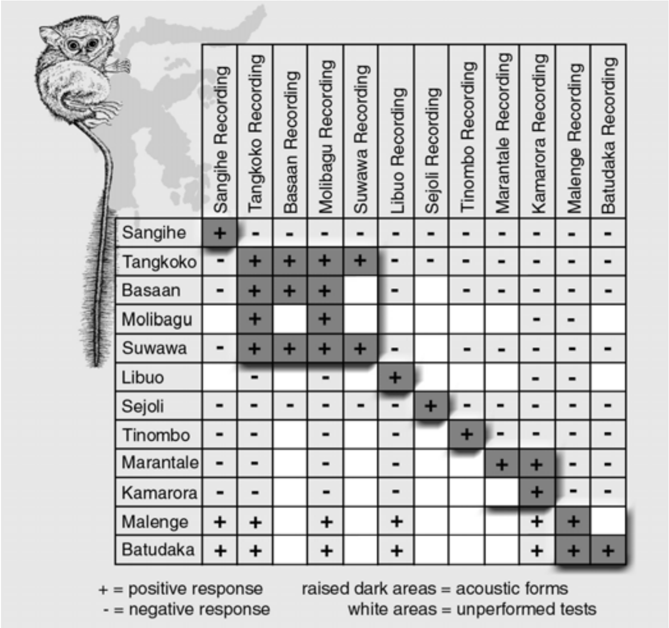


**Figure 2.** Spectrograms for seven acoustic forms of Eastern tarsiers (from Shekelle 2008). Spectrograms 1a, 1b (*Tarsius sangirensis*); Spectrograms 2a – 2e (*T. spectrumgurskyae* n. sp.); Spectrograms 3a – 3c (*T. supriatnai* n. sp.); Spectrograms 4a, 4b (*T. supriatnai* n. sp.); Spectrograms 5a, 5b (*T. wallacei*); Spectrograms 6a – 6e (*T. dentatus* = *dianae*); Spectrograms 7a – 7c (*T. tarsier* "Togian form", putative unnamed species).



| | Sangihe Recording | Tangkoko Recording | Basaan Recording | Molibagu Recording | Suwawa Recording | Libuo Recording | Sejoli Recording | Tinombo Recording | Marantale Recording | Kamarora Recording | Malenge Recording | Batudaka Recording |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sangihe | + | - | - | - | - | - | - | - | - | - | - | - |
| Tangkoko | - | + | + | + | + | - | - | - | - | - | - | - |
| Basaan | - | + | + | + | | - | | - | - | - | - | - |
| Molibagu | | + | | + | | | | | | - | - | |
| Suwawa | - | + | + | + | + | - | | - | - | - | - | - |
| Libuo | | - | | - | | + | | | | - | - | |
| Sejoli | - | - | - | - | - | - | + | - | - | - | - | - |
| Tinombo | - | - | | - | | - | | + | - | - | - | - |
| Marantale | - | - | | - | | - | | | + | + | - | - |
| Kamarora | - | - | | - | | - | | | | + | - | - |
| Malenge | + | + | | + | | + | | | | + | + | |
| Batudaka | + | + | | + | | + | | | | + | + | + |

**Figure 3.** Results of playback tests (from Shekelle 2008).

is often ~7 sec. It can be divided into three sections. At the beginning of the duet, the female calls are descending whistles, which begin high, ~10 kHz or higher, and descend rapidly to a final frequency below 6 kHz. There is much variation among populations in the initial frequency of the female calls, with populations at the northern end of the range of this species (e.g., Tangkoko) tending to use lower initial frequencies (~10 kHz), and those further south (e.g., Ratatotok, Molibagu) using much higher initial frequencies (12–15 kHz). As the duet progresses, the initial frequency descends and terminal frequency ascends gradually until, in the second section of the female phrase, the notes become nearly unmodulated, the frequency of these relatively flat notes being at a midpoint between the initial and terminal frequencies of the first note, therefore ~8–10 kHz. In the final section of the female phrase, the notes begin to ascend in pitch, with the terminal frequency of the final call being approximately the same as the initial frequency of the first call. The duet can be further characterized as follows: (1) the duration of the female notes increase from ~0.3 sec to ~1 sec, or more; (2) the interval between female notes decreases, from >1 sec to ~0.1 sec; and (3) the synchronization between male and female notes increases, with male calls filling the short gap between the female notes (refer to Fig. 2, particularly spectrogram 2d).

### ***Tarsius supriatnai*** sp. nov.

**Holotype:** Museum Zoologicum Bogoriense (MZB), Cibinong, Indonesia, 6595, adult male, collected by J. J. Menden, 10 May 1939.

**Type locality:** Bumbulan, Gorontalo.

**Hypodigms:** 1) AMNH 153286, 153287, 153288, 153289, 153290, 153291 (Bumbulan), 2) MZB 6595 (Bumbulan), skin and skull; (3) Rijksmuseum voor Naturlijk Historie NRL cat. a or f (Gorontalo).

**Etymology:** Jatna's tarsier. This species is named in honor of Dr. Jatna Supriatna, who has dedicated most of his professional life to the conservation of Indonesian biodiversity, and has sponsored much of the foreign collaborative work done on tarsiers.

**Local Name:** Mimito

**Distribution:** On the northern peninsula from the Isthmus of Gorontalo westward at least as far as Sejoli, and probably as far as Ogatemuku (see Driller *et al.* 2015), but not as far as Tinombo (Fig. 1).

**Field work:** MacKinnon and MacKinnon (1980), Shekelle *et al.* (1997), Shekelle (2003, 2008), and Driller *et al*. (2015).

**Diagnosis:** See above for *T. spectrumgurskyae*, duet call and provenance are absolutely diagnostic. Genetics diagnose a *T. spectrumgurskyae* – *T. supriatnai* clade from all others and are hypothesized to be themselves distinct. Driller *et al*. (2015) estimated a divergence date of 0.3 mya for the separation of the two.

**Morphology:** *Tarsius supriatnai* is very similar morphologically to *T. spectrumgurskyae* n. sp. (see under that species), differing in the generally larger bare spot at the base of the ear, the less shortened hindfoot, the very long tail, and longer middle finger.

**Description**

**Morphology:** Surveys of wild populations indicate body weight and tail length are probably within the range of several other species of *Tarsius*, but the sample sizes are small: body weight (female = 104−114 g, n = 2; male = 135 g, n = 1); this gives the superficial appearance that body weight dimorphism might be greater for this species, 81%, but with the sample sizes being so low we discourage speculation along these lines until more data have been collected; tail length (female = 232−243 mm, n = 2; male = 246 mm, n = 1) (data from Shekelle 2003). Surveys of museum specimens indicate a species with skull and teeth very similar to *T. spectrumgurskyae* n. sp., but the two specimens, compared to nine of the latter that were measured, have a lower anterior central incisor, and larger first and second molars, but not third molar (refer to Figs. 4 and 5, Table 1).

**Vocalizations:** MacKinnon and MacKinnon (1980) originally described the Gorontalo form, a form that was referred to as the Libuo form in various papers by Shekelle (Shekelle *et al*. 1997; Shekelle 2003, 2008). The duet of this acoustic form is characterized by a ~2-to-5-note female phrase accompanied by male calls. The frequencies of the female notes are each comparatively flat, in sharp contrast with the frequency modulated notes of the first section of the female phrase in the Manado form. The first of these notes begins at ~13 kHz and the last is ~7 kHz. Each note is about 0.6−1.0 sec in duration, with notes being separated by a brief gap of ~0.1 sec. The female phrase is repeated several times during the duet, with ~6 seconds elapsing from the end of one phrase to the start of the next. The male notes are wide-band, chevron-shaped chirps that ascend in frequency from ~6 kHz to ~10−12 kHz, before descending back again to ~6 kHz. In a well-coordinated

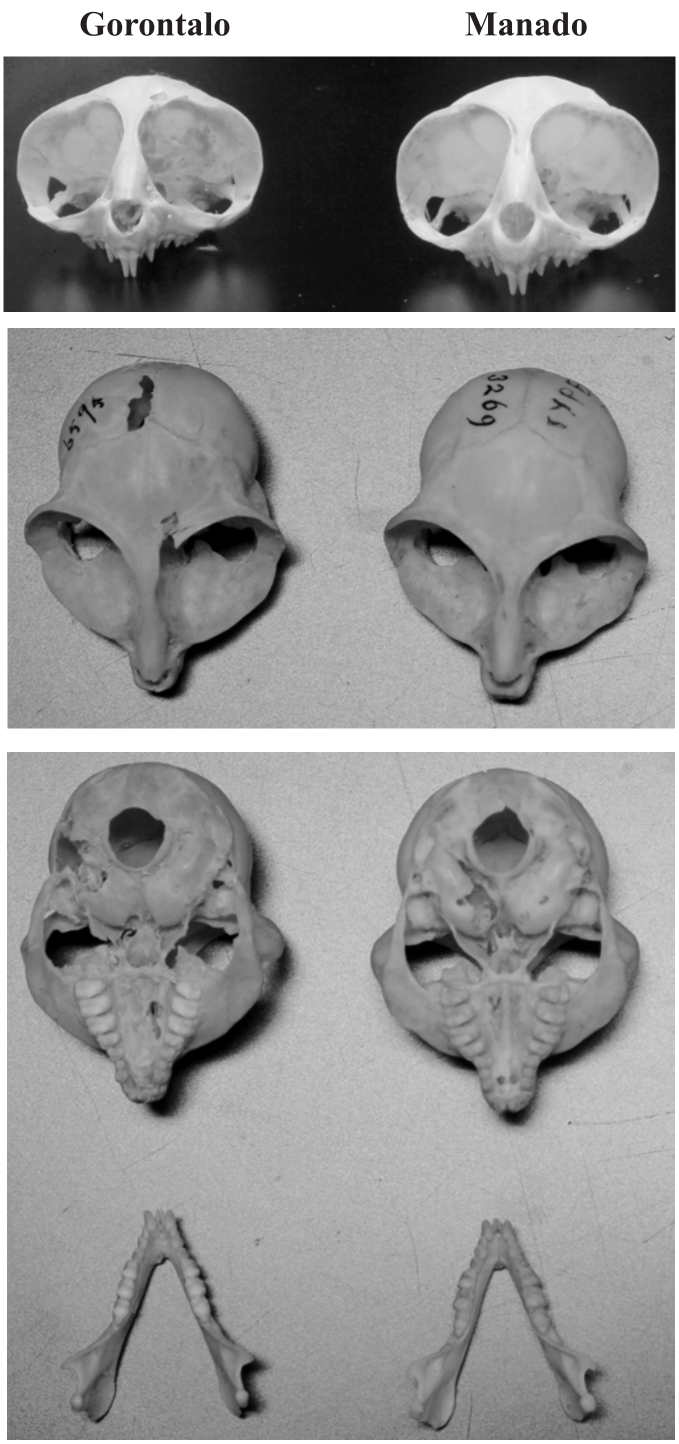


**Figure 4.** Type specimens. Top: frontal view of crania. Middle: inferior view of crania. Bottom: superior view of crania and mandibles, with occlusal surfaces of upper and lower dentition.

**Figure 5.** Photographs of two new species: A) Gursky's spectral tarsier *Tarsius spectrumgurskyae* n. sp. from Tangkoko Nature Reserve (photo by Alfrets Masala). B) Jatna's tarsier *Tarsius supriatnai* n. sp. (photo by Russell Mittermeier).

duet, the male notes occur in the gaps between the female notes. Between female phrases, male notes continue at the rate of about one per second. Again, as mentioned above, Yi *et al*. (2014) found that the Manado and Gorontalo forms are easily separable with quantitative analysis. The Sejoli form was described as distinct by Shekelle *et al.* (1997) and Shekelle (2003, 2008) on the basis of field playback tests, but not on the basis of either qualitative or quantitative variation in spectrographic analysis. The recordings were of admittedly low quality, but even so, had obvious resemblances to the Gorontalo form. Given the paucity of the evidence for the distinctiveness of this form, and in the interests of taxonomic conservatism, we do not separate the Gorontalo and Sejoli acoustic forms at this time. Further investigation may warrant their taxonomic separation.

| **Type specimens** | ***T. spectrumgurskyae*** **Manado form** | ***T. supriatnai*** **Gorontalo form** |
|---|---|---|
|  | **MZB3269** | **MZB6595** |
|  | Adult male | Adult male |
| **Musser and Dagosto (1987)** |  |  |
| Greatest length of skull | 37.1 | 37.4 |
| Zygomatic breadth | 26.9 | 26.2 |
| Breadth across orbits | 29.9 | 29.4 |
| Breadth of a single orbit | 17.2 | 17.3 |
| Height of a single orbit | 17.9 | 18.3 |
| Length of nasals | 7.0 | 6.8 |
| Breadth of bony palate at $M^3$ | 14.1 | 14.1 |
| Length of auditory bulla | 11.2 | 11.8 |
| Breadth of auditory bulla | 6.6 | 5.6 |
| Length of anterior part of bulla | 5.6 | 5.9 |
| Length of posterior part of bulla | 6.3 | 6.5 |
| Length of upper toothrow, C-$M^3$ | 12.8 | 12.1 |
| Length of lower toothrow, C-$M_3$ | 13.3 | 12.9 |
| Length of $M^1$ | 2.4 | 2.0 |
| Breadth of $M^1$ | 3.5 | 3.3 |
| Length of $M_1$ | 2.3 | 2.0 |
| Breadth of $M_1$ | 2.2 | 2.3 |
| **Groves (1998)** |  |  |
| Length of head and body | 167 | 125 |
| Ear length | 23.7 | 26.1 |
| Ear width |  |  |
| Tibia | 62.2 | 63.0 |
| Tarsus | 34.2 | 34.5 |
| Length of third finger | 25.2 | 24.1 |
| Inter orbital | 2.2 | 1.8 |
| Post orbital width | 22.4 | 21.3 |
| Nasal breadth | 3.6 | 3.3 |
| Palatal length | 13.6 | 13.7 |
| Mesopterygoid fossa width | 3.4 | 3.5 |
| Ramus angular process | 10.3 | 10.2 |
| Dentary length | 24.2 | 24.8 |
| Tail length | 230 | 236 |

**Table 1.** Measurements (in mm) of type specimens. The headings in the table, "Musser and Dagosto 1987" and "Groves 1998", refer to the measurements used in those two studies, not necessarily the measurements reported in those two detailed description of methodology).

**Figure 6.** Gursky's spectral tarsier *Tarsius spectrumgurskyae* n. sp. (left) and Jatna's tarsier *Tarsius supriatnai* n. sp. (right). Illustrations by Stephen D. Nash.

**Genetics:** As with *T. spectrumgurskyae* sp. n. (above), Shekelle *et al.* (2008, 2010) found genetic data to be broadly consistent with the hypothesis that acoustic forms are distinct species, but did not find the Manado form to be a single monophyletic clade, while Driller *et al.* (2015), with superior genetic evidence in both quantity and quality, supported their separation, with an estimated divergence date of 0.3 mya.

**Additional material examined:** We provisionally classify the following specimens within *T. supriatnai*, USNM 200281(Sungai Paleleh), USNM 200280, 200281, 200282, 200283, 200284 (Toli Toli).

## Conclusions

The results of this manuscript stem from the workshop, Primate Taxonomy for the New Millennium, held in Orlando, Florida, in January 2000. That workshop not only produced a consensus taxonomy for primates (Brandon-Jones *et al.* 2004), but also offered a research agenda: in the best interests of science and conservation to resolve the alpha taxonomy for the clade of each participant's expertise, and to do so before it is too late—before extinction wipes out the story of our evolutionary history. Toward those ends, we describe two new tarsier species, which provide a better fit with the biogeography of Sulawesi (see Hall 2001; Evans *et. al.* 2003; Shekelle and Leksono 2004), and removes the implausible discontinuity in the distribution of *T. tarsier* that occurred after tarsiers from the central core and southwestern peninsula were studied and named (e.g., Merker and Groves 2006; Merker *et al*. 2010; Groves and Shekelle 2010).

Species distributions on Sulawesi typically conform with (1) the geological history of the island as it coalesced from a proto-Sulawesi archipelago (see Hall 2001), and (2) geographic features associated with range fragmentation during the Pleistocene (Evans *et al*. 2003). During the Miocene and Pliocene, distributions appear to have been shaped by dispersal among islands (see Shekelle and Leksono 2004). Parapatric species boundaries formed when two islands with sibling taxa accreted to one another, forming a single island. These boundaries seem to remain stable for vast stretches of time, >1 mya (Merker *et al*. 2009). The process of island accretion is thought to have been completed by ~1 mya, forming the modern island of Sulawesi. Subsequent to that event, species distributions were reshaped by range fragmentation, owing to the unstable climate during the Pleistocene (see Evans *et al.* 2003).

In concordance with these two processes, ancient dispersal and more recent range fragmentation (see Shekelle and Leksono, 2004), the western boundary of *T. supriatnai* is hypothesized to be the microplate suture that lies between Tinombo and Ogatemuku. The boundary between *T. supriatnai* and *T. spectrumgurskyae* is hypothesized to be the Isthmus of Gorontalo. If the broad hypothesis for Sulawesi biogeography, as proposed by Shekelle and Leksono, is generally true, then the phylogenetic tree for tarsiers should show the split between *T. supriatnai* and *T. spectrumgurskyae*, which are separated by Pleistocene range fragmentation at the Isthmus of Gorontalo, to be younger than the split between *T. wallacei* and a *T. supriatnai* – *T. spectrumgurskyae* clade, which are separated by a more ancient accretion of two islands into a single landmass. These are, indeed, the results found by Driller *et al.* (2015), thereby offering further support for the Hybrid Biogeographic Hypothesis for Sulawesi (Shekelle and Leksono, 2004).

Our results also shed further light on the ongoing conservation crisis within the conservation hotspot of Wallacea (Myers *et al.* 2000). Biodiversity is often clustered in regions of endemism, and this is particularly true in Sulawesi, as demonstrated above by the process of species distribution formation. Primates, most of which are threatened at some level, serve as one vitally important flagship species for habitat conservation (Estrada *et al.* 2018). Thus, one key to stemming the current onslaught on biodiversity is to protect habitat by identifying primate species, naming them, Red-Listing them, and promoting them as flagship species to assist habitat conservation; tarsiers make excellent candidates for this conservation strategy on Sulawesi (refer to Shekelle and Leksono 2004).

It is vital to complete the process of identifying the alpha taxonomy of tarsiers before deforestation erases the evidence of the evolutionary history of the clade. The study by Merker *et al.* (2009), which offered robust support for the hypotheses advanced in this paper, would have been impossible were it not for large stretches of unbroken primary forest. This is because discontinuities in habitat lead to isolation, which then invariably leads to discontinuities among populations. With the passage of time it becomes increasingly difficult, and then even impossible, to infer whether the discontinuities among populations that were once continuous, but which were made allopatric by anthropogenic habitat loss, were caused by speciation, or perhaps by isolation by distance followed by genetic drift. Given tarsiers' role as flagship species for protecting all of the biodiversity on Sulawesi, as well as in other regions, urgent action on tarsier alpha taxonomy holds forth the opportunity to protect habitat that will assist the conservation of other species: babirusa, anoa, Sulawesi macaques, cuscus, and all the other species within this critically important biodiversity whether they have been identified and named by science or not. Therefore, the next step for conservation is to assess the conservation status of the two new species we report, both of which we expect to be threatened at some level, and use these to assist conservation efforts within their ranges, particularly in the critically important habitats of the greater Tangkoko conservation region in North Sulawesi, and the Nantu Wildlife Reserve in the province of Gorontalo (Fig. 1).

The etymology of these species has two functions. First, the name *Tarsius spectrum* is associated with much confusion, such that virtually all extant tarsiers have been classified under that name at one time or another, whereas today none are, though the name is still well-known to primatologists. To remove that confusion, and to correct an unfortunate disconnect resulting from reclassification, *spectrumgurskyae* connects for all time the name "*spectrum*" with the population of tarsiers that Gursky has spent her life studying. Second, the names honor two scientists who have played outsized roles in the study and conservation of tarsiers

Extant tarsiers are classified in three genera, allopatrically distributed in distinct biogeographic regions: *Tarsius* is found on Sulawesi and surrounding islands; *Cephalopachus* is found on a restricted subset of Sundaland, principally the southern parts of Sumatra, and the islands of Borneo, Bangka, and Belitung; *Carlito* is found on islands of the southern Philippines that were a single Ice Age landmass, sometimes called Greater Mindanao. *Tarsius* contains 11 species (in order of seniority): *T. tarsier* (= *spectrum*), *T. fuscus*, *T. sangirensis*, *T. dentatus* (= *dianae*), *T. pumilus*, *T. pelengensis*, *T. lariang*, *T. tumpara*, *T. wallacei*, *T. spectrumgurskyae*, *T. supriatnai*. Burton and Nietsch (2010) reported evidence for three more putative unnamed taxa from the Southeastern peninsula. Shekelle and Leksono (2004) predicted that Sulawesi would ultimately be shown to be home to at least 16 distinct tarsier taxa. The speciose alpha taxonomy of *Tarsius* stands in contrast with that of *Cephalopachus* and *Carlito*, but we question if this contrast is not rather based on an absence of evidence, as opposed to the evidence of absence. We encourage more fieldwork in order to answer this question.

We conclude by reminding readers of the words with which Shekelle *et al*. (2008) concluded their description of *Tarsius tumpara*, published nearly ten years ago, and assert that they are more pertinent than ever:

> "The bleak situation indicates that some primate species in Sulawesi may go extinct before they have even been identified, leaving scientists with unpleasant and controversial choices for taxonomy and conservation. We foresee increased criticism and controversy down either path: either publishing new species at an increased pace with the heightened chance of error, or not doing so at the risk that primate species are driven to extinction before they have been recognized and named." (p. 63)

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# Deforestation of Primate Habitat on Sumatra and Adjacent Islands, Indonesia

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**Abstract:** The severe declines in forest cover on Sumatra and adjacent islands have been well-documented but that has not slowed the rate of forest loss. Here we present recent data on deforestation rates and primate distribution patterns to argue, yet again, for action to avert potential extinctions of Sumatran primates in the near future. Maps of forest loss were constructed using GIS and satellite imagery. Maps of primate distributions were estimated from published studies, museum records and expert opinion, and the two were overlaid on one another. The extent of deforestation in the provinces of Sumatra between 2000 and 2012 varied from 3.74% (11,599.9 ha in Lampung) to 49.85% (1,844,804.3 ha in Riau), with the highest rates occurring in the provinces of Riau, Jambi, Bangka Belitung and South Sumatra. During that time six species lost 50% or more of their forest habitat: the Banded langur *Presbytis femoralis* lost 82%, the Black-and-white langur *Presbytis bicolor* lost 78%, the Black-crested Sumatran langur *Presbytis melalophos* and the Bangka slow loris *Nycticebus bancanus* both lost 62%, the Lar gibbon *Hylobates lar* lost 54%, and the Pale-thighed langur *Presbytis siamensis* lost 50%. Two species, the Pagai langur *Presbytis potenziani* and the Pagai macaque *Macaca pagensis*, both from the southern part of the Mentawai islands, are not represented in national parks or protected areas at all, and a further five species are found in only one protected area. The causes of deforestation are many and varied, but by far the leading causes are logging, followed by fire and/or conversion to plantations. Enforcement of existing regulations protecting primates, disentanglement of land claims and overlapping boundaries, a halt to logging in existing forests, a halt to road building through forests, clarification of how traditional *adat* law relates to protected areas, and the creation of new, enforceable laws protecting species from trade and exploitation will all be needed if Indonesia is to uphold the commitments to primate conservation that it has already made.

**Keywords:** deforestation, Indonesia, primates, primate habitat, Sumatra

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## Introduction

There are 22 primate species that occur on Sumatra and its neighboring islands. Three are ranked as Critically Endangered on the IUCN Red List of Threatened Species (Pagai macaque *Macaca pagensis*, Pig-tailed langur *Simias concolor*, and Sumatran orangutan *Pongo abelii*) (Roos *et al.* 2014; Supriatna and Ramadhan 2016), and a further ten are listed as endangered (Siberut macaque *Macaca siberu*, Black Sumatran langur *Presbytis sumatrana*, Mitred langur *P. mitrata*, Black-and-white langur *P. bicolor*, Black-crested Sumatran langur *P. melalophos*, Siberut langur *P. siberu*, Kloss's gibbon *Hylobates klossii*, Lar gibbon *H. lar*, Agile gibbon *H. agilis*, and Siamang *Symphalangus syndactylus*). Nine of the 22 species are endemic (MacKinnon and MacKinnon 1980; Brandon-Jones *et al*. 2004; Roos *et al*. 2014).

Sumatra was still densely forested as recently as 1950, but then clearing began in the lowland areas where topography and soil fertility were most favorable to human settlement and agriculture. Clearing for plantations and clearing for crops and settlements associated with transmigration programs in the 1970s and 1980s occurred largely in the lowlands or on gently sloping foothills (Whitten *et al*. 1987). Estimates vary, but recent sources suggest that Sumatra has lost 5 million ha of forest between 1990 and 2000 (Gaveau *et al*. 2012) and a further 3 million ha between 2000 and 2012 (Margono *et* *al*. 2014) for a total of 8 million ha due to legal and illegal logging, conversion of natural forests to industrial plantations, and forest encroachment by communities. The analysis reported here estimates that 3.5 million ha were lost between 2000 and 2012. The difference of 500,000 ha is likely due to our use of the Ministry of Forestry classification of forest and non-forest.

Sumatran forests are suffering one of the highest rates of destruction in the world (Collins *et al*. 1990; Margono *et al.* 2014). There are now only small scattered remnants of undisturbed lowland forest outside of protected areas. This lowland forest is the home of most Sumatran primates. Many (for example, orangutans, gibbons, some restricted range and endemic langurs, and some macaques) are sensitive to disturbance caused by logging, hunting and other human activities (Yanuar and Chivers 2010). Consequently, these species have little chance of surviving in highly fragmented or disturbed forests. For example, tree availability, as a source of food and nesting sites, is one of the most influential factors affecting the density of orangutans (van Schaik *et al*. 2001; Ancrenaz *et al*. 2005).

The many documented declines in forest cover and therefore primate habitat (for example, Supriatna *et al*. 2001, 2002; Mittermeier *et al*. 2007; Mariati *et al*. 2014; Supriatna and Mariati 2014), have largely been ignored by government and the private sector. Forest loss has continued to proceed at a high rate. Here we present recent data on the extent of deforestation and primate distributions and propose actions that will be necessary if extinctions in the near future are to be averted.

## Methods

### *Mapping forest loss*

Forest loss, or deforestation, is defined as the change from forest cover in 2000 to non-forest cover in 2012. We used the deforestation data from the Ministry of Forestry. Landsat 7 Enhanced Thematic Mapper (ETM) satellite images from 2000 and 2012 were used to calculate changes in the forest cover that coincided with the distribution of each primate species. Images of Sumatra were selected from 2000 and 2012, with cloud cover less than 50%, and all forested areas such as parks, protected forest, company concessions and other forested lands were included. This covered primary and secondary forest but did not include tree crops or production forest. Forest cover results were then validated using Google Earth (www.google.com/earth/) and ESRI online base map (www.esri.com) from the same time period. The rate of deforestation was also calculated using the formula described by Puyravaud (2003). The formula is based on Compound Interest Law and is considered more intuitive than the one proposed by FAO (see Puyravaud 2003). It is as follows:

$$r = 1/(t2 - t1)\ x\ Ln\ (a2/a1)$$

where $r$ is the rate of change, and $a1$ and $a2$ are the forest cover estimates at time $t1$ and $t2$ respectively.

### *Primate distributions*

Primate surveys in different parts of Sumatra have been carried out by many researchers, including Crockett and Wilson (1980), Kawamura and Megantara (1986), Supriatna *et al*. (1996), Supriatna and Hendras (2000), Supriatna *et al*. (2001), Whittaker (2005, 2006), Geissmann *et al*. (2006), Supriatna and Gursky-Doyen (2010), and Supriatna and Mariati (2014). Additional data on taxonomic status and distributions were gathered from Groves (2001), Brandon-Jones *et al*. (2004), Mittermeier *et al*. (2013), and Roos *et al*. (2014). We examined all records of primates on Sumatra in the Bogor Museum, and updated the distribution data of Groves (2001). These were published in Supriatna and Ramadhan (2016). Ground-truthing of these geo-referenced distribution maps was conducted throughout Sumatra between 2012 and 2014, except for the southern islands (Pagai and Sipora) of the Mentawai archipelago. Survey locations were chosen using the following criteria: areas likely to have species that had not been studied intensively, for example, species recently described; areas with species whose systematics had recently been revised; areas that had been recently logged and/or converted to plantations; and areas that had been recently burnt by forest fires. Further aspects of primate ecology and conservation status were gathered from primatologists who have studied these issues in the field (Indra Yustian, Sunarto, Tatang Mitrasetia, pers. comm.) and the considerable experience of most of the present authors, especially the senior author.

Based on primate distribution data from these sources, we plotted the current known distributions of each primate species. We then overlaid these geo-referenced distribution maps onto current forest cover maps and maps of forest lost between 2000 and 2012. In this way, we mapped changes in available habitat for all primate species and calculated current available habitat, defined as forest cover.

## Results

### *Extent of forest loss*

Deforestation in the provinces of Sumatra between 2000 and 2012 ranged from 3.74% to 49.85%, with a total of 3,547,740.60 ha (22.08 %) lost (Table 1). The highest rate was found in the provinces of Riau, Jambi, Bangka Belitung, and South Sumatra (Fig. 1). Most clearing took place in already degraded production forests and not in primary conservation forests, except in Tesso Nilo National Park in Riau Province, where the highest rate of forest loss was found (9.28% per year, Mariati *et al.* 2014). In the rest of Riau province, deforestation occurred mainly in production forests, which were converted to acacia and oil palm plantations. Illegal logging was widespread in the Giam Siak and Rimbang Baling protected areas and in Tesso Nilo National Park (Supriatna and Mariati 2014). Similar trends have occurred in Jambi Province in the mid-western part of the island, close to Bukit Tigapuluh National Park, where many companies have

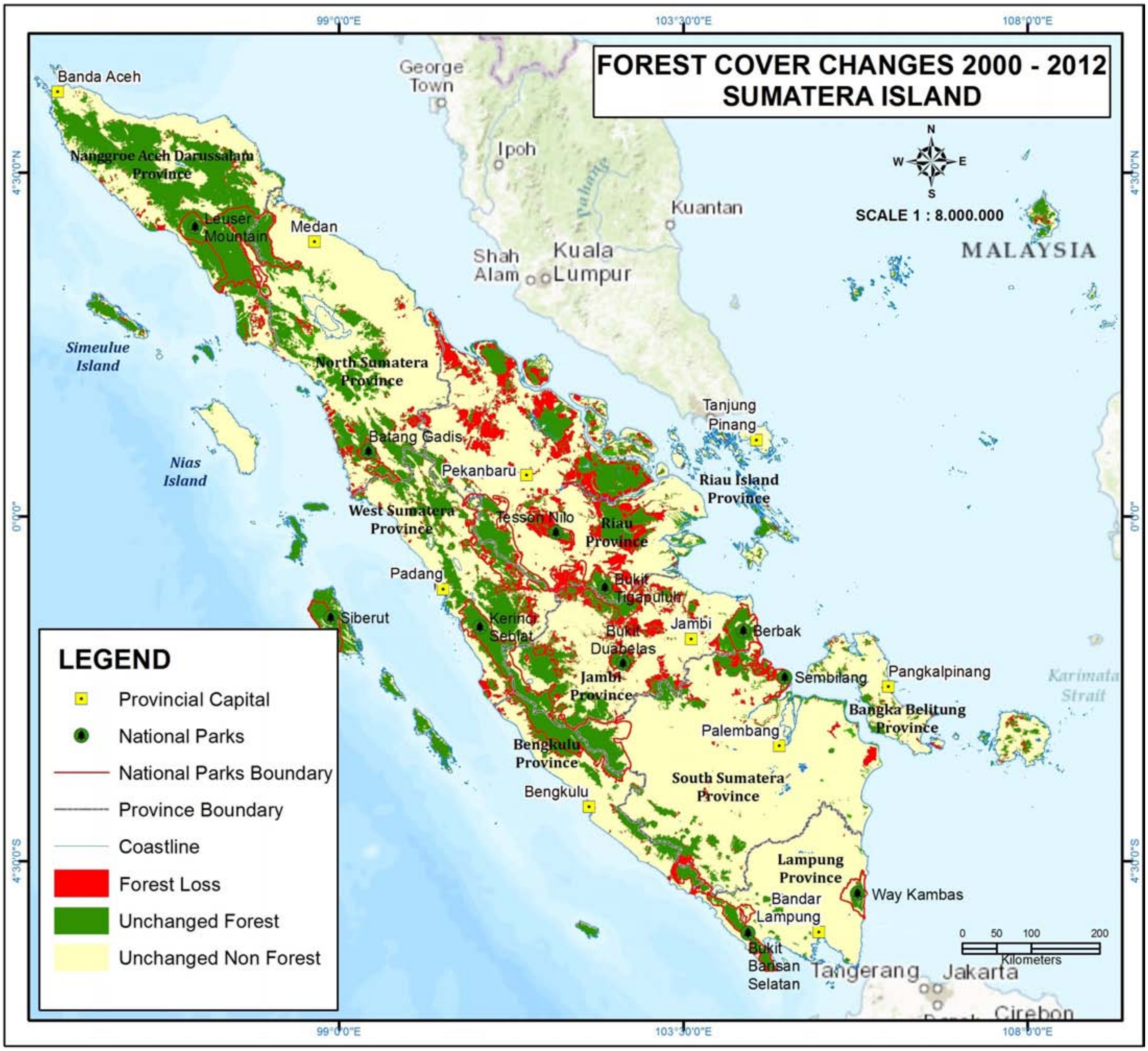

**Figure 1.** Deforestation in Sumatra (by province) between 2000 and 2012. Green areas show forest cover remaining in 2012 and red areas show forest lost between 2000 and 2012. National Parks are also shown.

converted their forest concessions into plantations of acacia and oil palm**.**

In North Sumatra, most forest was lost in the region of the Rawa Singkil Game Reserve, on the southern border of Gunung Leuser National Park. It is located between Gunung Leuser National Park and Batang Gadis National Park (Fig.1). Several companies converted their forest concessions into oil palm plantations. Illegal logging has also affected many areas in the Gunung Leuser National Park itself. All of those affected areas are the habitat of the Critically Endangered Sumatran orangutan *Pongo abelii*, as well as other primates, such as Thomas's langur *Presbytis thomasi*, the Lar gibbon *Hylobates lar*, and the Siamang *Symphalangus syndactylus*.

Figure 2 shows the trend in the rate of forest loss between 2000 and 2012. All provinces show rates of forest loss trending downward. Even provinces with relatively low total forest loss, such as Aceh and Lampung (Table 1) are showing the same downward trend. In Lampung, where there is little forest cover left, this suggests the possibility that none will remain in the near future. Way Kambas National Park may even be at risk. In Aceh, where there is still substantial forest cover remaining, it shows how the opportunity that exists now to arrest decline is disappearing.

Table 2 shows the percentage of forest lost across the range of each Sumatran primate species. The greatest impact was on the Banded langur *Presbytis femoralis*, in Tesso Nilo Forest and on Kampar Peninsula, both in Riau. This species

**Table 1.** Changes in forest cover in each province of Sumatra between 2000 and 2012.

| Province | 2000 (ha) | 2012 (ha) | Deforestation (ha) | Deforestation (%) |
|---|---|---|---|---|
| Aceh | 3,420,356.1 | 3,190,664.8 | 229,691.30 | 6.72 |
| Bangka-Belitung | 319,716.2 | 254,409.4 | 65,306.80 | 20.43 |
| Bengkulu | 807,772.0 | 709,978.8 | 97,793.20 | 12.11 |
| Jambi | 1,872,869.2 | 1,297,884.7 | 574,984.50 | 30.70 |
| Riau Islands | 297,664.3 | 271,572.3 | 26,092.00 | 8.77 |
| Lampung | 309,401.8 | 297,841.9 | 11,559.90 | 3.74 |
| Riau | 3,700,863.9 | 1,856,059.6 | 1,844,804.30 | 49.85 |
| West Sumatera | 2,219,120.9 | 1,955,018.7 | 264,102.20 | 11.90 |
| South Sumatera | 1,156,946.5 | 972,495.9 | 184,450.60 | 15.94 |
| North Sumatera | 1,959,816.4 | 1,710,860.6 | 248,955.80 | 12.70 |
| **Grand Total** | **16,064,527.30** | **12,516,786.70** | **3,547,740.60** | **22.08** |

**Table 2.** Loss of Sumatran primate habitat due to deforestation, between 2000 and 2012.

| Species | 2000 (ha) | 2012 (ha) | Deforestation (ha) | Deforestation (%) |
|---|---|---|---|---|
| *Nycticebus coucang* | 16,269,872 | 11,609,881 | 4,659,991 | 28.64 |
| *Nycticebus bancanus* | 683,587 | 257,496 | 426,091 | 62.33 |
| *Cephalopachus bancanus* | 1,971,709 | 1,708,159 | 263,550 | 13.37 |
| *Presbytis siamensis* | 454,319 | 228,749 | 225,570 | 49.65 |
| *Presbytis sumatrana* | 1,955,141 | 1,708,159 | 246,982 | 12.63 |
| *Presbytis bicolor* | 3,236,717 | 726,554 | 2,510,163 | 77.55 |
| *Presbytis mitrata* | 1,412,558.50 | 792,381 | 620,178 | 43.90 |
| *Presbytis thomasi* | 3,355,323 | 3,149,562 | 205,761 | 6.13 |
| *Presbytis femoralis* | 1,152,684 | 203,485 | 949,199 | 82.35 |
| *Presbytis melalophos* | 1,815,742.50 | 697,812 | 1,117,931 | 61.57 |
| *Presbytis potenziani* | 810,125 | 777,728 | 32,397 | 4.00 |
| *Simias concolor* | 810,125 | 777,728 | 32,397 | 4.00 |
| *Trachypithecus cristatus* | 17,192,006.50 | 12,106,052 | 5,085,955 | 29.58 |
| *Macaca fascicularis* | 16,269,872.50 | 11,609,881 | 4,659,992 | 28.64 |
| *Macaca nemestrina* | 16,269,872.50 | 11,609,881 | 4,659,992 | 28.64 |
| *Macaca siberu* | 190,500 | 182,880 | 7,620 | 4.00 |
| *Macaca pagensis* | 182,887 | 160,940 | 21,947 | 12.00 |
| *Hylobates klossii* | 810,125 | 777,728 | 32,397 | 4.00 |
| *Hylobates lar* | 6,912,123 | 3,207,166.60 | 3,704,956 | 53.60 |
| *Hylobates agilis* | 9,857,169 | 7,891,990 | 1,965,179 | 19.94 |
| *Symphalangus syndactylus* | 16,269,872 | 11,609,881 | 4,659,991 | 28.64 |
| *Pongo abelii* | 5,310,464 | 4,857,722.40 | 452,742 | 8.53 |

lost 82% of its habitat or 949,199 ha of forest between 2000 and 2012. Other species suffering high rates of forest loss include the Bangka slow loris, *Nycticebus bancanus* (62%), the Black-and-white langur *Presbytis bicolor* (78%), and the Black-crested Sumatran langur *Presbytis melalophos* (62%).

*Protected areas and primate habitat*

Table 3 shows that two primates are not represented in the protected area and national park system at all, and that a further five are found in only one protected area. The two unrepresented species are the Pagai macaque, *Macaca pagensis*, and the Mentawai langur, *Presbytis potenziani.* Both occur on Sipora and the Pagai islands off the west coast of Sumatra (Whittaker 2005, 2006). There was a proposal to create a game reserve of 84,500 ha on Sipora, but it has lapsed. There may be only 17,569 ha of intact forest left on the three islands: Pagai North, Pagai South and Sipora (Pemerintah Kabupaten Padang Pariaman, 2014). A subspecies of *C. bancanus*, the Belitung tarsier *C. bancanus saltator*, occurs on Bangka and Belitung islands. There is some forest remaining on these islands, but no protected areas or national parks have been established there. Some of the remaining forest on Belitung has been proposed as a protected watershed. It would not have the same legal status as a national park.

## Discussion

While logging itself does not cause deforestation, logging followed by conversion to agriculture and plantations does. The process is as follows. Although Indonesia's forest law allows selective logging under a system that would give the forest 35 years to recover, commercial logging companies often over-log areas deliberately. After over-logging, an application is submitted to the government to have the over-logged area declared "degraded", which implies that the area is no longer fit to be called a forest and can now be converted to a plantation. This change in status requires an official reclassification of the forested land. Once that change is approved, another company—often a sister company belonging to the same conglomerate—applies for a license to convert that new "wasteland" forest to plantations of either oil palm or acacia for pulp wood. Once the license is issued, the remaining trees are removed and go to a pulp mill. Then plantations are established, the products of which go to mills likely to be owned by members of the same conglomerate (WWF 2004). Companies often cannot prevent local cooperatives, farmers' associations, village organizations, fake companies, and smallholders from encroaching their logging concession, further exacerbating the problem. The above process has been widespread and continues to occur over and over again (Gaveau *et al*. 2009).

This kind of land use change has affected the largest remaining lowland forest blocks on non-peat soils. When the Bukit Tigapuluh National Park was designated in 1995, it was still connected with some of the surrounding forests. In 1996, the first two industrial timber plantation concessions, with licences to clear-cut the forest, appeared in this landscape. At that time, most of the unprotected natural forest (outside national park and protection forest boundaries) was inside selective logging concessions, supposedly safe from conversion by law. Today, Bukit Tigapuluh's approximately 320,000 ha of natural forest are isolated, surrounded by plantations and deforested lands. The endemic primates that occur in these areas are the Black-and-white langur, *Presbytis bicolor*, the Black-crested Sumatran langur, *Presbytis melalophos*, the Agile gibbon, *Hylobates agilis*, and the Siamang, *Symphalangus syndactylus*.

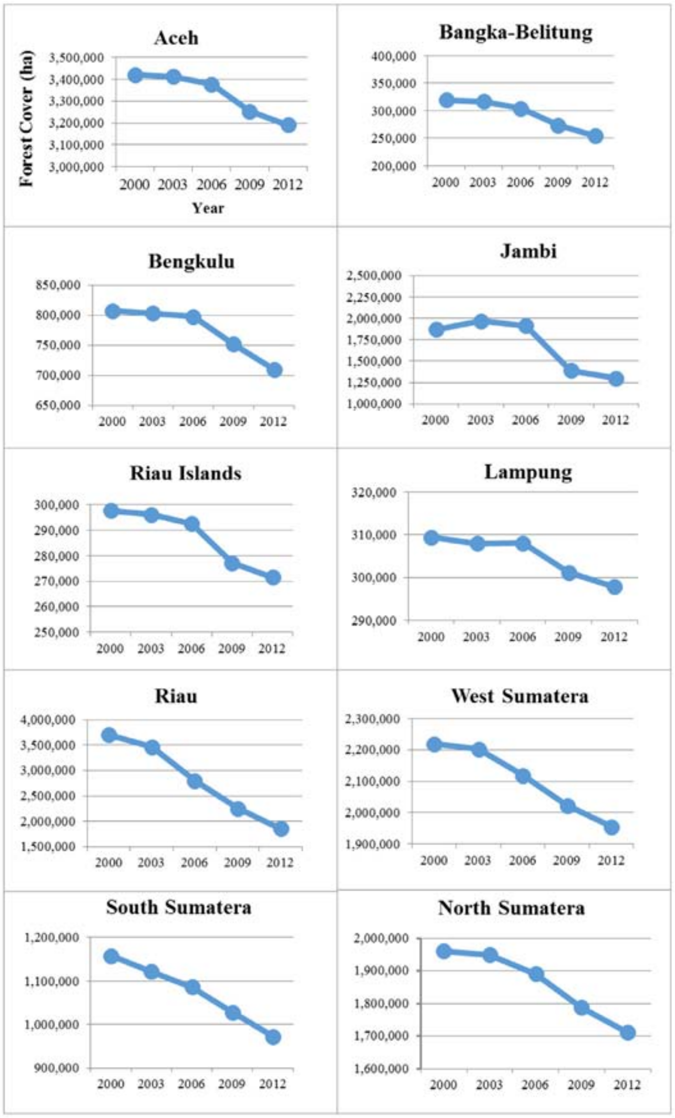

**Figure 2.** Rate of forest loss in Sumatran provinces between 2000 and 2012.

The difference between logging and land conversion for agriculture or tree plantation is that the latter leads to permanent forest loss, while logging (especially selective cutting) provides the opportunity for forests to regenerate. Moreover, land-clearing methods applied in the establishment of timber estates or commercial agriculture contributes to forest fires.

Forest fires are another major cause of deforestation in Sumatra. Although many point to natural causes such as El Niño, human activities and forest management practices play important roles in causing forest fires. In 1997–1998, the El

**Table 3**. Occurrence of primates in national parks and other protected areas in Sumatra. NP = National Park, PA = Protected Area.

| **Primate species** | **Leuser NP (1,092,692 ha)** | **Lingga isaq PA (80,000 ha)** | **Rawa Singkil Game Park (102,500 ha)** | **Batang Gadis NP (108,000 ha)** | **Tesso Nilo NP (83,018 ha)** | **Bukit tigapuluh NP (127,698 ha)** | **Bukit Dua belas NP (60,500 ha)** | **Kerinci seblat NP (1,375,359 ha)** | **Sembilang NP (205,100 ha)** | **Berbak NP (162,700 ha)** | **Way Kambas NP (130,000 ha)** | **Bukit Barisan NP (376,999 ha)** | **Siberut NP (190,500 ha)** | **Muh Hatta Game Park (71,807 ha)** | **Kampar PA (20,000 ha)** | **Total # of parks** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Pongo abelii* | × | × | × | × | | | | | | | | | | | | 4 |
| *Symphalangus syndactylus* | × | × | | × | × | × | × | × | | | × | × | | × | | 10 |
| *Hylobates lar* | × | × | | | | | | | | | | | | | | 2 |
| *H. agilis* | | | | × | × | × | × | | | | × | × | | × | | 8 |
| *H. klossii* | | | | | | | | | | | | | × | | | 1 |
| *Presbytis thomasi* | × | × | × | | | | | | | | | | | | | 3 |
| *P. sumatrana* | | | × | × | | | | | | | | | | | | 2 |
| *P. melalophos* | | | | | | × | × | × | | | | × | | × | | 5 |
| *P. siamensis* | | | | | × | | | | | | | | | | × | 2 |
| *P. femoralis* | | | | | | | | | | | | | | | × | 1 |
| *P. mitrata* | | | | | | | | | | | × | × | | | | 2 |
| *P. bicolor* | | | | | | × | × | | | | | | | | | 2 |
| *P. potenziani* | | | | | | | | | | | | | | | | 0 |
| *P. siberu* | | | | | | | | | | | | | × | | | 1 |
| *Trachypithecus cristatus* | × | × | × | × | × | × | × | × | × | × | × | × | | × | × | 14 |
| *Simias concolor* | | | | | | | | | | | | | × | | | 1 |
| *Macaca nemestrina* | × | × | × | × | × | × | × | × | × | × | × | × | | × | | 13 |
| *M. fascicularis* | × | × | × | × | × | × | × | × | × | × | × | × | | × | × | 14 |
| *M. siberu* | | | | | | | | | | | | | × | | | 1 |
| *M. pagensis* | | | | | | | | | | | | | | | | 0 |
| *Nycticebus coucang* | × | × | × | × | × | × | × | × | × | × | × | × | | × | × | 14 |
| *Cephalopachus bancanus* | | | | | | | | × | × | × | × | × | | | | 5 |

Niño Southern Oscillation—a cyclical warming and cooling of the eastern Pacific Ocean—brought drought conditions to Sumatra, rendering forests on peaty soils especially vulnerable to fire. At the same time, the price of palm oil increased, and plantation developers in Sumatra, eager for land, deliberately burned large areas of forest. During this time fires reportedly destroyed almost 1 million ha of forests (World Bank 2001).

Forest fires in Indonesia have been recurrent for the last 17 years. In 2015, the fires were even more destructive than they were in 1997–1998, burning 3.4 million ha of forest. The smoke from deforestation by fire adversely affects the health of people in neighbouring countries as well as in Indonesia. The release of carbon into the atmosphere contributes to climate change. The cost of the 2015 fires is estimated to have been approximately US$14 billion and may be more if the costs of mitigating the impact in several other Southeast Asian countries are included (WRI 2015). Most of those fires were in Sumatra and Kalimantan.

*Illegal logging*

Logging occurs mainly in concessions granted to companies. However, as long as 16 years ago the Indonesian Ministry of Forestry (2002) officially stated an opinion that had been prevalent for some time:

> "Illegal logging has come to constitute a well-organized criminal enterprise with strong backing and a network that is so extensive, well-established and strong that it is bold enough to resist, threaten, and in fact physically tyrannize forestry law enforcement authorities. Illegal cutting occurs in concession areas, unallocated forest areas, expired concessions, state forestry concessions, areas of forest slated for conversion, and in conservation areas and protected forests."

This continues to be the case today. Currently, illegal logging is increasing in conservation areas (protected areas and national parks) since these areas now have better timber potential than production areas. Many experts believe that the main actors in illegal logging are: (a) laborers from communities within the local forest area as well as from other areas; (b) investors, including traders, concession holders, or holders of legal timber cutting permits (IPK), and buyers of illegal timber; and (c) government officials (both civilian and military), law enforcement personnel and certain legislators (Supriatna *et al.* 2002).

*Policy changes*

Government policy also contributed to forest loss when decisions on forest use were decentralized from the Ministry of Forestry to district governments in 1999 and renewed in 2004. District governments have been allowed to allocate 100-ha forest concessions to be logged by small-holders and communities without appropriate planning and without an understanding of forest ecology (Supriatna 2009). The World Bank (2001) and Holmes (2002) predicted that with this kind of policy, lowland natural forest would be likely to disappear from Sumatra by 2005. There has been no follow up of Holmes's (2002) prediction to determine whether and at what rate forest loss is progressing. Although a recent review did confirm some of his prediction, that forest cover is being lost not only in production forest, but also in protected areas, including national parks, not all lowland forest has disappeared (Supriatna 2009).

It has been government policy to expand palm oil production since 2005, which has resulted in more deforestation. Everyone wants to grow oil palm. Decentralization also allowed government authorities to issue oil palm licenses more freely. This may have had an even more significant impact on forest loss than the 100-ha logging concessions.

*Road construction*

Roads built across the Tesso Nilo Forest block in Riau province to provide transport for pulp and paper companies have significantly increased deforestation rates by facilitating encroachment into the forest by local communities and illegal loggers from other places. More than 80 km of roads have been used by people, not only to cut trees along the roads, but also to access once remote parts of the forest (Mariati *et al*. 2014). The resulting picture looks like a comb: the roads acting as primary axes, with many new small access tracks to huts and new small business houses selling to people, encroaching along these main roads. These "fishbone" patterns have been found in many other tropical countries.

Satellite images, provincial public works plans and budget allocation documents reveal that roads are being constructed throughout Sumatra. Satellite images show thousands of logging roads penetrating deep into protected forests and national parks. Aceh Province has a plan to construct a system of feeder roads extending from Banda Aceh, south to the Leuser Ecosystem boundary. A road was recently constructed in the Kerinci Seblat National Park, Jambi Province, despite local and governmental agreement forbidding road construction. Accessibility of a forest is often the most important factor leading to deforestation (Etter *et al*. 2006; Laurance *et al*. 2009; Clements *et al*. 2014; Laurance *et al*. 2015).

*Impact of deforestation on primates*

The last review of population sizes, ecology and conservation status of Sumatra's primates, part of a review across all of Indonesia, was carried out in 2000 (Supriatna *et al*. 2001). Fifteen years later, many surveys have been conducted and the results of some long-term research studies are available. These are summarized below and compared to the review of Supriatna *et al*. (2001).

Human activities (predominantly the processes described above of logging, land conversion, and fire) have caused widespread forest fragmentation so that even where some high quality habitat remains, it is often disaggregated into small, isolated forest fragments. Fragmentation restricts the dispersal of primates. Their home ranges or territories become limited, sub-populations become isolated from one another, and there is competition for habitat (Groom *et al*. 2006). Limited home ranges and the isolation of sub-populations causes population declines. Small populations are less viable than large ones (Cowlishaw and Dunbar 2000). Road construction patterns such as those described above indicate that habitat fragmentation will become increasingly widespread in the future.

Seven years ago, Indonesian and international experts on orangutans were invited by the Ministry of Forestry to discuss ways of preventing the extinction of Sumatran orangutans in the wild. Five hundred was considered by the expert panel to be the minimum size at which orangutan populations could be expected to have the necessary genetic diversity to cope with the various challenges posed by environmental change. Populations of fewer than 500 individuals lack the resilience to hold out against the prospect of extinction without the aid of environmental protection and population management efforts (Indonesia Ministry of Forestry 2009). Most isolated orangutan sub-populations now have fewer than 500 individuals.

The impacts of deforestation on gibbon populations in Sumatra have been studied by Yanuar and Chivers (2010). Agile gibbons are most dependent on closed canopy forests and year-round fruit availability. They were encountered or heard in relatively high numbers in undisturbed forest, where the related Siamangs also appeared to be abundant. Gibbons and Siamangs still occurred in selectively logged forests, but in lower numbers. Siamangs were encountered in forests without Agile gibbons, but not the other way round (Yanuar and Chivers 2010). Siamangs appear to be more resilient to forest degradation. This is not surprising considering that Siamangs are able to survive on a more folivorous diet, whereas the smaller gibbons need a higher proportion of fruit in their diets (Raemaekers 1979).

In Way Kambas National Park, Lampung, South Sumatra, langurs (*Trachypithecus* spp. and *Presbytis* spp.) have been observed in small forest patches and more heavily disturbed forests, and even in rubber plantations that still included some of the original forest trees. However, gibbons and Siamangs are absent. No primates were encountered in monoculture rubber plantations, although a group of Long-tailed macaques was observed on the periphery of one of them, suggesting that this particular species may have a high adaptive flexibility. Habitat degradation and logging were observed in virtually every forest (Geissmann *et al*. 2006).

In many villages in South Sumatra, pet primates are openly displayed or are shown without hesitation. They include species that are legally protected by Indonesian law, showing ignorance of, or disregard for, the law and a general lack of law enforcement. Primates are also illegally hunted in Sumatra for food, profit and trophies, and to fulfill obligations related to cultural rites of passage. Magnifying the problem, as a result of habitat fragmentation, many animals are now concentrated in smaller areas, making them easier targets for hunters, as well as making them less able to recover from population declines, especially when animals of reproductive age are taken (Supriatna *et al*. 2001).

The swamp area between Rawa Singkil Protected Area and Gunung Leuser National Park, has the largest remaining populations of Sumatran orangutans (Singleton *et al*. 2009). Estimates of the total population of Sumatran orangutan have declined dramatically over the last two decades due to habitat loss. Some surveys concluded that more than 1,000 orangutans were lost each year due to forest loss during the late 1990s (Singleton *et al*. 2009). According to survey results published in 2008, only around 6,600 Sumatran Orangutans remained in the wild (Wich *et al*. 2008; Singleton *et al*. 2009). Fortunately, a new survey conducted in 2015 estimated a total population of 14,613 (Wich *et al*. 2016). This was a more systematic survey then the earlier ones, finding orangutans at higher elevations than they were thought to occur at, in areas that had not been previously surveyed, and in some logged forests. This has extended the known range to 17,800 km$^2$. However, even given that there is a larger and more widely distributed population than previously thought, Wich *et al*. (2016) warn that with the current rate of forest loss, the total population is likely to be reduced to approximately 4,500 individuals by 2030.

### *Role and performance of national parks and other protected areas*

Many of the protected areas in Sumatra cover regions with extremely rugged terrain, or with slopes or elevations unsuitable for agriculture. Most of the largest national parks and protected areas are located in the mountain range of Bukit Barisan, running from north to south on the western side of the island. Most Sumatran primates occur in lowland forest or forests of lower slopes, which are not well-represented in protected areas. Densities of fauna in most protected areas are therefore already low and will decline further unless dispersal between them is facilitated by, for example, corridors of natural habitat. Encroachment of people makes restoration and conservation of such corridors increasingly difficult. The protected areas themselves face a number of basic management problems, including poor staff morale and discipline; lack of incentives for good performance by staff; limited capacities and training; emphasis on park infrastructure rather than enforcement or awareness-raising activities; budget allocations made according to previous budgets rather than threats or needs on the ground at the present time; and emphasis on administration rather than field duties for park managers (Supriatna *et al*. 2002).

In addition, most parks have little support from local communities and decision-makers. The government of Indonesia made commitments to the special Consultative Group meeting on forestry issues in January 2000, including a commitment to stop illegal loggers, especially those operating in national parks. At that time, conservation donors maintained that there was little point in funding conservation efforts if they were not supported by effective government enforcement. Unfortunately, widespread illegal logging and corruption remain in evidence. In fact, illegal logging in Sumatra's protected areas may even be increasing (FWI 2001; FWI and GWF 2002; Gaveau *et al*. 2012)

In many conservation areas, especially in the nature reserves where no economic activity is allowed, the incentives for local people to preserve the natural habitat and to abstain from encroachment are very weak. It has been reported, for example, that 25 unlicensed sawmills were in the immediate vicinity of Bukit Tigapuluh National Park (Anggraeni 2000). These sawmills had no official allocation of legal timber and thus relied upon an illegal supply from the surrounding forest. The estimated processing capacity of those sawmills at that time was around 230,000 m of roundwood per year (Anggraeni 2000).

Existing protected areas are not secure and their protection effectiveness, if measured as the percentage of area degraded annually, is poor. Most Sumatran protected areas are under-resourced and some receive no regular budget at all. Priority conservation areas are reliant on supplementary donor financing, which covers only a limited project period. Several national parks are supported by international donors where, unfortunately, the annual forest loss is similar in size to under-funded areas (Supriatna 2009; Margono *et al*. 2012).

There are many overlapping and conflicting claims to lands within protected areas. According to newspaper reports, this situation has worsened with decentralization and new perceptions of local community land rights. Way Kambas National Park in Lampung Province is a good example. It is a high conservation priority lowland forest which is nearly 50% degraded because of conflicting ownership claims. Several thousand people have submitted court claims based on the perceived illegality of the original creation of the national park. The purpose and intention of the park has been noted on the provincial spatial plan or forest land use map, but little action leading to official gazettal is evident. It is only when local governments (governor, regent) have passed decrees based on field-level consultations with local communities, that an area can be legally gazetted, as set forth in a final decree issued by the Minister of Forestry. There is little incentive for this to happen.

Changing production forests into national parks by converting the tenure of logged-over areas would seem, on the face of it, to be a secure and effective way of reducing deforestation. However, even though some forests, such as Tesso Nilo and its surrounds have been proposed for conversion to national park status, the process of demarcating forest boundaries is slow and confusing, involving overlapping and conflicting claims to lands within the park and within other forested lands belonging to companies. This legal uncertainty makes it easier to excise land from proposed parks for other uses (Uryu *et al*. 2007). Issues with conflicting land tenure claims, imprecise boundaries and differences between *adat* (traditional) law and government law are recurring issues throughout Indonesia (for example, Riggs *et al*. 2016) that need to be resolved to secure primate habitat into the future.

In May 2011, the Government of Indonesia prohibited district governments from granting new forest concession licenses (President Instruction No. 10; Fajar 2013), which was extended for another two years in 2013, despite some opposition from powerful palm oil interests (Butler 2013). This moratorium covered licenses for three types of activities: (i) conversion of primary forests and peatlands to oil palm plantations (oil palm concessions); (ii) conversion of primary forests and peatlands to fast-growing tree plantations for pulp and paper (timber concessions); and (iii) logging of commercially valuable tree species in forests (logging concessions). It was meant to protect over 65 million ha of forest and peatlands (Sloan 2014). However, in the first two years, around 4.5 million ha were removed from the moratorium for mining and agro-industries, and it seems a further 5.5 million ha, which overlaps with current forest licenses may also become exempt. This has occurred mainly due to a lack of clarity of maps of the moratorium areas. Nevertheless, the moratorium is an important development and demonstrates a serious attempt by the government of Indonesia to protect Indonesia's forests (Butler 2013; Sloan 2014).

## Conclusions

The loss of primate habitat will continue as human populations continue to increase and more and more forest is converted to plantation estates and agricultural lands, and roads are built across Sumatran forests. As a consequence, many primates will become forced to share what remains of their territories with people. The resulting conflict between the need for human livelihoods and the need to protect primates, especially those that are Critically Endangered such as the Sumatran orangutan, has quickly escalated. Using GIS and remote sensing imagery, we found that deforestation rates have increased in the habitats of many primates. Orangutan habitat in North Sumatra and Aceh has been severely reduced and the habitats of many other primates in the provinces of North Sumatra, Riau, Jambi and South Sumatra have also declined markedly in area. High deforestation rates have occurred as a result of legally converting natural forest into oil palm, rubber and Acacia plantations, and illegal logging of the forests, even in protected areas and national parks. The problem is exacerbated by the fact that Indonesia remains largely an agricultural country. A significant proportion of the population relies on farming for survival. Population pressure and the lack of off-farm employment leads to demands for more agricultural land, which can only come at the cost of forests. With recent taxonomic revisions, some primates such as those of the Mentawai islands of western Sumatra (*Presbytis potenziani*, *Macaca pagensis*) and the subspecies *Cephalopachus bancanus saltator* on Bangka and Belitung islands in eastern Sumatra, are not found in protected areas at all. The remaining habitat of these three species, covering only a few thousand hectares, is not enough for them to survive unless the forest remnants in which they occur become protected and connected with each other.

The results presented here now constitute a baseline against which improvements can be monitored. Any further loss cannot be countenanced. Habitat degradation cannot be allowed to continue if many of Sumatra’s primates are to survive. Enforcement of existing regulations, disentanglement of land claims and overlapping boundaries, a halt to logging in existing forests, a halt to road building through existing forests, clarification of how *adat* (traditional) law relates to protected areas, and the creation of new, enforceable laws protecting species from trade and exploitation will all be needed if Indonesia is to uphold its stated commitment to primate conservation.

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# The Taxonomy, Distribution, and Conservation Status of the Slender Loris (Primates, Lorisidae: *Loris*) in Sri Lanka

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**Abstract:** External body dimensions and proportions, skull morphology, coat coloration, vocalizations, and genetics have contributed to an increase in the number of diagnosable species among nocturnal primates. Two species of slender loris are currently recognized for Sri Lanka: the red slender loris *Loris tardigradus* (Linnaeus, 1758), endemic to the wet zone and montane areas; and the grey slender loris *Loris lydekkerianus* Cabrera, 1908, which is widespread and also occurs in India. The red slender loris has two subspecies, namely the western red slender loris *Loris tardigradus tardigradus* (Linnaeus, 1758) and the Horton Plains slender loris *Loris tardigradus nycticeboides* Hill, 1942. *Loris t. tardigradus* is found in the lowland wet zone and *L. t. nycticeboides* is restricted to the montane region of south-central Sri Lanka. Two subspecies are also ascribed to *Loris lydekkerianus* in Sri Lanka, namely the northern Ceylon slender loris *Loris lydekkerianus nordicus* Hill, 1933, and the highland slender loris *Loris lydekkerianus grandis* Hill and Phillips, 1932. *Loris l. nordicus* is found in the dry zone, and *L. l. grandis* is restricted to the submontane region of Kandy and Matale. Another two subspecies are known from southern India. We examined specimens (live and museum) from all climate/vegetation zones in Sri Lanka, for facial and pelage features, external body morphology, and skull morphology, and concluded that there are at least two species and at least six subspecies, though we suspect that some, or all, of these subspecies may be distinct species. Names are available for four of these taxa, and here we describe two new subspecies.

**Key words:** taxonomy, *Loris lydekkerianus*, *Loris tardigradus*, morphology, slender loris, Sri Lanka

## Introduction

The slender lorises (Suborder Strepsirrhini, Family Lorisidae, *Loris* É. Geoffroy Saint-Hilaire, 1796) are small nocturnal primates found only in India and Sri Lanka (Groves 1998, 2001; Nekaris and Jayawardene 2004). Groves (1998) recognized two species of slender loris for Sri Lanka: the red slender loris *Loris tardigradus* (Linnaeus, 1758) and the grey slender loris *Loris lydekkerianus* Cabrera, 1908. The former is endemic to Sri Lanka, whereas the latter species is also found in southern India.

The oceanic island of Sri Lanka is 65,610 km$^2$, and is separated from India by the 19-km-wide Palk Strait (Wijesinghe *et al.* 1993). Sri Lanka, along with the Western Ghats of India, is remarkable for its biodiversity, and is one of the world's Biodiversity Hotspots following the analyses and parameters of Mittermeier *et al*. (2004). Our knowledge of its biodiversity is, however, still highly dependent on surveys completed a century or more ago (Pethiyagoda 2005). Recent taxonomic studies are scarce for small mammals and primates (Weerakoon and Goonatilake 2006) and the inventory is evidently far from complete. This is highlighted by the descriptions of a new species of mouse deer *Moschiola kathygre* Groves and Meijaard, 2005, a new species of shrew *Suncus montanus*

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Meegaskumbura and Schneider, 2008, and a new species of Golden palm civet *Paradoxurus stenocephalus* Groves, Rajapaksha and Manemandra-Arachchi, 2009, over the last seven years.

The slender loris was first described as *Lemur tardigradus* Linnaeus, 1758, based on an illustration in Seba (1735), probably depicting a red slender loris from Sri Lanka (Thomas, 1908). Geoffroy Saint-Hilaire (1796), under the impression that Linnaeus had described a slow loris, described the slender loris as a new genus and species, *Loris gracilis*. The generic name was conserved by the International Commission on Zoological Nomenclature (1999). Until the 20th century, Linnaeus's name was taken by almost all authors to be based on a slow loris (genus *Nycticebus*). It was Stone and Rehn (1902) who argued that Linnaeus's name *tardigradus* actually referred to a slender loris, and Thomas (1908) concurred, tightening and extending aspects of their argument. Gentry *et al*. (1998) later designated a lectotype in the Stockholm Museum of Natural History.

Fischer (1804) recognized É. Geoffroy Saint-Hilaire's (1796) *Loris gracilis* as a reddish species ("schlanker Loris"), from Ceylon (Sri Lanka), and in addition described *Loris ceylonicus* ("ceylonischer Loris") as a yellowish-brown species. From the descriptions, it is difficult to determine whether these do or do not refer to the same taxon, and in the absence of type specimens it is impossible to say with certainty. Provisionally both names may be placed as junior synonyms of Linnaeus's name. The measurements given by Fischer (1804: 163−166) are apparently within the range of what is here considered to be *Loris tardigradus tardigradus* (Linnaeus, 1758): *Loris gracilis* has a greatest skull length from the tip of the snout to the convexity of the occiput of 48 mm, while in *Loris ceylonicus* this measurement is 50 mm.

Lesson (1840) renamed the reddish slender loris from "l'île de Ceylan" as *Arachnocebus lori*, but apparently for the first time described one of the blackish forms (likewise from "l'île de Ceylan") under the name *Bradylemur tardigradus* var. c—that is to say, he failed to recognize its affinity to the reddish slender loris and referred it to the genus *Bradylemur*, which he had erected for slow lorises (now *Nycticebus*).

From 1840 to 1905, no new species or subspecies of loris were added to the Sri Lankan loris fauna. Then Lydekker (1905), evidently unaware of Stone and Rehn's (1902) paper, and taking two mounted specimens from Madras (now Chennai) as "typical" for *Loris gracilis*, described "the Ceylon Loris" as *Loris gracilis zeylanicus* on the evidence of another mounted specimen (this is BM 1904.10.12.3, with no precise locality other than "Ceylon", according to Jenkins, 1987). Although not strictly a homonym of Fischer's *Loris ceylonicus*, Recommendation 58A of the *Code* states that "An author should not base a new species-group name on a personal or geographical name if another name derived from the same word or from words of the same meaning (even if differently formed) is in use in the same or an allied or associated genus…" Notwithstanding, the name has not been used for over a century, and so ranks as a *nomen oblitum*.

In 1932, a new subspecies of slender loris, the highland slender loris *Loris tardigradus grandis*, was described by Hill and Phillips (1932) from Gammaduwa in the Knuckles Range, and the following year Hill (1933) described another subspecies from the northern dry zone, the northern Ceylon slender loris *Loris tardigradus nordicus*. In 1937, Mr. A. C. Nolthenius caught a pair of loris on his estate below the Horton Plains (1522−1826 m), and kept them in captivity for several years in Colombo (Nicholls 1939). They were described as a further new subspecies by Hill (1942), the Horton Plains slender loris *Loris tardigradus nycticeboides*. Two further subspecies had meanwhile been described from southern India, the Mysore slender loris *Loris tardigradus lydekkerianus* Cabrera, 1908, from Madras, and the Malabar slender loris *Loris tardigradus malabaricus* Wroughton, 1917, from Kutta, South Coorg (more fully described in Hill 1953).

The classification of slender lorises has been debated for many decades (Hill 1953; Phillips 1980; Groves 1998, 2001; Brandon-Jones *et al*. 2003; Roos 2003; Nekaris and Jayawardene 2004; Nekaris *et al*. 2006), yet we are still essentially using Hill (1953) for the taxonomy, with a slight revision by Groves (1998). According to Hill (1953), there is a single species of slender loris, with six subspecies: four in Sri Lanka and two in India. On the basis of museum specimens, Groves (1998) recognized two distinct species: *Loris tardigradus* (Linnaeus, 1758), monotypic and restricted to the wet zone of southwestern Sri Lanka, and *Loris lydekkerianus* Cabrera, 1908, in the rest of the range of the genus in both Sri Lanka and India. These changes were corroborated by Coultas (2002) and Nekaris and Jayawardene (2004) on the basis of behavioral and morphological evidence from wild populations, and were further supported by phylogenetic analyses and studies of museum specimens by Roos (2003) and Nekaris *et al*. (2006). Groves (1998) placed the taxon *nycticeboides* in *L. lydekkerianus* as a subspecies, but Nekaris and Jayawardene (2004) transferred it to *L. tardigradus*, while Yapa and Ratnavira (2013) suggested that it might be a distinct species.

Valid taxonomy is essential for species conservation. Biodiversity assessment—the taxonomy, biogeography and conservation status of a region's fauna and flora—is vital for investment in and implementation of conservation measures (Mace 2004). Conservation management demands reliable data to verify the distribution boundaries of taxa for their identification as spatial conservation units. To fulfill these concerns, we reviewed the taxonomy of the Sri Lankan slender lorises, following a meeting of experts and interested parties in 2009 that included representatives of the following organizations: The Open University of Sri Lanka, University of Colombo, Ministry of Environment and Natural Resources, Department of Wildlife Conservation, Forest Department, National Science Foundation, National Zoological Garden, University of Peradeniya and IUCN Sri Lanka.

In our study, we examined the following alternative hypotheses regarding the taxonomy of the slender loris: (1) that a two-species classification—*L. tardigradus*, either monotypic or with *nycticeboides* as a subspecies, and *L.*

**Table 1.** Number of samples represented in seven groups of Sri Lankan lorises (see Table 2).

| **Sample origin** (n = sample size) | **Group 1** | **Group 2** | **Group 3** | **Group 4** | **Group 5** | **Group 6** | **Group 7** |
|---|---|---|---|---|---|---|---|
| Live lorises captured from wild (n = 82) | 10 | 28 | 7 | 2 | 12 | 5 | 18 |
| Live lorises observed from the wild (n = 13) | 2 | 3 | 2 | 1 | 1 | 1 | 3 |
| Photograph from the live lorises (n = 9) | 1 | 2 | 1 | 1 | 1 | 1 | 2 |
| Fresh specimens (dead specimens) (n = 4) | 1 | - | - | 1 | - | - | 2 |
| Mounted skins with skulls (n = 20) | 4 | 2 |  | 1 | 5 |  | 8 |
| Skin only (n = 5) | - | - | - | 1 | 2 | 1 | 1 |
| Skulls only (n = 29) | 5 | 6 | - | - | 1 | 13 | 4 |
| Complete mounted skeleton (n = 1) | 1 | - | - | - | - | - | - |

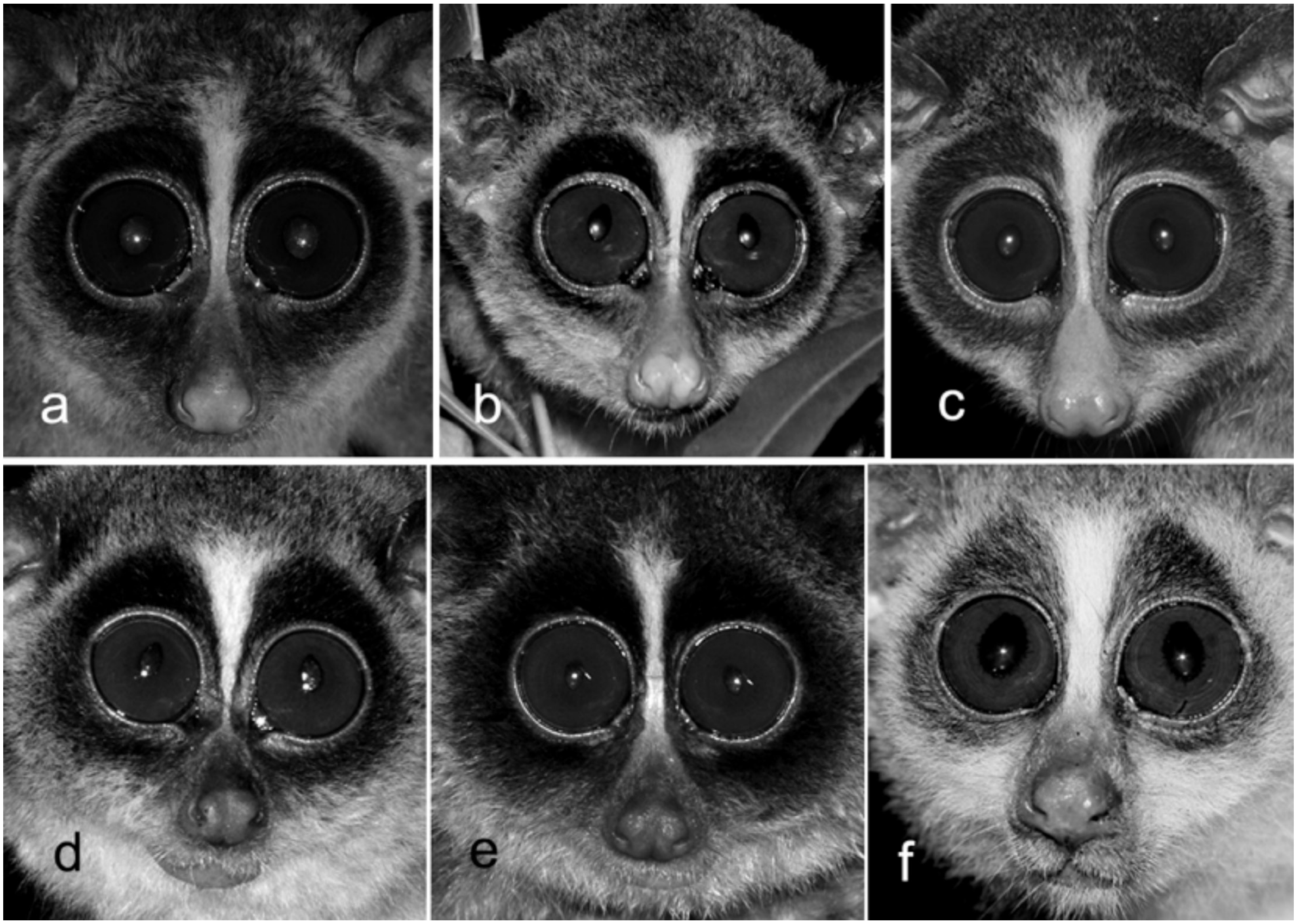

**Figure 1.** Variation of circumocular patch shapes in different slender loris groups in Sri Lanka: **a.** Northwestern group (marquise -elliptical with pointed ends), **b.** Southwestern group (ovoid/rounded), **c.** Uva group (ovoid/rounded), **d.** Highland grey (pear), **e.** Montane group (broad pear), and **f.** Northern grey group (teardrop).

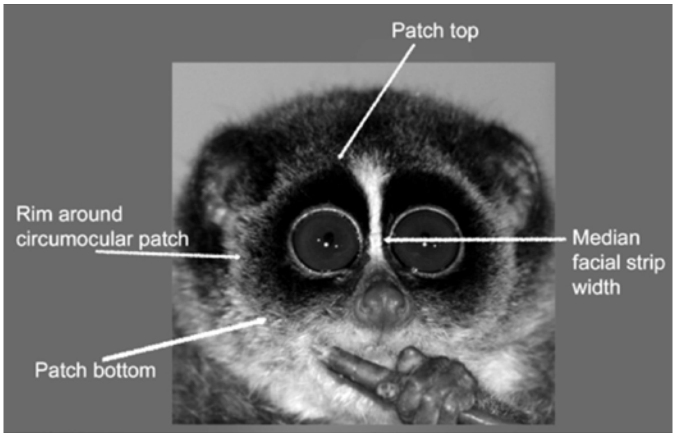

**Figure 2.** Some facial features used for the analysis.

*lydekkerianus*, with subspecies *grandis* and *nordicus* and perhaps *nycticeboides*—adequately describes the taxonomy of the slender loris in Sri Lanka; and (2) that a single-species classification, with four subspecies, adequately describes the taxonomy of the slender loris in Sri Lanka.

## Methods

### *Examination of live animals and photographs*

Ninety-five live lorises were examined, 82 of which were captured and measured in the wild, and 13 were closely examined in the field, but not captured, by the first author. A further four lorises were received as dead specimens. Clear photographs of nine live slender lorises contributed further information (see Table 1). These samples were from different climatic regions: (1) wet zone (annual rainfall >2500 mm), (2) intermediate zone (annual rainfall, 2500−1900 mm), and (3) dry zone (annual rainfall <1900 mm), at different elevations (1) low elevation (0−400 m asl), (2) mid elevation (400−1200 m asl), and (3) high elevation (>1200 m asl), in Sri Lanka.

Captures were done by hand by trained field researchers; two to four at a time. After taking measurements, the lorises were released where they were captured. The research was carried out under the Department of Wildlife Conservation Sri Lanka permit number WL/3/2/1/9, and guided and supervised by the National Research Committee of the Department of Wildlife Conservation. Measurements taken in the field followed the guidelines of Groves (2003). Facial and pelage features were examined of all of the 82 live animals captured.

There are wet and dry seasons in Sri Lanka. The first author has been studying wild lorises since 2002, and has never observed seasonal variation pelage. Aging is the only factor affecting pelage variation, and only facial and pelage features of mature animals were used for analysis. Facial marks and terms used in the study are shown in Figures 1 and 2 and in the conservation database for lorises (Schulze *et al*. 2003). Nine measurements were taken from each live animal to assess phenetic variation among samples. Measurements were taken to the nearest 0.01 mm using digital calipers. The measurements were: upper arm length (UAL), forearm length (FAL), thigh length (TL), leg length (LL), knee length (KL), maximum head length (MHL), head breadth (HB), maximum breadth over postorbital bars (MBOP) and ear length (EL). Standard measuring points are shown in the conservation database for lorises (Schulze *et al*. 2003).

### *Examination of museum specimens*

Forty-four specimens from natural history museum collections were examined: National Museum of Sri Lanka, Colombo (NHMC) (skin + skull = 4; skin only = 2), University of Colombo Zoology Museum (UOCSL) (skull only = 1; complete mounted skeleton = 1), British Museum (Natural History), London (BMNH) (skin + skull = 6; skin only = 2; skull only = 3), Field Museum of Natural History Chicago (FMNH) (skin + skull = 8; skull only = 1), Royal College of Surgeons of London (RCSL) (skulls only = 15, but two of them belonging to skins in the NHMC), and National Museum of Scotland (NMS) (skin only = 1). We also examined 11 slender lorises captured live that were euthanized (Department of Wildlife Conservation Sri Lanka permit number WL/3/2/1/9), using standard protocols under the supervision of a qualified veterinarian and strictly following the American Society of Primatologists' principles for the ethical treatment of primates and the International Primatological Society's international guidelines for the acquisition, care and breeding of nonhuman primates. Their skins and skulls are preserved as voucher specimens. Three road kills, one electrocuted specimen, and seven skulls were received from various parts of the country during the study period. These and the 11 live specimens that were euthanized will be deposited in the National Museum of Sri Lanka, Colombo (NHMC) under the Slender Loris Conservation Project (SLCP) collection.

Pelage characters and facial mask differences were examined from the 23 skins deposited in the various museums, and from the three road kills, the electrocuted individual and the 11 euthanized specimens. Major fur characters, color marks and terms used in the study are shown in Figures 1 and 2, and in the conservation database for lorises (Schulze *et al.* 2003). The sample included the type specimens for the described subspecies *Loris gracilis zeylanicus*, *Loris tardigradus nycticeboides*, *L. t. nordicus* and *L. t. grandis*.

Eleven cranial and mandibular measurements were taken (standard measuring points are shown in Schulze *et al*. 2003). Measurements were taken to the nearest 0.01 mm with digital calipers, as follows: greatest length of skull (GLS), length of nasal (LON), biorbital breadth (BB), zygomatic breath (ZB), breadth of braincase (BOB), mastoid breadth (MB), palate length (PL), condylobasal length (CBL), condylo-canine length (CCL), alveolar length of maxillary toothrow (ALMT), mandible length (ML).

### *Analysis – facial and pelage features*

Recent studies suggest that vision may play a greater role in the lives of nocturnal primates than was originally supposed (Bearder *et al*. 2006). Lorisiforms have monochromacy resulting from the loss of a functional SWS1 opsin (Tan *et al*. 2005); therefore, white and strongly contrasting colours and patterns are easily distinguishable, aiding these animals in identifying potential mates and conspecifics. Variation in the facial mask is especially useful in distinguishing between species (Nekaris and Jaffe 2007; Nekaris and Munds 2010; Munds *et al*. 2013), and such contrasting patterns are seen in the facial masks of slender lorises. Thus live animals and skins were grouped according to facial/pelage features and area of origin. A guide was created for future researchers to replicate or expand upon this study (Figs. 1 and 2).

Twenty-three facial and pelage features were used for this study, as follows: overall shape of the circumocular patch (Fig. 1); shape of the top and bottom of the circumocular patch (patch top is rounded, pointed distinct or pointed diffuse, patch bottom is broad, pointed toward muzzle, narrow rounded or extends toward zygomatic arch); width of the median facial strip, white rim around the circumocular patches (prominent, thin or absent), presence of dorsal frosting, yellow pigmentation on muzzle and ears, and base colour of ventral hair. Facial and pelage features of only mature animals were used for analysis; 106 loris specimens were used (Table 2). Initially, cluster analysis was carried out for all specimens, using 23 features (variables), by the complete linkage method by Euclidean Distance, in Minitab 16. Then the specimens were grouped by area of origin and again the complete linkage method by Euclidean Distance, given in Minitab 16, was used to create a dendrogram. Standardized Canonical Discriminant Function Coefficients for each of the variables (23 facial/pelage variables) was calculated by using General Discriminant Analysis (GDA) as given in STATISTICA 10. Variables with "0.000" values of Standardized Canonical Discriminant Function Coefficients were omitted from the subsequent analysis. Discriminant Function Analysis (DFA) was undertaken with STATISTICA 10 to assess the significance of this clustering pattern. A subsequent Principal Components Analysis was carried out for the groups with small sample size (n<13) using Minitab 16.

*Analysis – external body measurements*

Nine body measurements were used for each live animal, in order to analyze the morphometric variation among samples. Males and females were combined because limited samples were available from each sex. Most external measurements given by Kar Gupta (2013) of 12 females and 22 males from an Indian site differ little between sexes (with the exception of body weight), and initial inspection of our own metric data did not reveal consistent differences between the sexes. All these measurements have been widely used to analyze morphometric variation in *Loris* (Hill and Phillips 1932; Hill 1942).

Two separate analyses were done to test the two different models, as described above. For the first model, live specimens were grouped based on distribution and the identification characters given by Hill (1953) and Phillips (1980). For the second model, they were grouped based on similarities of facial and pelage features.

Initially, a one-way ANOVA was used to determine any significant differences between the groups for each measurement, using Minitab16. Principal Components Analysis (PCA) and subsequently Discriminant Function Analysis (DFA) were undertaken to assess patterns in the data, where evident, and whether this pattern was significant; and further, these groups were compared using box plots with STATISTICA 10.

*Analysis – skull measurements (cranial and mandibular)*

Eleven cranial and mandibular measurements were taken (see above). Only adult specimens (based on the degree of fusion of skull sutures, especially the basilar suture) were used in the analyses. All these measurements have been widely used to analyze cranial and mandibular variation in *Loris* (Hill and Phillips 1932; Hill 1942; Groves 1998).

Two separate analyses were again done to test the two different models. For the first model, skulls were grouped based on names given by specimen collectors (when available) or area of origin; for the second model, skulls were grouped based on similarities of facial/pelage features (where an associated skin was available), and skulls without skins were grouped based on area of origin.

Again, a one-way ANOVA was used to determine any significant differences between the groups for each skull measurement and subsequent Principal Components Analysis (PCA) were done using Minitab16. Discriminant Function Analysis (DFA) using STATISTICA 10 was undertaken to assess patterns in the data, where evident, and whether this pattern was significant; and further, these groups were compared using box plots using STATISTICA 10. The sizes of the groups in DFA must be greater than the number of variables on which the analysis is based, to avoid the almost certain risk of a spurious positive separation (Mitteroecker and Bookstein 2011). Accordingly, we reduced the skull measurements for the DFA to 7, and ran a series of analyses on the basis of those groups of size >7 (namely, groups 1, 2, 5, 6 and 7), entering the two smaller groups as ungrouped. To avoid having to visualise plots of more than two dimensions, we ran three different analyses, entering the five basic groups in different batches of three.

*Geographical distribution*

In all, 154 sites were surveyed in the wet and intermediate zones and part of the dry zone in Sri Lanka, using the occupancy monitoring techniques of Mackenzie *et al*. (2003). Another 38 sites were surveyed opportunistically for lorises using a broad reconnaissance survey technique, which had been employed for a previous island-wide study of slender lorises by Nekaris and Jayawardene (2004); in this method observers followed pre-existing trails and did both repeat and one-off transect surveys (White and Edwards 2000; Nekaris and Jayawardene 2004). GPS locations were recorded for all loris observations, and ArcGIS® and ArcMap™ version 10 was used to create the map.

### *Conservation status*

We followed the 2001 IUCN Red List Categories and Criteria version 3.1 (IUCN 2014) to evaluate the conservation status.

## Results – Phenotypic Study

One hundred and sixty-two specimens (live wild-caught lorises = 82; live lorises observed in the wild = 13; photographs of live lorises = 9; fresh dead specimens = 4; mounted skins with skulls = 20; skin only = 5; skulls only = 28; and one complete mounted skeleton) were examined (Table 1).

### *Test of the current two-species classification – external body measurements*

One-way ANOVA showed that the *Loris lydekkerianus* group (n = 34) was significantly larger than the *Loris tardigradus* group (n = 24) for nine body variables—UAL (F = 11.2, p = 0.001); FAL (F = 14.6, p<0.000); LL (F = 8.1, p = 0.006); KL (F = 19.3, p<0.000); MHL (F = 13.4, p = 0.001); HB (F = 7.5, p = 0.008); MBOP (F = 30.2, p<0.000)] and EL (F = 39.5, p<0.000). The PC1 vs. PC2 graph also showed a clear separation of these two groups (Fig. 3). The two specimens of Montane slender loris (*Loris tardigradus* / *lydekkerianus nycticeboides*) from Nuwara Eliya and one specimen of

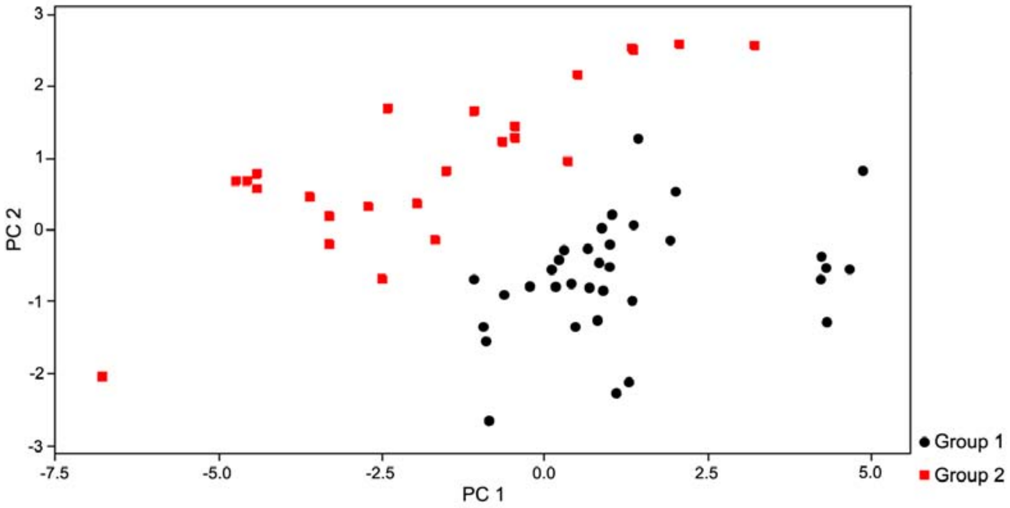

**Figure 3.** PC1 vs. PC2 factor scores graph for all (*L. tardigradus* = 34, *L. lydekkerianus* = 24) phenotypes captured (adult) during the study (male and female lumped) for nine measured variables (UAL, FAL, TL, LL, KL, MHL, HB, MBOP and EL); PC1 accounts for 62.6 % of the variance, PC2 for 15.1%, and PC3 (not shown) for 6.5%. PC 1 is largely a size factor mainly dependent on KL, LL and FAL, which are negatively weighted. PC 2 mainly dependent on EL, which is positively weighted: group 1 – *Loris lydekkerianus* group and 2 – *Loris tardigradus* group. Specimens were separated based on the area of origin (group 1 – Wet zone lorises and group 2 – dry and intermediate zone lorises). Separation between the two groups is nearly, but not fully, complete.

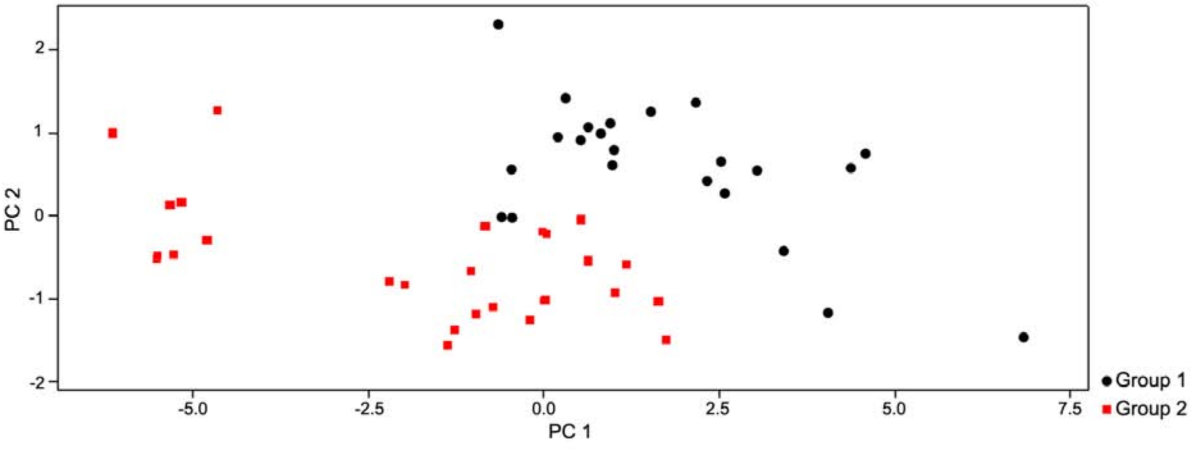

**Figure 4.** PC1 vs. PC2 factor scores graph (47 loris skulls) for 11 measured variables (GSL, LON, BB, ZB, BOB, MB, PL, CBL, CCL, ALMT and ML); PC1 accounts for 68.0% of the variance, PC2 for 7.6%, and PC3 (not shown) for 4.9%. Skulls were separated into two groups [group 1 - *Loris tardigradus* (n = 23) and group 2 - *Loris lydekkerianus* (n = 34)] based on the name given by the specimen collector (if available) or, if not, according to the area of origin and distribution given by Hill (1953) and Phillips (1980). Note that the separation of the two groups is incomplete.

Highland grey loris (*Loris lydekkerianus* group) from Knuckles were clustered between the two groups.

*Test of the current two-species classification – skull measurements*

The *Loris lydekkerianus* group was significantly larger than the Loris tardigradus group for 10 skull variables—MHL (F = 7.6, p = 0.008), LON (F = 8.5, p = 0.007), BB (F = 16.2, p<0.000), ZB (F = 30.4, p<0.000), BOB (F = 20.1, p<0.000), MB (F = 25.9, p <0.000), PL (F = 8.9, p =0.005), CBL (F = 9.2, p = 0.004), CCL (F = 13.3, p = 0.001), and ALMT (F = 8.5, p = 0.006). The PC1 vs. PC2 graph showed separation of these two groups, but again the two specimens of montane slender loris (*nycticeboides*) were clustered with the *Loris lydekkerianus* group, while one male specimen from Mirigama fell between the two groups (Fig. 4).

*Test of the current four-subspecies classification – external body measurements*

One-way ANOVA showed that *L. l. nordicus* was significantly larger than the other three described subspecies (*L. t. tardigradus*, *L. t. nycticeboides* and *L. l. grandis*) and unidentified specimens for nine body variables—UAL (F = 16.52, p<0.001); FAL (F = 18.14, p<0.001); TL (F = 5.35, p = 0.023); LL (F = 7.78, p = 0.007); KL (F = 16.33, p<0.001); MHL (F = 4.59, p = 0.037); HB (F = 4.48, p =0 .038); MBOP (F = 19.57, p<0.001), and EL (F = 33.9, p<0.001). The other groups did not show any significant differences (p>0.05) from each other. The PC1 vs. PC2 graph showed a clear separation of *L. t. tardigradus* and *L. l. nordicus* from other groups; however, a single female specimen of *L. l. grandis* from Knuckles was clustered with the *L. l. nordicus* group (Fig. 5).

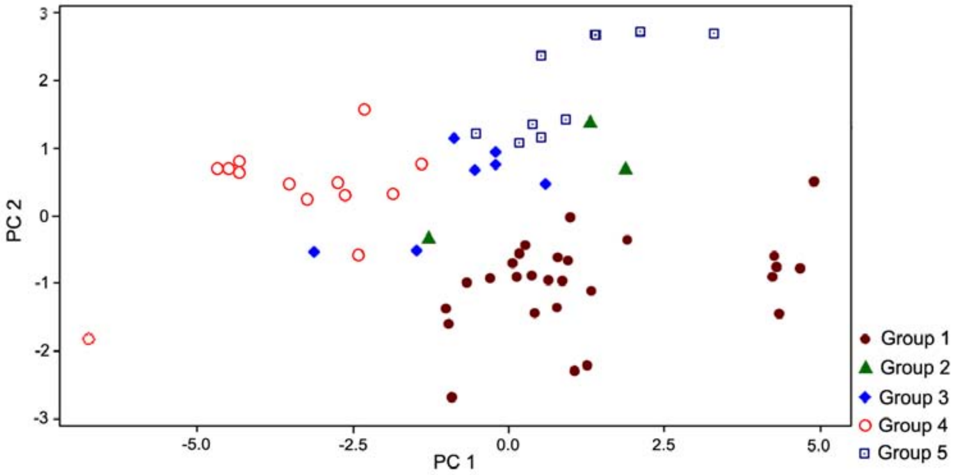

**Figure 5.** PC1 vs. PC2 factor scores graph for all (n = 58) phenotypes captured (adult) during the study (male and female lumped) for nine measured variables (UAL, FAL, TL, LL, KL, MHL, HB, MBOP and EL); PC1 accounts 61.0 % of the variance, PC2 for 16.7%, and PC3 (not shown) for 6.5%. Specimens were separated based on the area of origin and identification given by Hill (1953) and Phillips (1980). Groups: 1 – *L. t. tardigradus*, 2 – *L. t. nycticeboides*, 3 – *L. l. grandis*, 4 – *L. l. nordicus* and 5 –unidentified specimens. Only Group 1 is fully separated from the other groups.

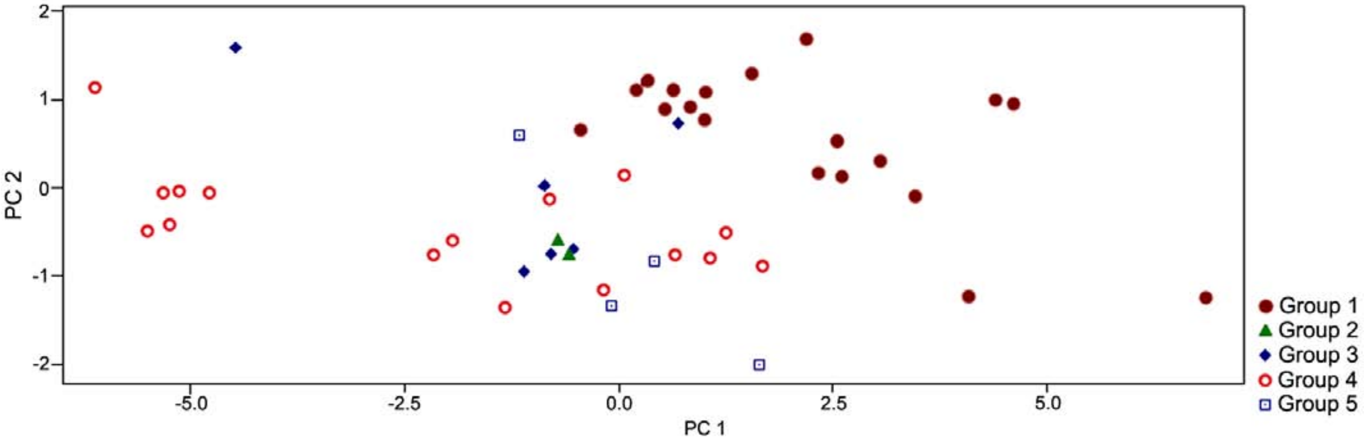

**Figure 6.** PC1 vs. PC2 factor scores graph (47 loris skulls) for 11 measured variables (GSL, LON, BB, ZB, BOB, MB, PL, CBL, CCL, ALMT and ML); PC1 accounts for 67.6% of the variance, PC2 for 7.0%, and PC3 (not shown) for 5.8%. Skulls were separated into groups based on the name given by the specimen collector (if available) or if not according to the area of origin and distribution given by Hill (1953) and Philips (1980). Groups: 1 – *L. t. tardigradus*, 2 – *L. t. nycticeboides*, 3 – *L. l. grandis*, 4 – *L. l. nordicus*, and 5 – unidentified specimens. The groups are mostly incompletely separated from each other.

### *Test of the current four-subspecies classification – skull measurements*

One-way ANOVA showed that *L. l. nordicus* was significantly larger than the three other lorises (*L. t. tardigradus*, *L. t. nycticeboides* and *L. l. grandis*) for 10 skull variables—MHL ($F = 23.35$, $p<0.001$), LON ($F = 18.7$, $p = 0.003$), BB ($F = 17.87$, $p<0.001$), ZB ($F = 50.91$, $p<0.001$), BOB ($F = 41.78$, $p<0.001$), MB ($F = 61.75$, $p<0.001$), PL ($F = 29.95$, $p<0.001$), CBL ($F = 11.53$, $p = 0.001$), CCL ($F=21.12$, $p<0.001$) and ALMT ($F = 14.55$, $p<0.001$). No significant differences ($p>0.05$) were observed between the other groups. The PC1 vs. PC2 graph did not show any clear separation (Fig. 6).

### *Proposed classification based on facial and pelage features*

We observed several differences in the facial and pelage features (Fig. 1) of live individuals encountered in the field. A cluster analysis using the complete linkage method divided the 106 loris specimens into seven clusters, which are sorted

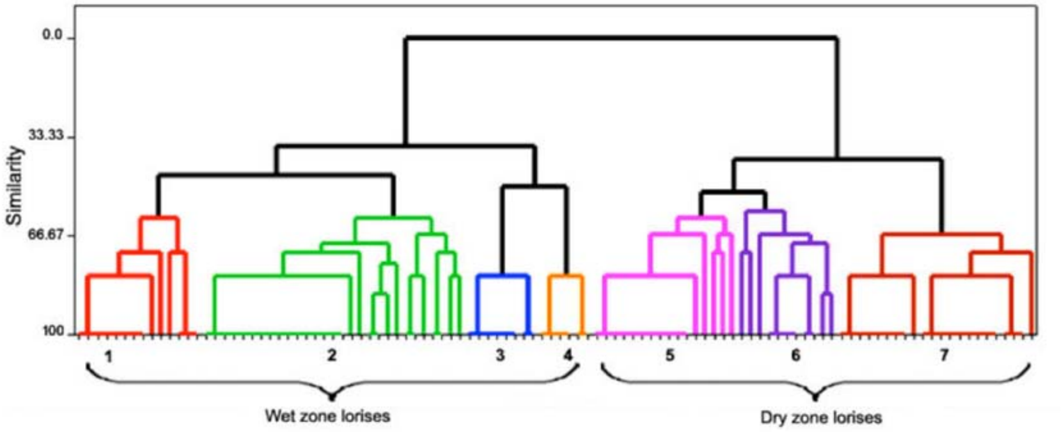

**Figure 7.** Dendrogram of complete linkage and Euclidean distance for the 23 features (facial and pelage) examined in 97 slender loris specimens, and photographs of nine live slender lorises were clearly seperated into two clusters: the wet zone cluster (*Loris tardigradus*) and dry zone cluster (*Loris lydekkerianus*). Subgroups can be designated as: 1 – Northwestern (Gampaha and Kurunegala); 2 – Southwestern (Colombo, Kalutara, Rathnapura, Kegalla, Galle, and Matara), 3 – Rakwana (Deniyaya-Rakwana mountain range), 4 – Montane (Nuwara Eliya and Badulla), 5 – Highland grey (Matale, Kandy and Kurunegala), 6 – Uva (Badulla, Ratnapura, Monaragala and Ampara) and 7 – Northern grey (Anuradhapura, Polonnaruwa, Puttlum, Mannar, Vauniya and Trincomale). Separation between the groups is complete, although groups 3 and 4 consist of a limited number of specimens (group 3 = 6, and group 4 = 7).

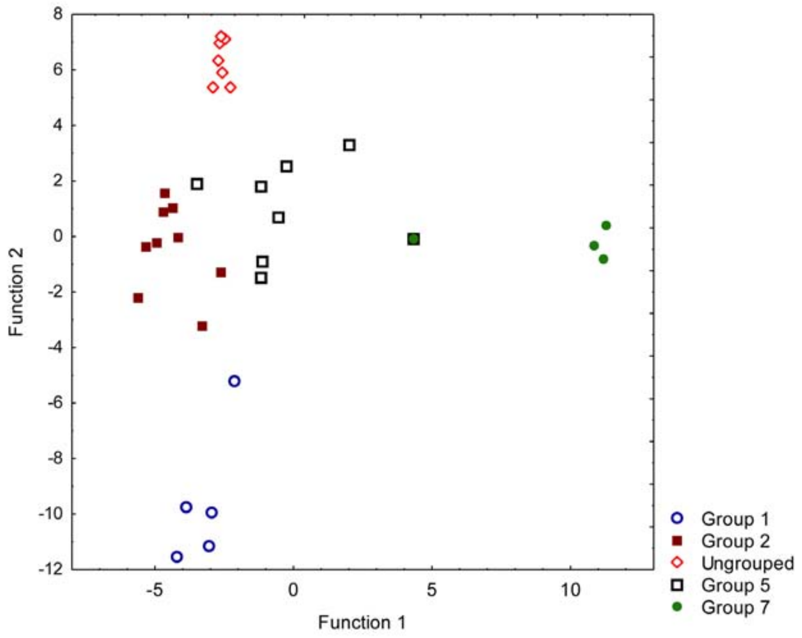

**Figure 8:** Discriminant Function Analysis, based on 13 facial and pelage features of 106 slender loris specimens (Function 1 vs Function 2 graph); Function 1 accounts 48.2% of the variance and Function 2 for 33.5% of the variance: Group 1 - Northwestern, Group 2 - Southwestern, Group 5 - Highland gray, Group 7 - Northern grey, and ungrouped [combined group 3 (Rakwana) + group 4 (Montane) + group 6 (Uva)]. Groups 1 and 2 are completely separated from each other and from groups 5 and 7, which however overlap slightly with each other.

largely, but not 100%, according to areas of distribution (Fig. 7), as follows:

Group 1: Northwestern (Gampaha, Kurunegala)

Group 2: Southwestern (Colombo, Kalutara, Ratnapura, Kegalla, Galle, Matara)

Group 3: Rakwana (Deniyaya-Rakwana range)

Group 4: Montane (upper montane region of Nuwara Eliya, Badulla)

Group 5: Highland grey (Matale, Kandy, Kurunegala)

Group 6: Uva (Badulla, Ratnapura, Monaragala, Ampara)

Group 7: Northern grey (Anuradhapura, Polonnaruwa, Puttlum, Mannar, Vauniya, Trincomale)

Frequencies of facial and pelage features in the seven groups are given in Table 2. Thus, the classification proposed is based on these facial pelage features and distribution. The members of group 1 (n = 14) clustered with 61% similarity, of group 2 (n = 29) with 61% similarity, group 3 (n = 8) at 80%, group 4 (n = 6) at 80%, group 5 (n = 16) at 61%, group 6 (n = 8) at 69% and group 7 (n = 22) at 66% similarity. All of the wet zone lorises (groups 1, 2, 3 and 4) (n = 57) were clustered at 36% similarity level, and the dry zone and intermediate zone lorises (groups 5, 6 and 7) (n = 49) at 44% similarity. One individual from Dambulla was clustered with group 6 rather than group 7 where it theoretically should belong (58%

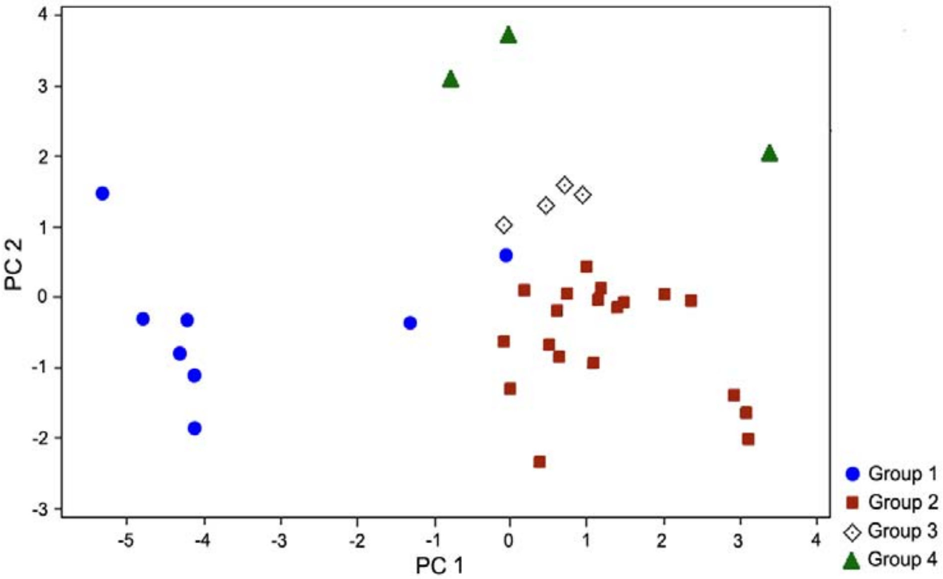

**Figure 9:** PC1 vs. PC2 factor scores graph for adult wet zone phenotypes (n=34) examined during the study (male and female lumped) for nine measured variables (UAL, FAL, TL, LL, KL, MHL, HB, MBOP and EL); PC1 accounts 56.2 % of the variance, PC2 for 18.6%, and PC3 (not shown) for 7.6%. Groups: 1 - Northwestern, 2 - Southwestern, 3 - Rakwana, and 4 - Montane. The four groups are completely separated from each other, although note that sample sizes of groups 3 and 4 are small.

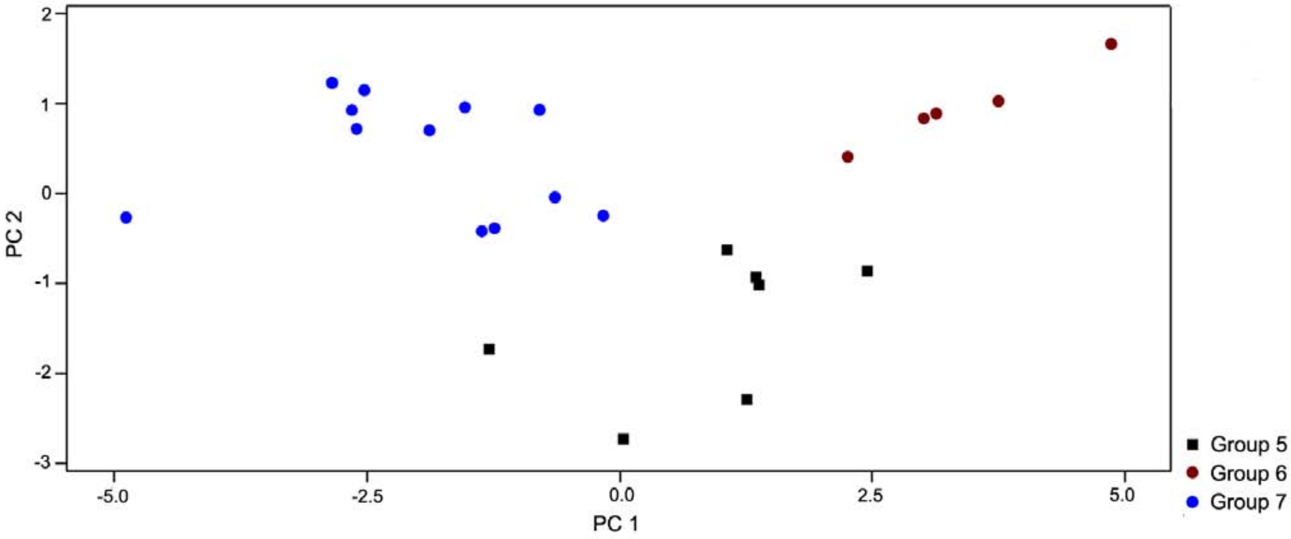

**Figure 10.** PC1 vs. PC2 factor scores graph for adult dry and intermediate zone phenotypes (n=24) examined during the study (male and female lumped) for nine measured variables (UAL, FAL, TL, LL, KL, MHL, HB, MBOP and EL); PC1 accounts 60.4 % of the variance, PC2 for 13.6%, and PC3 (not shown) for 9.0%. Groups: 5 - Highland grey, 6 - Uva, and 7 - Northern grey. The three groups are completely separated from each other.

**Table 2.** Frequencies of facial and pelage features in seven groups of Sri Lankan lorises: 1 - Northwestern group; 2 - Southwestern group; 3 - Rakwana group; 4 - Montane group, 5 -Highland grey group; 6 - Uva group; and 7- Northern grey group.

| Character | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 | Group 7 |
|---|---|---|---|---|---|---|---|
| **a. Circumocular patch**<br>**1. Overall shape** | | | | | | | |
| M = Marquise<br>T = Teardrop<br>O = Ovoid/rounded<br>P = Pear | M = 13 (93%) | M = 0 | M = 0 | M = 0 | M = 0 | M = 0 | M = 0 |
| | T = 0 | T = 0 | T = 0 | T = 6 (100%) | T = 0 | T = 0 | T = 22 (96%) |
| | O = 0 | O = 27 (93%) | O = 0 | O = 0 | O =2 (11%) | O = 8 (100%) | O = 0 |
| | P = 1 (7%) | P = 2 (7%) | P = 8 (100%) | P = 0 | P = 16 (89%) | P = 0 | P = 1 (4%) |
| **2. Shape on the top** | | | | | | | |
| R = Rounded<br>P = Pointed distinct<br>PD = Pointed diffused | R = 0 | R = 24 (83%) | R = 0 | R =0 | R = 3 (17%) | R = 6 (75%) | R = 0 |
| | P = 13 (93%) | P =3 (10%) | P = 0 | P = 6 (100%) | P = 15 (83%) | P = 2 (25%) | P = 19 (83%) |
| | PD = 1 (7%) | PD = 2 (7%) | PD = 8 (100%) | PD = 0 | PD = 0 | PD = 0 | PD = 4 (17%) |
| **3. Shape on the bottom** | | | | | | | |
| BP = Broad, pointed toward muzzle<br>NR = Narrow, rounded EZ = Extent toward zygomatic arch | BP = 14 (100%) | BP = 1 (3%) | BP = 2 (25%) | BP = 0 | BP = 1 (6%) | BP = 0 | BP = 0 |
| | NR = 0 | NR = 28 (97%) | NR = 6 (75%) | NR = 0 | NR = 17 (94%) | NR = 8 (100%) | NR = 10 (43%) |
| | EZ = 0 | EZ = 0 | EZ = 0 | EZ = 6 (100%) | EZ = 0 | EZ = 0 | EZ = 13 (57%) |
| **4. Median facial strip width** | | | | | | | |
| N = Narrow<br>M = Moderate<br>B = Broad | N = 4 (26%) | N = 28 (97%) | N = 8 (100%) | N = 0 | N = 0 | N = 0 | N = 0 |
| | M = 10 (74%) | M = 1 (3%) | M = 0 | M = 6 (100%) | M = 18 (100%) | M = 8 (100%) | M = 1 (4%) |
| | B = 0 | B = 0 | B = 0 | B = 0 | B = 0 | B = 0 | B = 22 (96%) |
| **5. White rim around circumocular patch** | | | | | | | |
| P = Prominent white rim<br>T = Thin white rim<br>A = Absent | P = 1 (7%) | P = 5 (17%) | P = 0 | P = 6 (100%) | P = 17 (94%) | P = 8 (100%) | P = 23 (100%) |
| | T = 13 (93%) | T = 24 (83%) | T = 0 | T = 0 | T = 1 (6%) | T = 0 | T = 0 |
| | A = 0 | A = 0 | A = 8 (100%) | A = 0 | A = 0 | A = 0 | A = 0 |
| **b. Frosting on dorsum** | | | | | | | |
| H = Highly frosted<br>L = Lightly frosted<br>N = No frosting | H = 0 | H = 0 | H = 8 (100%) | H = 0 | H = 15 (83%) | H = 8 (100%) | H =23 (100%) |
| | L = 0 | L = 5 (17%) | L = 0 | L = 4 (67%) | L = 2 (11%) | L = 0 | L = 0 |
| | N = 14 (100%) | N = 24 (83%) | N = 0 | N = 2 (33%) | N = 1 (6%) | N = 0 | N = 0 |
| **c. Yellow pigmentation muzzle and ears** | | | | | | | |
| H = Highly pigmented<br>L = Very low | H = 13 (93%) | H = 29 (100%) | H = 0 | H = 0 | H = 17 (94%) | H = 6 (75%) | H = 22 (96%) |
| | L = 1 (7%) | L = 0 | L = 8 (100%) | L = 6 (100%) | L = 1 (6%) | L = 2 (25%) | L = 1 (4%) |
| **d. Ventral hair base color** | | | | | | | |
| W = Whitish or light grey<br>G = Dark grey or black | W = 0 | W = 0 | W = 0 | W = 0 | W = 2 (11%) | W = 0 | W = 23 (100%) |
| | G = 14 (100%) | G = 29 (100%) | G = 8 (100%) | G = 6 (100%) | G = 16 (89%) | G = 8 (100%) | G = 0 |

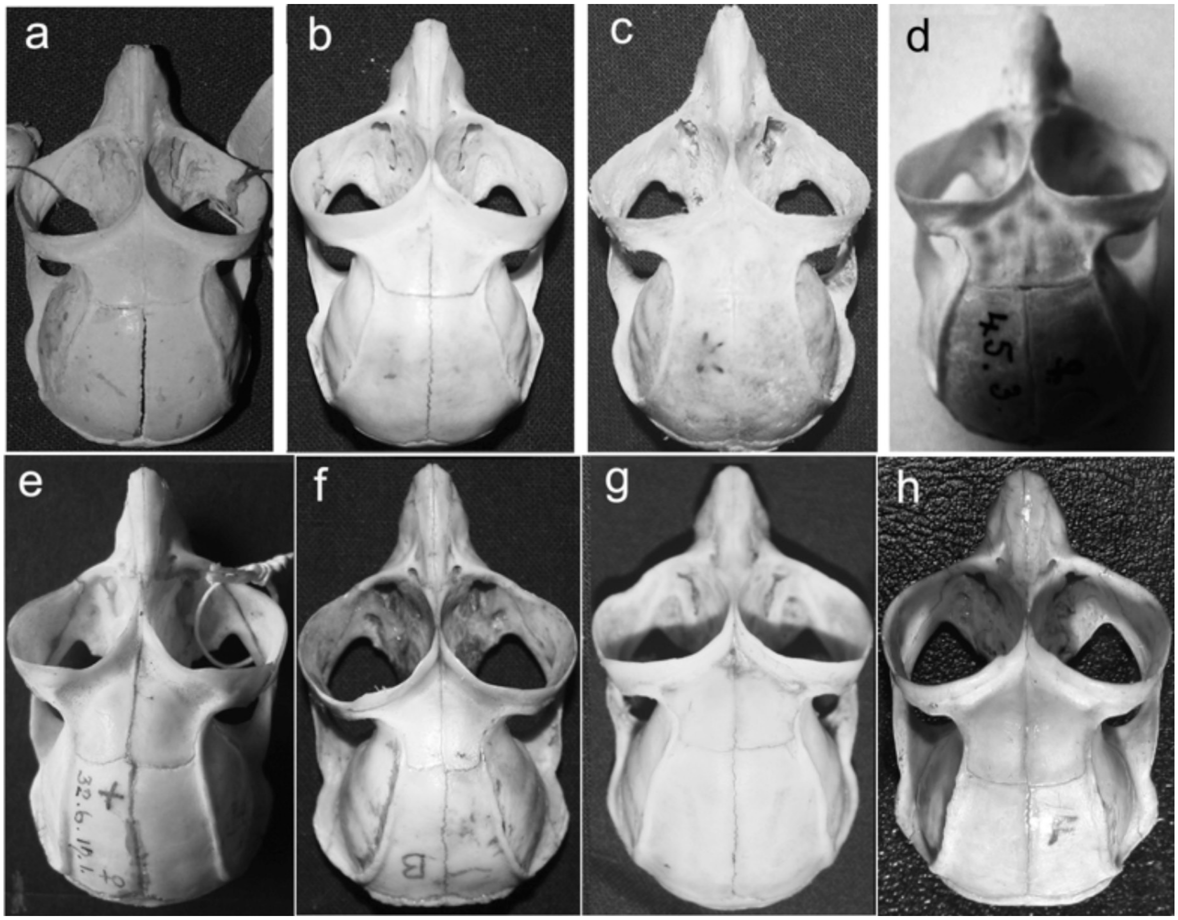

**Figure 11.** Dorsal views of skulls from the different loris groups: **a.** Northwestern [group 1 - ♂ Henarathgoda-Gampaha (30 m asl)], **b.** Southwestern [group 2 - ♂ Kottawa-Galle (100 m asl)], **c.** Rakwana [group 3 - ♂ Morningside-Singharaja (1100 m asl)], **d.** Montane [group 4 - ♀ below Horton Plains, holotype of *L. t. nycticeboides* (1520–1824 m asl)]; **e.** Highland grey [group 5 - ♀ [Gammaduwa-Knuckles holotype of *L. t. grandis* (850 m asl)], **f.** Highland grey [group 5 - ♀ Redbana-Knuckles (650 m asl)]; **g.** Uva [group 6 - ♂ Nilgala-Monaragala (200 m asl)], and **h**. Northern grey [group 7 - ♀ Talawa-Anuradhapura (100 m asl)].

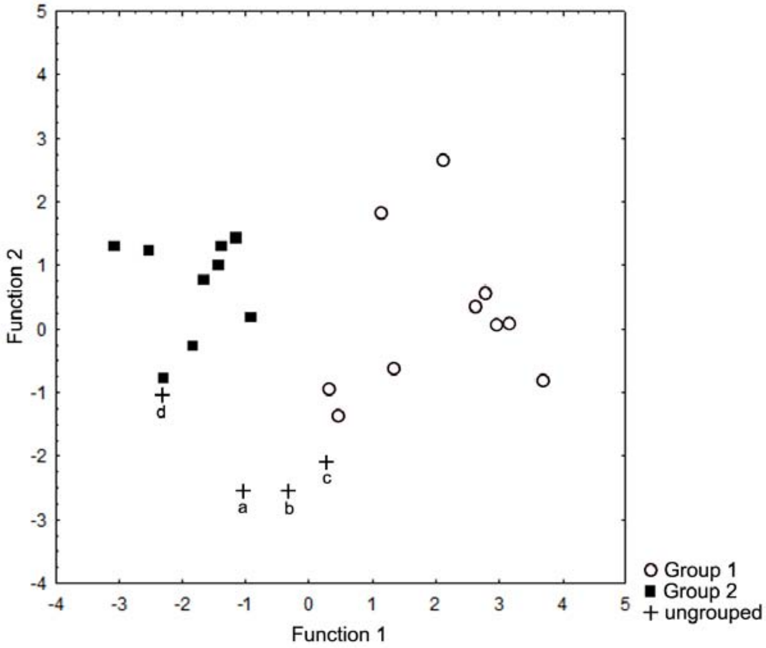

**Figure 12.** Discriminant Analysis, based on seven skull variables (GLS, LON, BB, MB, CBL, ALMT and ML): group 1 - Northwestern, group 2 - Southwestern and ungrouped [group 3 (Rakwana) + group 4 (Montane)]: a = Montane ♀, b = Montane ♂, c = Rakwana ♀ and d = Rakwana ♂. Function 1 accounts for 77.8% of the variance and mainly contrasts biorbital breadth (BB), and condylobasal length (CBL). Function 2 accounts for 22.2% of the variance and contrasts biorbital breadth (BB), mastoid breadth (MB) and mandible length (ML). Groups 1 and 2 are completely separated from each other.

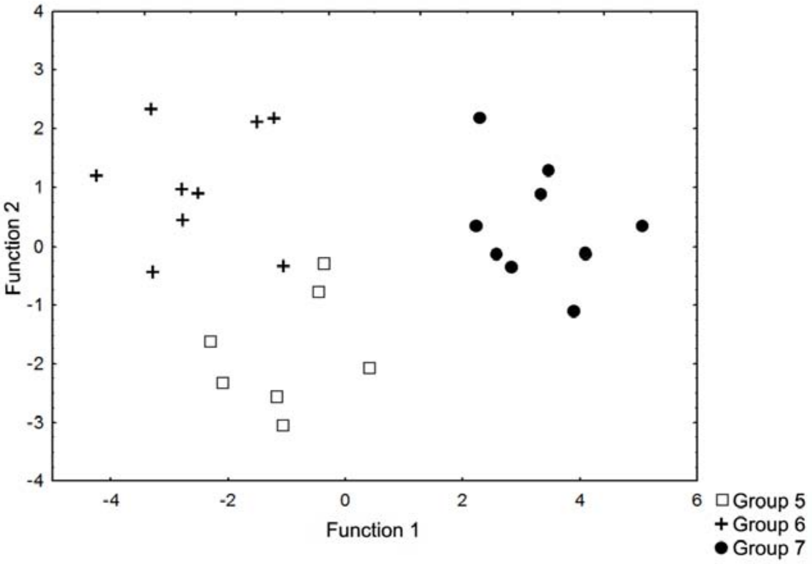

**Figure 13.** Discriminant Analysis, based on seven skull variables (BB, ZB, BOB, MB, CCL, ALMT and ML): Groups: 5 - Highland grey, 6 - Uva and 7 - Northern grey. Function 1 accounts for 82.8% of the variance and mainly contrasts biorbital breadth (BB), zygomatic breath (ZB), alveolar length of maxillary toothrow (ALMT, breadth of braincase (BOB), condylo-canine length (CCL) and greatest length of skull (GSL); Function 2 accounts for 17.2% of the variance and contrasts mastoid breadth (MB), biorbital breadth (BB) and mandible length (ML). The three groups are completely separated from each other.

similarity), and two individuals from Redbana-Knuckles were clustered with group 6 rather than group 5 at 58% and 66% similarity respectively.

General Discriminant Analysis (GDA) showed that only 17 of 23 variables were supported to create a function, and these variables were used for subsequent Discriminant Analysis. Thirteen variables were selected for the Discriminant Analysis. Only four groups [northwestern (group 1), southwestern (group 2), highland grey (group 5) and northern grey (group 7)] had large enough sample sizes to form the basis for the analyses; thus the other three groups [group 3 (Rakwana), group 4 (montane) and group 6 (Uva)] were entered as ungrouped. The DF1 largely reflects the median facial strip width and overall shape of the circumocular patch; DF2 reflects the median facial strip width, dorsal frosting, white rim around circumocular patch, and overall shape of the circumocular patch. Figure 8 shows DFA plots for 13 facial and pelage features. Separations were complete, except that one specimen of group 7 from Dambulla (Matale) was classed with group 5. The other specimens, entered as ungrouped, classed separately in the basic four groups. Northwestern (group 1), southwestern (group 2), highland grey (group 5) and northern grey (group 7) were all significantly separated from each other. Thus DFA supported the cluster analysis divisions (P<0.001). PCA results for the ungrouped specimens showed a clear separation only of group 3 (Rakwana), group 4 (montane) and group 6 (Uva) from each other.

## Test of the Proposed Classification Using External Body Measurements

We tested the possibility of the proposed classification based on facial and pelage features, using external body measurements. External body morphology of slender lorises show minor sexual dimorphism (Kar Gupta 2013). but we did not separate sexes in our analyses due to the limited number of samples.

*External body measurements of wet zone lorises* (*Loris tardigradus*)

The lorises of the Southwestern group (group 2) were significantly larger (p<0.05) than those of the Northwestern group (group 1) for eight measured variables—UAL (F = 23.1, p<0.001); FAL (F = 60.1, p<0.001); TL (F = 50.5, p<0.001); LL (F = 33.3, p<0.001); KL (F = 38.8, p<0.001); MHL (F = 39.1, p<0.001); HB (F = 21.4, p<0.001); MBOP (F = 11.8, p = 0.002). The PCA results for wet zone lorises showed (Fig. 9) that the three groups [Northwestern (group 1), Southwestern (group 2) and Montane (group 4)] were clearly separate from each other, while the Rakwana (group 3) was clustered between the three. We then performed a Discriminant Analysis on the basis of seven body variables. Only the Northwestern (group 1) and Southwestern (group 2) groups had a large enough sample size to form a basis for the analysis; thus the other two groups [Rakwana (group 3) and Montane (group 4)] were entered as ungrouped. The three groups (Northwestern, Southwestern and ungrouped) were significantly (p<0.001) distinct; DF1 accounted for 70.6% of the total variance, and DF2 accounted for 29.4%.

*External body measurements of dry and intermediate zone lorises* (*Loris lydekkerianus*)

The animals of the Northern grey group (group 7) were significantly larger (p<0.05) than any other group found in the dry and intermediate zones for seven measured variables—UAL (F = 37.6, p = 0.003); FAL (F = 40.5, p<0.001); TL (F = 22.5, p<0.001); LL (F = 12.0, p = 0.002); KL (F = 11.4, p<0.001); HB (F = 12.3, p = 0.002); MBOP (F = 13.3, p = 0.002). The PCA results for the dry and intermediate zone lorises showed that the three groups [Highland grey (group

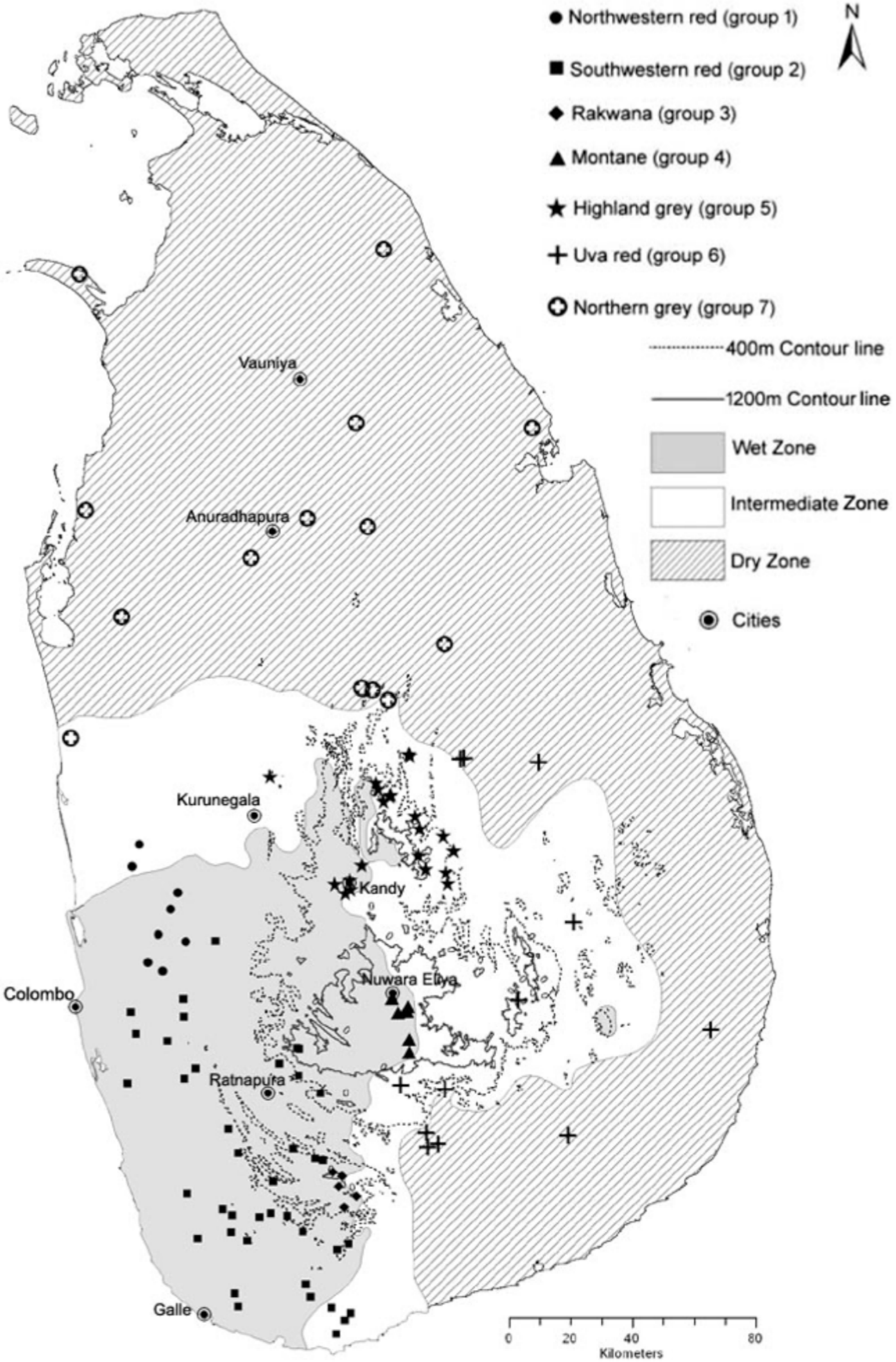

**Figure 14.** Distributions of the different slender loris groups in Sri Lanka.

**Table 3**: Summary of the species and subspecies classification.

| Group | Species classification | Subspecies classification | Common name | Climatic zone and distribution | Coat color and identification | No. of individuals examined |
|---|---|---|---|---|---|---|
| Group 1 | *Loris tardigradus* | *L. tardigradus parvus* | Northwestern red slender loris | Northwestern wet zone and intermediate zone. Gampaha and Kurunegala districts | Dark golden brown. Marquise-shaped, broad circumocular patch | 24 |
| Group 2 | *Loris tardigradus* | *L. tardigradus tardigradus* | Southwestern red slender loris | Southwestern wet zone. Colombo, Kalutara, Ratnapura, Kegalla, Galle and Matara districts | Varies from yellow brown to dark brown or grayish. Circumocular patches are ovoid in shape and much narrowed at the bottom | 41 |
| Group 3 | *Loris tardigradus* | *L. tardigradus* ? | Rakwana slender loris | Southwestern wet zone. High altitude (>800 m asl) of Deniyaya-Rakwana mountain range. | Dark grey brown or brownish black with heavily frosted. Circumocular patches are pear shaped and white rim around circumocular patch is absent. | 10 |
| Group 4 | *Loris tardigradus* | *L. tardigradus nycticeboides* | Montane slender loris | Wet zone, found 1700-1800 m asl of Nuwara Eliya | Dark brown or brownish black. Long, thick, woolly coat. Circumocular patches are pear shaped and white rim around circumocular is prominent. | 7 |
| Group 5 | *Loris lydekkerianus* | *L. lydekkerianus grandis* | Highland grey slender loris | Wet zone and intermediate zone. Kandy and Matale districts | Grey or grey-brown with heavily frosted. Circumocular patches are broad, pear shaped and white rim around circumocular is prominent. | 22 |
| Group 6 | *Loris lydekkerianus* | *L. lydekkerianus uva* | Uva red slender loris | Southeastern dry and Intermediate zone. Badulla, Monaragala, Ratnapura and Ampara districts | Yellow brown or reddish brown with heavily frosted. Circumocular patch is relatively narrow and rounded. White rim around circumocular is prominent. | 21 |
| Group 7 | *Loris lydekkerianus* | *L. lydekkerianus nordicus* | Northern grey slender loris | Northern dry zone. Anuradhapura, Polonnaruwa, Kurunegala, Puttalam, Vouniya, Trincomale and Matale districts | Grey or grey-brown with heavily frosted coat. Broad median facial stripe, and the circumocular patches are elongated with a tear-drop shape. | 38 |

5), Uva (group 6) and Northern grey (group 7)] were clearly separated from each other (Fig. 10).

### Test of the Proposed Classification Using Skull Morphology

The dorsal views of skulls from the seven different loris groups are shown in Figure 11. Slender loris skulls are slightly sexual dimorphic (Groves 1998), but the data had to be lumped due to the limited number of specimens.

*Skull measurements of wet zone lorises* (*Loris tardigradus*)

One-way ANOVA shows the Northwestern group (group 1) was significantly smaller than the Southwestern group (group 2) ($p<0.05$) for seven skull variables—GLS ($F = 8.1$, $p = 0.011$); BB ($F = 15.6$, $p<0.001$); ZB ($F = 6.9$, $p = 0.017$); PL ($F = 12.4$, $p = 0.002$); CBL ($F = 13.2$, $p = 0.002$); CCL ($F = 12.3$, $p = 0.003$); ML ($F = 11.3$, $p = 0.004$). In order to investigate these differences further, and find whether the groups [northwestern (group 1) and southwestern (group 2)] separate absolutely, we ran Discriminant Analyses while entering the two available specimens of group 3 (Rakwana) and the two available of group 4 (montane) as ungrouped. The three groups: northwestern (group 1), southwestern (group 2) and ungrouped were significantly ($p<0.001$) distinct from each other (Fig. 12). DF1 largely reflects condylo-canine length and biorbital breadth; DF2 reflects biorbital breadth, mastoid breadth and mandible length. The two montane specimens (group 4) fall close to each other, well away from any of the wet zone specimens on which the dispersion is based; we take this as strong evidence that this group, for which the name *nycticeboides* is available, constitutes a distinct taxon. On the other hand, the two specimens from Rakwana (group 3) fall far from each other; one is on the edge of group 2 (southwestern) and the other one is on the edge of group 1 (northwestern).

*Skull measurements of dry and intermediate zone lorises* (*Loris lydekkerianus*)

One-way ANOVA shows the northern grey group (group 7) was significantly larger ($p<0.01$) than Uva (group 6) for 11 skull variables—GLS ($F = 15.5$, $p = 0.001$); LON ($F = 16.6$, p = 0.001); BB (F = 17.0, p = 0.001); ZB (F = 66.5, p<0.001); BOB (F = 67.6, p<0.001); MB (F = 44.6, p<0.001); PL (F = 22.1, p<0.001); CBL (F = 13.2, p = 0.002); CCL (F = 29.0, p<0.001); ALMT (F = 14.3, p = 0.002); ML (F = 7.6, p = 0.014)], and highland grey (group 5) for six variables [namely, GLS (F = 5.0, p = 0.042); LON (F = 5.2, p = 0.039); ZB (F = 10.7, p = 0.006); BOB (F = 12.9, p = 0.004); MB (F = 20.8, p<0.001); PL (F = 7.0, p<0.019)]. Furthermore, the highland grey (group 5) was larger than Uva (group 6) for five skull variables—BB (F = 6.1, p = 0.027); ZB (F = 4.6, p = 0.002); BOB (F = 8.5, p = 0.011); CBL (F = 5.7, p = 0.032); CCL (F = 13.4, p = 0.003); ALMT (F = 14.3, p = 0.002). The PCA result for dry and intermediate zone lorises showed that the three groups [highland grey (group 5), Uva (group 6) and northern grey (group 7)] were clearly separate from each other. Discriminant Analysis on the basis of seven body variables showed the three groups [highland grey (group 5), Uva (group 6) and northern grey (group 7)] were significantly (p<0.001) distinct from each other (Fig. 13). DF1 largely reflects condylo-canine length and biorbital breadth; DF2 reflects biorbital breadth, mastoid breadth and mandible length.

## Discussion

Initial analysis of the external body morphology confirms the existence of two major groups in Sri Lanka, namely, wet zone lorises and dry/intermediate zone lorises. This supports the current two species classification of *Loris tardigradus* (wet zone) and *Loris lydekkerianus* (dry/intermediate zone) of Groves (1998) and Brandon-Jones *et al*. (2003). The position of the taxon *nycticeboides* is equivocal—a subspecies of *L. lydekkerianus* in Groves (1998) but of *L. tardigradus* in Nekaris and Jayewardene (2004)—and it is interesting that in the present study three specimens of the montane slender loris (group 4), potential representatives of *nycticeboides*, were clustered between the two groups. Separate analysis within these two groups (wet zone and dry/intermediate zone) confirmed the existence of several taxa (which we here rank as subspecies) within both of them: in the wet zone groups, northwestern (group 1), southwestern (group 2) and montane (group 4), and in the dry/intermediate zone groups, the highland grey (group 5), the Uva (group 6), and the northern grey (group 7).

Our analysis of the skull morphology also confirms the existence of these two major groups, again tending to support the two species classification; but again the two available skulls of the montane slender loris (*nycticeboides*) were clustered between the two groups. Separate analysis within these two groups also confirmed the existence of several potential taxa (presumed subspecies) within the two major groups. Overall, skull morphology shows that the northwestern (group 1), southwestern (group 2), montane (group 4), highland grey (group 5), Uva (group 6) and northern grey (group 7) lorises are quite distinct from each other, although groups 7 and 5 may interbreed in the vicinity of Kurunegala and Dambulla; while group 3 (Rakwana) is possibly not a homogeneous group craniometrically, in that one specimen falls within group 2, the other within group 6.

Both the cluster analysis based on facial/pelage features and the Discriminant analysis of skull measurements concur in showing that Sri Lankan lorises can be categorized into six groups: 1-northwestern; 2-southwestern; 4-montane; 5-highland grey; 6-Uva; and 7-northern grey. Further, our results of the facial and the pelage analysis of Sri Lankan slender lorises shows some consistency with the previous studies of slow lorises by Nekaris and Jaffe (2007), Nekaris and Munds (2010), and Munds *et al.* (2013).

Analysis of mitochondrial DNA has started, and will be reported in a future publication when further data have been collected. Generally, the members of the northern grey group (group 7) are large and distinctive in both body and skull proportions and facial features. This group is distributed in the northern dry zone up to the Jaffna peninsula; its southwestern boundary is the Deduru Oya, whereas the southeastern boundary is not clear. All specimens of group 7, both museum specimens and living animals, can be readily differentiated from the other 6 groups.

Members of the northwestern group (group 1) are smaller, and have unique facial features and distinctive body and skull proportions when compared to other groups. Based on our field observations, the distribution of this group is concentrated around Gampaha and Kurunegala, with its southern boundary at the Kelani Ganga River; although two specimens (skulls with skins) labeled simply as Colombo (BMNH.1937-7-2.7 and CONHM 7H) are identical with the northwestern group (group 1), our field observations are unable to detect any northwestern (group 1) loris from the Colombo district. The northern and eastern boundaries of the northwestern group are still not clear. The pelage colour of the northwestern (group 1) shows some similarity to that of the southwestern (group 2), but they differ in size, especially FAL and TL, and in the shape of the circumocular patch (marquise shaped, broader at the bottom, and extended toward the muzzle in the northwestern group); and all specimens, both museum specimens and living animals, can be readily differentiated.

The southwestern group (group 2) lorises are medium-sized, with distinctive body proportions when compared to the northwestern (group 1), montane (group 4), highland grey (group 5), Uva (group 6) and northern grey (group 7) groups. Considering the skull variables, the group is well discriminated from most other groups; only the separation from the Rakwana group is not significant, although the discriminant analysis of external body morphology does distinguish them, and similarly in facial/pelage features the southwestern (group 2) and Rakwana (group 3) lorises are significantly (p<0.001) distinct from each other. The coat is hardly frosted in the southwestern (group 2), but dorsally strongly frosted in the Rakwana group (group 3).

In the montane group (group 4), facial/pelage features are noticeably different from all other loris groups, and the external body proportions are strongly different from those of the other wet zone lorises, while their very long, dense fur is unique to this group and easily distinguishes it from any other loris taxon in Sri Lanka. Furthermore, the two available skulls [the holotype of *L. l. nycticeboides* Hill, 1942, and the specimen from Conical Hill, Nuwara Eliya] are noticeably different from all wet zone groups. The distribution of this group is apparently confined to the upper montane region (>1600 m asl) of the Central Highlands. Initial mitochondrial DNA study (based on cytochrome oxidase I) results shows the montane (group 4) is genetically close to the southwestern (group 2) (Gamage 2015).

The Rakwana group (group 3) is a unique taxon restricted to high altitudes (over 700 m asl) in the Rakwana-Deniyaya mountain range. The facial/pelage features are significantly ($p<0.001$) different from all other loris groups, the notable unique characters being the broad, pear-shaped, dark circumocular patches, which are extended up to the crown, and no white rim is visible around the eyes. The single male skull clearly separates from the skulls of all other groups; yet the skull of a subadult female from Gongala was clustered with the southwestern (group 2). The Rakwana group is parapatric to several other groups. Along its western, southern and northern boundary, it meets the southwestern (group 2), and on its eastern boundary it meets the Uva (group 6) (Fig. 14). This group needs further study with more material.

In its external morphology and facial features the highland grey (group 5) is clearly different from northern grey (group 7), Uva (group 6), northwestern (group 1) and the southwestern (group2), although in its external body morphology the separations from the Rakwana (group 3) and montane (group 4) groups are not quite so clear. The prominent white rim around the circumocular patch is present in both the highland grey (group 5) and montane (group 4) groups, but not in the Rakwana (group 3). It is markedly different in body and skull proportions, especially from the Uva (group 6), with which it shares a high degree of frosting; the circumocular patch is always pear-shaped compared to being rounded in the Uva (group 6). The highland grey (group 5) is restricted to high altitudes (>400 m asl) in the Knuckles Range and the Kandy region (especially the wet part of the central highlands), while its sister group, the Uva (group 6), is widely distributed in the intermediate and dry zone areas at lower elevations (<500 m asl) in the Uva basin (northern and eastern flank of the Central Highlands up to the eastern dry zone) (Fig. 14).

Our examination of type specimens shows that the type of *nycticeboides* belongs to the montane group (group 4), the type of *nordicus* belongs to the northern grey group (group 7), and the highland grey group (group 5) includes the type of *grandis*. The type of *zeylanicus* probably belongs to southwestern group (group 2).

We maintain that there is good evidence for the existence of at least two different species, of which one must at present be regarded as conspecific with the Indian lorises, while the existence of at least three, probably four, further species is probable, but more evidence is needed before they can be fully diagnosed and defined.

## Taxonomic Conclusions

Here, we distinguish provisionally two species of slender loris in Sri Lanka with six subspecies (see Table 3). As noted in the introduction, the names *tardigradus*, *gracilis*, *ceylonicus*, *lori* and *zeylanicus* are based on small red lorises, and are likely to represent one of our groups. Although Linnaeus used depictions of specimens in Albertus Seba's (1734) collection for his description of what he called *Lemur tardigradus*, it is hardly possible to tell which group of the red loris [northwestern (group 1), southwestern (group 2) or Uva (group 6)] it actually belongs to; and the type locality was described simply as Ceylon. The type specimen nominated by Gentry *et al*. (1998) does not resolve this question: as illustrated in <http://linnaeus.nrm.se/zool/mamm/images/M532011.jpg>, it is a faded specimen preserved in alcohol and little trace of the original colour or pattern remains.

Lesson's (1840) *Arachnocebus lori* also has Seba as the primary reference, so is an objective synonym of Linnaeus's *tardigradus*. Lesson's other name, *Bradylemur tardigradus*, is a secondary homonym of *tardigradus* Linnaeus, and is in any case a strange mixture of slow and slender lorises, only his Variety *C* being a Sri Lankan slender loris (one of the black ones), but it is hard to tell which to group it might pertain.

Remaining are the two species described by Fischer (1804). His *Loris gracilis* is evidently just a renaming of Linnaeus's *tardigradus*, but his *Loris ceylonicus* is meant to be something different. He described it as "yellowish brown", which could correspond, like Linnaeus's *tardigradus*, to either the northwestern group (group 1), or the southwestern group (group 2) or the Uva group (group 6), but it seems impossible to say what group is actually involved, and as this name has not been used for more than two hundred years and no type specimen is known to be available, here we propose arbitrarily that the name *Loris ceylonicus* is a synonym of *tardigradus*. Hill and Phillips (1932) wrote "Hitherto, however, all the lorises from Ceylon that appear to have been at all thoroughly examined have come from within a radius of 30 or 40 miles of Colombo"(Hill and Phillips 1932, p.109). Two groups described here—the northwestern (group 1) and southwestern (group 2) groups—are found in the western region, within a radius of 30 or 40 miles of Colombo. Of these, the southwestern group (group 2) is widely distributed throughout the wet zone proper, and may thus be considered more likely to represent *tardigradus* Linnaeus, 1758.

Our taxonomic arrangement of the slender lorises of Sri Lanka is as follows.

***Loris tardigradus tardigradus*** (Linnaeus, 1758)
Southwestern group (group 2)

**Type:** Gentry *et al*. (1998) designated a Swedish Museum of Natural History, Stockholm, specimen (NRM 532011) as lectotype (see <http://linnaeus.nrm.se/zool/mamm/images/M532011.jpg>).

**Type locality:** Ceylon.

**Diagnosis:** *Loris tardigradus* has distinctive facial features: the circumocular patches are ovoid in shape and much narrowed at the bottom and in the middle; the patches are brown, dark brown or chestnut brown. The median facial strip is narrower than in any other Sri Lankan loris group; with strong yellow pigmentation on the muzzle, hands, feet, ears and eyelids in both sexes. Preocular hair varies from brown to dusky white to silvery grey. Coat colour on the body varies from yellowish brown to dark brown or grey brown. The fur is between wavy and curly; and longer than in *Loris tardigradus parvus* n. ssp. (see below). The pelage of the ventral surface is generally yellowish, creamy or dusky whitish. Throat hair is generally superficially yellow/cream, with bases yellowish, light grey, grey or black. A dark dorsal stripe is visible. Skull size is similar to the montane (4), highland grey (5) and Uva (6) groups, and much larger than in the northwestern (1) group. Ridges on the skull are moderately developed, including the temporal ridges and the curved ridge on the occiput. The dorsal surface of the skull is not smooth, with a moderately developed wing-shaped mastoid; skull length ranges from 48.7 mm to 51.1 mm. The body is much larger and more elongated than in the northwestern (1) and Uva (6) groups.

**Description:** A few specimens from Kalutara have broadly pear-shaped circumocular patches. Animals found in Galle and Matara have a much more brightly coloured belly and the hair bases are dark grey. Those found in Ratnapura, Hiniduma, Akuressa and Deniyaya have a dusky white belly and the hair base colour is black.

**Distribution:** The distribution is shown in Figure 14. This species is found throughout the wet part of the southwestern region, from Colombo, Kalutara, Ratnapura, Kegalla, Galle, Matara and possibly the wetter part of Hambantota.

**Common name:** Southwestern red slender loris

The following specimens have been examined:

**Skin plus skull:** NHMC 7I [adult ♂ Colombo]; FMNH 95027 [adult ♀ Maharagama], SLCP 2015.09 [adult ♀ Madakada-Kaluthara], SLCP 2015.15 [adult ♂ Kottawa-Galle], SLCP 2012.02 [adult ♀ Kudawa-Sinharaja].

**Skull only:** SLCP 2012.03 [adult sex? Oliyagan-Matara], SLCP 2012.11 [adult sex? Maharagama], SLCP 2012.07 [adult ♂ Kottawa-Galle], SLCP 2012.01 [adult sex? Massmulla]; RCSL. A112.53 [adult ♂ Polgahawela], UOCSL 99.7.31 [adult sex? Kaduwela-Colombo].

**Living animals:** Madakada-Kalutara [adult ♀ = 1; juveniles = 2], Beraliya-Kalutara [adult ♂ = 1], Yagirala-Kalutara [juvenile ♀ = 1], Kottawa-Galle [adult ♂ = 3, juveniles = 1], Hiyara-Galle [adult ♂ = 1], Massmulla-Matara [adult ♂ = 1, juveniles = 2], Rammale Kanda-Matara [adult ♂ = 1], Diyadawa-Matara [adult ♂ = 2], Velihena-Matara [adult ♀ = 2], Kekanadura-Matara [adult ♀ = 1], Oliyagan-Matara [adult ♂ = 2, ♀ = 2, juvenile = 1], Kondagulankanda-Matara [adult ♀ = 1], Kalubovitiyana-Matara [juvenile = 1], Kanneliya-Galle [sub-adult ♀ = 1], Kudawa-Sinharaja [adult ♂ = 1, ♀ = 1], Madampa-Rathnapura [adult ♂ = 1, ♀ = 1], Delwala-Rathnapura [adult ♀ = 1], Gilimalee-Rathnapura [adult ♂ = 1], Peak Wilderness-Rathnapura [adult ♀ = 1].

**Conservation status:** Our study confirmed that this subspecies is found only in primary and secondary forest in the southwest wet zone. All of 48 sites where it is known to occur are fragmented. The Extent of Occurrence (EOO) is 4,800 km$^2$ and the Area of Occupancy (AOO) is 751 km$^2$. Furthermore, the estimated population is <2,500 mature individuals. Thus, this subspecies is assessed as Endangered [B1b(i, ii and iii), C1].

***Loris tardigradus parvus*** new subspecies
Northwestern group (group 1)

This group has unique facial features, body morphology and skull morphology. Further research on this new subspecies is needed. It seems sharply distinct from the southwestern *Loris t. tardigradus*, and we predict that further work will show that it is a distinct species, but the present sample size is insufficient.

**Type:** Adult female skin, skull and tissues (in alcohol), SLCP 2015.13, to be deposited in the Natural History Museum of Colombo (NHMC). Collected by the Slender Loris Conservation Project (SLCP), 11 February 2010.

**Type locality:** Mirigama, Gampaha District, Western Province, Sri Lanka (07°15.813'N, 80°08.405'E).

**Diagnosis:** This subspecies has a unique marquise-shaped, broad circumocular patch, which is much broader at the bottom compared to *Loris tardigradus tardigradus*, and is extended toward the muzzle. The median facial strip is relatively broad. There is yellow pigmentation on the muzzle, hands, feet, ears, and eyelids, rather slight in males and more marked in females. Pre-ocular hair is light brown in males, creamy or silvery in females. Dark, golden-brown pelage with short fur. Males have yellowish hair on the ventrum, females also have yellowish hair but a little darker; throat hair is superficially creamy, the base colour is yellow; the hind limbs are more strongly coloured, both ventrally and dorsally (see Fig. 15). This is the smallest form of loris; body weight is 123−170 g. Head and body length (<200.5 mm), upper arm length (<55.5 mm) and thigh length (66.6 mm) are much shorter than in any other loris. Temporal ridges are only moderately developed, and the dorsal surface of the skull is smooth and rounded, with a moderately developed mastoid.

**Distribution:** The distribution is shown in Figure 14. Live animals were observed in Gampaha and Kurunegala districts. Three museum specimens (BMNH 1937.7.2.7, BMNH 10.5.19, and NHMC 7H) labeled "Colombo" (listed below) were classified in this group.

**Common name:** Northwestern red slender loris

The following specimens have been examined:

**Skin plus skull:** BMNH 1937.7.2.7 [adult ♀ Colombo], NHMC 7B [adult ♂ Henarthgoda-Gampaha]; 7d [adult ♀

**Figure 15.** Northwestern red slender loris, *Loris tardigradus parvus*, female holotype from Mirigama, Gampaha District, Sri Lanka (07°15.813'N, 80°08.405'E).

Henarthgoda-Gampaha], 7H [adult ♀ Colombo]; SLCP 2015.06 [adult ♀ Mirigama-Gampaha], 2015.17 [adult ♂ Mirigama-Gampaha].

**Skull only:** BMNH 10.5.19 [adult sex? Colombo]; FMNH 92861 [adult ♀ Gampaha]; RCSL OH/69 [adult ♀ Ceylon]; SLCP 2015.00 [adult ♂ Mirigama-Gampaha], 2015.20 [adult ♂ Dunagaha-Gampaha].

**Living animals:** Mirigama [adult ♂ = 2, ♀ = 1, juveniles = 2]; Pilikuththuwa- Gampaha [adult ♂ = 1]; Horagolla-Gampaha [adult ♀ = 1, juvenile ♀ = 1].

**Etymology:** The species epithet is in reference to its small size. The word *parvus* is Latin for little.

**Conservation status:** Inhabits the Northwestern part of the wet zone region. Unfortunately, nearly 96% of the natural vegetation has already been destroyed in this region. Available natural vegetation is <9km$^2$, which is severely fragmented, and deforestation continues apace (Jayasuriya *et al*. 2006). The Extent of Occurrence is 140 km$^2$ and Area of Occupancy is 9 km$^2$. Further, the Sri Lanka 2011–2030 National Physical Plan has many of its remaining habitats included in the Western Metro Region (Sri Lanka, Ministry of Construction 2012). The estimated population is <250 mature individuals and no subpopulation is estimated to contain more than 50 mature individuals. Thus, this subspecies is assessed as Critically Endangered [B2a,b(i, ii & iii), C2a(i)].

***Loris tardigradus nycticeboides*** Hill, 1942
Montane group (group 4)

Facial and pelage features, external body morphology and skull morphology are unique to this loris, genetic data (based only on the CO1 region) place it very close to *L. tardigradus* (see Gamage 2015). Yapa and Ratnavira (2013) have argued that it could represent a distinct species, and we have much sympathy with this view, but further research is needed.

**Type:** Adult female, skin and skull, British Museum (Natural History) BMNH 45.3.Plains. Collected by Mr. A. C. Nolthenius in 1937.

**Paratype:** Adult male, skin only, National Museum of Scotland NMS 1946.4.

**Type locality:** Below Horton plains, Sri Lanka.

**Diagnosis:** A long, thick, woolly coat is a diagnostic character for this species; the colour is brown, dark brown or brownish black; frosting is observed on wild animals. The circumocular patch is pear shaped, black or brownish black in colour, and wider above in both sexes; a whitish rim is visible all around, in both sexes. The median facial strip is wide; yellow pigmentation on the muzzle, hands, feet, ears and eyelids is very reduced; the hands, feet and muzzle are flesh colour. Muscular ridges are moderately developed, including the temporal ridges and the curved ridge on the occipital; dorsal surface of the skull is relatively curved; mastoid is poorly developed.

**Description:** Body weight ranges from 140–220 g, with head-body length 202–220 mm; maximum head length 52.0–57.0 mm.

**Distribution:** The distribution is shown in Figure 14. According to field observations, this species is found at elevations of 1700–2100 m asl around Nuwara Eliya. The slender loris found at a similar elevation in the Peak Wilderness is much closer to *Loris tardigradus tardigradus* (group 2).

**Common name:** Montane slender loris, Horton Plains slender loris

**Notes:** The first author (SNG) has been conducting a long-term study (10 years) on the ecology of the montane slender loris since 2006, but has yet to hear any vocalizations.

The following specimens have been examined:

**Skin plus skull:** BMNH 45.3 [adult ♀ below Horton Plains, holotype of nycticeboides Hill, 1942]. SLCP 2015.18 [adult ♂ Conical Hill-Nuwara Eliya]

**Skin only:** NMS 1946.4 [adult ♂ below Horton Plains, paratype of nycticeboides Hill, 1942].

**Live animals:** Conical-Nuwara Eliya [adult ♂ = 1, ♀ = 1], Kikiliamana Nuwara Eliya [adult ♂ = 1, ♀ = 1], Horton Plains National Park [♀ = 1], Hakgala-Nuwara Eliya [2].

**Conservation status:** A recent occupancy modeling study identified *L. t. nycticeboides* as closely associated with elevation, canopy height and canopy connectivity; the best habitat is montane evergreen forest at elevations of 1600 m to 2100 m asl, with a tall canopy (height >4 m) and good canopy connectivity (Gamage *et al*. 2015). Forest dieback, uncontrolled firewood extraction, and encroachment are causing a continuous reduction of its habitat. The Extent of Occurrence is 76 km$^2$, and the Area of Occupancy is 28 km$^2$. The estimated population is <100 mature individuals and no subpopulation is estimated to contain more than 50 mature individuals. Thus, this subspecies is assessed as Critically Endangered [B1b(i, ii and iii), C2a(i)].

***Loris lydekkerianus nordicus*** Hill, 1933
Northern grey group (group 7)

Here, we provisionally retain the northern grey group (7) as a subspecies of *Loris lydekkerianus*, described from the dry country of south-eastern India. We lack morphological and genetic data from Indian slender lorises, and direct comparisons are necessary to test this allocation.

**Type:** Sub-adult female skin and skull, British Museum (Natural History) BMNH 35.4.1.1.

**Type locality:** Thalawa, Anuradhapura, Sri Lanka.

**Diagnosis:** *Loris lydekkerianus nordicus* has a distinctive broad median facial stripe, and the circumocular patches are elongated with a tear-drop shape; the patches are grey or grey brown, and a white rim is visible around them. Grey or grey-brown coat with short, thin wavy fur. The hairs of the ventral surface are white, with hair bases also white or light grey, never becoming dark. The throat hair is white, and the bases are also white. Yellow pigmentation on hands, feet, ears and eyelids present in both sexes. The ears are large, length 23−29 mm. Size averages larger than any other taxon. All muscular ridges of the skull are well developed, especially the temporal ridges and the superior nuchal line (curved ridge on the occiput), which forms a small raised crest or ridge. The occiput is not rounded (nearly flat in dorsal view) and the dorsal surface of the skull is flat with a prominent wing-shaped mastoid process.

**Description:** Animals in the northwestern region of the range show less yellow pigmentation than elsewhere; especially the muzzle is hardly pigmented. Females are more heavily frosted than males. Well-built body, weight 230−293 g, head body length 214−240 mm, and head length 52.0−58.6 mm . Skull length ranges from 49.0−54.8 mm.

**Distribution:** The distribution is shown in Figure 14. This species is found throughout the northern dry zone; the south western boundary is Deduru Oya (river) and the southeastern boundary is Maduru Oya National Park. This loris has never been observed in the southeastern dry zone or wet zone areas, although its range appears to overlap with the Highland grey group (5) in Matale and Kurunegala.

**Common name:** Northern grey slender loris

The following specimens have been examined:

**Skin plus skull:** BMNH 35.4.1.1 [sub-adult Thalawa-North Central Province, holotype of nordicus Hill, 1933], 1966.3916 [adult ♂ Wilachchia-Anuradhapura], 15.3.1.16 [adult ♀Anuradhapura)]; FMNH 95028 [adult ? Chawakacheri-Jaffna], 95029 [adult ♂ Chawakacheri-Jaffna], and 95030 [adult ? Chawakacheri-Jaffna]; SLCP 2015.16 [adult ♀ near Thalawa-Anuradhapura]; University of Rjarata Sri Lanka, Zoology Museum 2008.04 [adult ♀ Mihintale-Anuradhapura].

**Skin only:** BMNH 15.3.1.14 [adult ♂Anuradhapura].

**Skull only:** BMNH 1966.3916 [adult ♂Wilachchia-Anuradhapura], 15.3.1.15 [♂ Anuradhapura]; SLCP 2015.05 [adult ♂ Kebethigollawa-Anuradhapura], SLCP 2015.10 [adult ? Dambulla].

**Living animals:** Thalawa-Anuradapura [adult ♀ = 1], Mihintalee-Anuradhapura [adult ♀ = 3, adult ♂ = 1, Juveniles = 2], Kebethigollawa-Anuradhapura [♂ adult = 1, sub-adult = 1], Anawilundawa-Puttlum [adult ♂ = 3, ♀ = 2], Dambulla-Matale [adult ♀ = 1], Wilpattu National Park [adult ♀ = 1], Galenbindunuwewa-Anuradapura [adult ♀ = 1], Mannar [♂ adult = 1], Polonnaruwa [adult ♂ = 1, ♀ = 2] and Trincomale [adult ♂ = 1].

**Conservation status:** This subspecies inhabits the northern dry zone of Sri Lanka. In contrast to the wet zone lorises, this subspecies has a considerable amount of forest left in its range; but these forests are highly fragmented and continually being lost because of deforestation for large-scale agriculture and infrastructure development (Jayasuriya *et al*. 2006). The Extent of Occurrence is 17,400 km$^2$, and the Area of Occupancy is 3000 km$^2$. The estimated population is <8500 mature individuals but no subpopulation is estimated to contain more than 1000 mature individuals. Thus, this subspecies is assessed as Vulnerable [B1ab(i, ii and iii), C1,2a(i)].

***Loris lydekkerianus grandis*** Hill and Phillips, 1932
Highland grey group (group 5)

Facial and pelage features, external body morphology and skull morphology is unique and well differentiated from *Loris lydekkerianus nordicus*. This form may turn out to be a distinct species.

**Type:** Sub-adult female skin and skull, British Museum (Natural History) BMNH 32.6.17.1.

**Type locality:** Gammaduwa, Knuckles, Sri Lanka.

**Diagnosis:** This taxon has a distinct, much darker, pear-shaped circumocular patch, and the rim around the patch is white and prominent. The median facial strip is relatively wide. The face and hind limbs are more whitish than *Loris tardigradus tardigradus* (group 2). General character is a grey or grey-brown with thick, relatively long fur; females are more heavily frosted than males, as in the Rakwana group (3). The coat contains a mixture of wavy and woolly hair. The ventrum is superficially white or dusky white in females, and slightly more yellowish brown in males, whereas hair bases are black in both sexes. The throat hair is superficially white and the hair bases are dark grey or black. Both sexes have yellow pigmentation on the muzzle, hands, feet, ears and eyelids. The ears are relatively short and the preocular hair is grey. The body is relatively stout, with muscular ridges moderately developed, including the temporal ridges and the curved ridge on the occiput. The occiput is less rounded in dorsal view and the dorsal surface of the skull is relatively curved with moderate development of the mastoid; skull length ranges 49.1–51.1 mm.

**Description:** Those found at higher altitudes are stouter and less frosted than those at lower altitudes. Those from high elevations (>900 m asl) in Knuckles have a very low degree of frosting and relatively stout body and short limbs compared to those found at lower elevations. Some individuals from Kurunegala and Dambulla show intermediate characters between this species and *L. l. nordicus*. Body weight ranges from 176–216 g, head-body length 208–220 mm, and maximum head length 53.9–55.3 mm.

**Distribution:** The distribution is shown in Figure 14. This species is found in the Knuckles Range and wet and intermediate parts of Kandy and Matale districts (200–1300 m asl). If this taxon really does overlap with *L. l .nordicus* in Matale and Kurunegala, as noted above under the heading of that taxon, then of course the two cannot be regarded as conspecific under any species concept; but this needs to be verified.

**Common name:** Highland grey slender loris

**Notes:** The skin from Opalgala, NHMC 7xA, is more brownish-toned than other specimens seen, and so bears a superficial resemblance to *Loris tardigradus nycticeboides*.

The following specimens have been seen:

**Skin plus skull:** BMNH 32.6.17.1 [sub-adult ♀ Gammaduwa-Knuckles, type of grandis Hill and Phillips, 1932]; FMNH 99479 [adult ♂ Digana-Kandy], 95204 [adult ♂ Pindeniya-Central Province], 95025 [adult ♂ Peradeniya-Central Province], 95026 [adult ♂ Peradeniya -Central Province]; SLCP 2015.16 [adult ♀ Pitawala-Knuckles], SLCP 2015.19 [adult ♀ Redbana-Knuckles].

**Skull only:** RCSL L2/OH 68 [Adult ♂ Opalgalla-Knuckles].

**Skin only:** NHMC 7xB [adult ♂ Mausakanda, Gammaduwa-Knuckles], 7xA [adult ♂ Opalgalla Gammaduwa-Knuckles; skin of RCSL L2/OH 68].

**Living animals:** Mausakanda-Knuckles [juvenile ♀], Pitawala-Knuckles [adult ♂ = 1, ♀ = 1], Mahalakotuwa-Knuckles [Juvenile ♂ = 1], Narangamuwa-Knuckles [adult ♀ = 1], Thangappuwa-Knuckles [adult ♂ = 1], Redbana-Knuckles [Adult ♀ = 2], Udwattakele-Kandy [adult ♂ = 1], Elahera-Matale [adult ♀ = 1], Dagawila-Kandy [sub-adult ♀ = 1], Wattegama-Kandy [adult ♀ = 1].

**Conservation status:** This subspecies inhabits lowland wet evergreen forest and mid-elevation evergreen forests in the Kandy and Matale districts. These forests are highly fragmented and continuously being lost due to encroachment, firewood extraction and expansion of plantation industry (Jayasuriya *et al*. 2006). In the Knuckles range, cardamom cultivation degrades its habitat (S. N. Gamage pers. obs.). The Extent of Occurrence is 1,750 km2, and the Area of Occupancy is 520 km2. The estimated population is <1,200 mature individuals. Thus, this subspecies is assessed as Endangered [B1ab(i, ii and iii), C1].

***Loris lydekkerianus uva*** new subspecies
Uva group (group 6)

Facial/pelage features, external body morphology and skull morphology, all based on limited material, show apparently significant differences between the Uva group and other Sri Lankan lorises. The genetic data (based only on the CO1 region) place it very close to *L. lydekkerianus grandis* (see Gamage 2015). The Uva group can be treated provisionally as a subspecies of *Loris lydekkerianus*, but it may turn out to be specifically distinct.

**Type:** Adult male skin, skull and tissues (in alcohol), SLCP 2015.12, to be deposited in the Natural History Museum of Colombo (NHMC). Collected by the Slender Loris Conservation Project on 1 May 2012.

**Type locality:** Nilgala, Monaragala District, Uva Province, Sri Lanka (07°10.727'N, 81°17.477'E).

**Diagnosis:** The circumocular patch is relatively narrow, rounded and light brownish. The pelage is yellow brown/reddish brown with a little grey tone; golden frosting is present. The ventrum is more whitish than in *Loris t. tardigradus* or *L. t. parvus* n. ssp.; hair-base color of the belly is grey, never becoming black. The throat hair is creamy on both the shaft and base. White frosting is present on the hind limbs. The median facial stripe is wider than in *Loris t. tardigradus* or *L. t. parvus* n. ssp. There is much yellow pigmentation on the muzzle, hands, feet, ears and eyelids (see Fig. 16). Muscular ridges of the skull are moderately developed; the occiput is more rounded in dorsal view; and the dorsal surface of the skull is rounded; a moderately developed mastoid. Relatively short body and limbs; head-body length is 208.25±7.14 mm and upper arm length is 54.30±1.25 mm.

**Distribution:** The distribution is shown in Figure 14. It is found mainly in the Uva Basin (southeastern dry and intermediate zones); Badulla, Monaragala and Ampara districts.

**Common name:** Uva red slender loris.

**Figure 16.** Uva red slender loris *Loris lydekkerianus uva*, male holotype male from Nilgala, Monaragala District, Sri Lanka (07°10.727'N, 81°17.477'E).

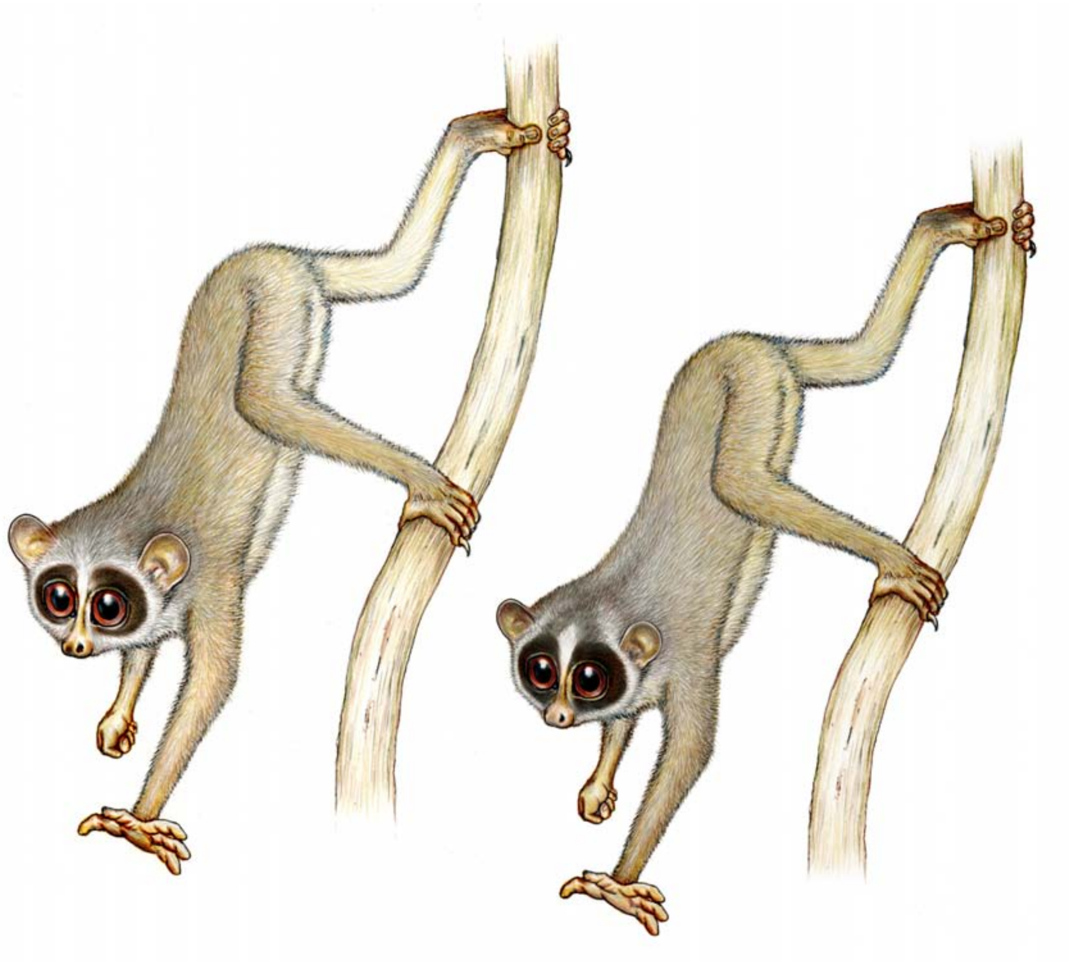

**Figure 17.** The Uva red slender loris *Loris lydekkerianus uva*, left, and the Northwestern red slender loris, *Loris tardigradus parvus*, right. Illustrations by Stephen D. Nash**.**

The following specimens have been examined:
**Skin plus skull:** SLCP 2012.12 [adult ♂ Nilgala-Monaragala].
**Skin only:** BMNH 54.349 [♂ Namunukula-Badulla].
**Skull only:** RCSL - A112.528 [adult ♀ Monaragala-Uva], A112.523 [adult ♂ Monaragala-Uva], A112.5292 [adult ♀ Monaragala-Uva], A112.522 [adult ♂ Monaragala-Uva], A112.524 [adult ♂ Monaragala-Uva], A112.525 [juvenile ♂ Monaragala-Uva], A112.526 [adult ♂ Monaragala-Uva], A112.529 [adult ♀ Monaragala-Uva], A112.5294 [adult ♀ Monaragala-Uva], A112.5296 [adult ♀ Monaragala-Uva], A112.5291 [adult ♀ Monaragala-Uva], A112.5298 [adult ♀ Monaragala-Uva], SLCP 2015.21 [adult Velioya -Balangoda]**Living animals:** Lahugala-Ampara [adult ♂ = 1], Nilgala-Monaragala [adult ♂ = 1], Rawana Ella-Badulla [adult ♂ = 1], Veelioya-Monaragala [adult ♂ = 1], Passara-Badulla [adult ♂ = 1], Belihuloya-Balangoda [adult ♂ = 1; adult ♀ = 1].
**Etymology:** The species epithet is in reference to its distributional range in the Uva Basin; Uva is a historical name for the south eastern dry and intermediate zone of Sri Lanka.
**Conservation status:** The Extent of Occurrence is 7,520 km$^2$, and the area of occupancy is 2,600 km$^2$. This subspecies is very rare, being most common in undisturbed moist mixed evergreen forests. These forests are highly fragmented and continually being lost because of deforestation for large-scale agriculture and infrastructure development (Jayasuriya *et al*., 2006). We assess the subspecies as Vulnerable [B1ab(i, ii and iii)].

Rakwana group (group 3)

Facial and pelage features, external body morphology and skull morphology show some differences between the Rakwana group (3) and *Loris tardigradus* but our sample size is not enough for any meaningful analysis. Until further evidence becomes available, it is impossible to consider proposing this as a further subspecies at this stage. We note, however, that "a very rich, rusty-coloured loris has been seen near Morningside near the Sinharadja Forest Reserve… a new subspecies or species?" (Yapa and Ratnavira 2013: 151).
**Description:** The limited material indicates a dark grey brown or brownish black coat with long dense fur. Both sexes show frosting, but females are more heavily frosted. Pelage of the ventrum is cream or dusky-white with hair bases black. The throat hair is white and bases are black. Dorsally very dark, hence dorsal stripe is not visible. Circumocular patches are pear shaped with black or brownish black color; wider above in both sexes and extended up to crown; no rim is visible

around the circumocular patch. Both sexes have very little yellow pigmentation on the muzzle, hands, feet, ears and eyelids. Pre-ocular hair is dark-brown or nearly black. Muscular ridges are poorly developed, especially temporal ridges; the dorsal surface of the skull is smooth and rounded. The superior nuchal lines are not detectable or poorly developed; the occiput is rounded in dorsal view; poorly developed mastoid in female (sub-adult), moderately developed in male. **Distribution:** Distribution is shown in Figure 14. This form is found at high elevations (800−1300 m asl) of Rakwana-Deniyaya mountain range. Its western, northern and southern boundary meets group 2 (*Loris tardigradus tardigradus*) and its eastern boundary meets group 6 (*Loris lydekkerianus uva* new subspecies).

The following specimens have been examined:
**Skin plus skull:** SLCP 2015.04 [sub-adult ♀ Gongala-Rathnapura], 2015.14 [adult ♂ Morningside-Sinharaja].
**Living animals:** Gongala-Rathnapura [adult ♀ = 1], Morningside-Sinharaja [adult ♂ = 1, ♀ = 1, Juveniles = 1], Ensalwatta-Estate Sinharaja division [adult ♂ = 1, Juvenile ♀ = 1], Handapanella-Rathnapura [adult = 1], Deniyaya [adult ♂ = 1, sub-adult ♀ = 1].

## Future studies

We have retained the division of Sri Lankan slender lorises into two species. Further surveys and DNA samples will help to fully clarify the affinities of the Sri Lankan loris taxa to each other and to the Indian lorises. The latter have recently been briefly surveyed by Kumara *et al*. (2013). In Sri Lanka, the affinities o*f L.* cf. *tardigradus nycticeboides* are unclear; we have provisionally placed it in *L. tardigradus*, following Nekaris and Jayewardene (2004). Groves (1998, 2001) placed it in *L. lydekkerianus*, while Yapa and Ratnavira (2013) have suggested that it may be specifically distinct. The latter authors have also claimed they found “a totally isolated subpopulation of *L. lydekkerianus* […] deep within *tardigradus* territory, in the Deniyaya area” (Yapa 2013: 146). We intend to follow up on some of these questions in a future publication.

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# Population, Distribution, Vocalization and Conservation of the Gaoligong Hoolock Gibbon (*Hoolock tianxing*) in the Tengchong Section of the Gaoligongshan National Nature Reserve, China

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**Abstract:** We conducted surveys to estimate the current population and distribution of the recently described Gaoligong hoolock gibbon (*Hoolock tianxing*) in Yunnan Gaoligongshan National Nature Reserve Tengchong Bureau (TC-GLGS). The reserve supports the northernmost known population of the species in China. A total of 17–20 gibbons in 6–7 family groups were recorded in TC-GLGS in a population census conducted in 2016. The mean group size was 2.8–2.9 individuals (range 2–4) with a population density of 0.18–0.21 groups/km$^2$. All groups contained a single adult pair, and juveniles and/or infants were observed in all but two. Mean dawn time was 07:26 h during the survey, and vocalizations were concentrated in the first hour after dawn (57.9% of total song bouts), with an average song bout duration of 25.7 min (n = 19). Four other primate species occurred in sympatry with the gibbons in the study area, with *Macaca arctoides* and *M. assamensis* being the most abundant. TC-GLGS appears to support the single largest subpopulation of *H. tianxing* in China, but the population density was very low, despite the presence of large areas of healthy, closed-canopy forest, suggesting that the population may have been well below carrying capacity. The suppressed population size is a combined result of rampant hunting in the past, loss of lower elevation forest, and ongoing disturbance by cattle grazing in the remaining gibbon habitat. Long-term conservation challenges facing the Gaoligong hoolock gibbon in China include the prevention of poaching and disturbance, restoration of deforested areas <2,000 m asl, and the establishment of biological corridors between forest fragments. Translocation to areas contiguous with larger subpopulations should be considered for single groups in isolated forest fragments.

**Key words:** Skywalker gibbon, population surveys, group, density, Yunnan

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## Introduction

The hoolock gibbons, genus *Hoolock*, are restricted to moist broad-leaved forests of the Eastern Himalaya, and are the northernmost of the four extant gibbon genera (*Hoolock*, *Hylobates*, *Nomascus*, and *Symphalangus*) (Chivers 2013). Since the majority of hoolock gibbon populations occur in remote and often inaccessible mountain ranges, their taxonomy, distribution and status are not clearly known (Geissmann *et al*. 2013; Fan *et al.* 2017). At the end of 2016, there were two widely-accepted species, namely the western hoolock gibbon *(Hoolock hoolock*) and the eastern hoolock gibbon (*H. leuconedys*), with the Chindwin tributary of the Irrawaddy in Myanmar delimiting their ranges (Geissmann *et al*. 2013; Fan *et al*. 2017). A population of the eastern hoolock gibbon living between Myanmar's Nmai Hka tributary of the Irrawaddy and the Salween (Nujiang in Chinese) of China's Yunnan Province was recently described as a new species: *Hoolock tianxing* Fan *et al*., 2017, the Gaoligong hoolock gibbon or Skywalker hoolock gibbon. The authors proposed that it should be categorized as Endangered under the IUCN Red List criteria.

A number of behavioral and ecological studies have been conducted on *H. tianxing* in Yunnan; they include calling (Lan *et al.* 1999; Zhang *et al*. 2011; Yin *et al.* 2016), ranging behaviour (for example, Zhang *et al*. 2013; Yuan *et al.* 2014), diet and activity budget (Fan *et al.* 2013), and habitat use (for example, Bai *et al*. 2011). The distribution and status of *H. tianxing* in Gaoligongshan and China have been summarized by Lan *et al.* (1995), Zhang *et al*. (2007) and Fan *et al.* (2011).

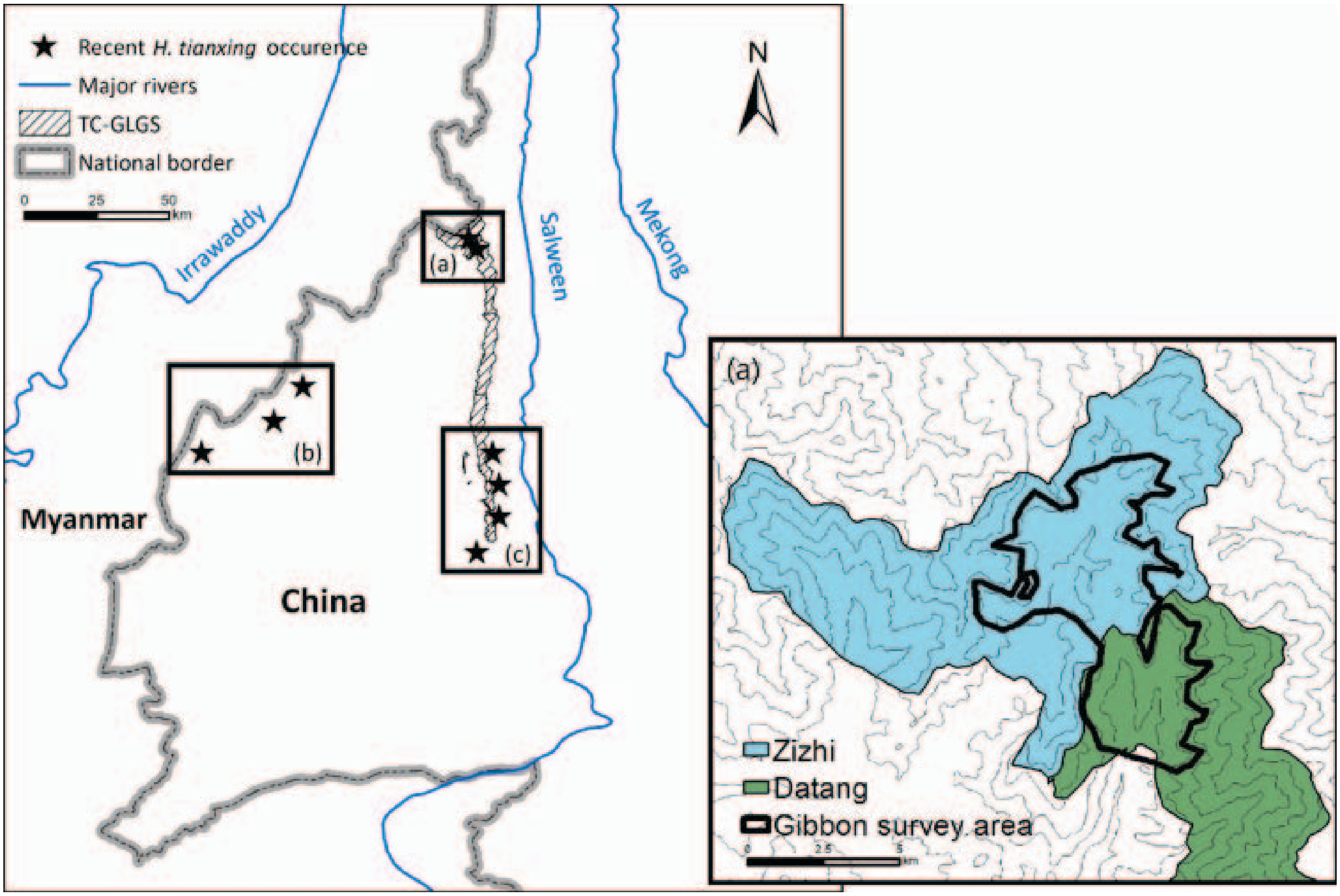

**Figure 1.** Geographic location and the gibbon survey area of Yunnan Gaoligongshan National Nature Reserve Tengchong Bureau (TC-GLGS), and the current distribution of *Hoolock tianxing* in China in three major clusters.

**Figure 2.** Adult male *Hoolock tianxing* of DT-A group, taken on 24 November 2016 during the gibbon population census. Photo by Chi Fung Mak.

The latest survey was that of Fan *et al.* (2011) in 2008–2009. They estimated less than 200 individuals in no more than 43 groups in 17 isolated locations, with the biggest subpopulation containing only five groups. Some of these groups live outside protected areas and are threatened by poaching and habitat loss, and most are not regularly monitored (Fan 2016). Although the largest population of eastern hoolock gibbon *sensu lato* is in Myanmar, there is still a lack of reliable and up-to-date information on their distribution and population sizes there (Geissmann *et al.* 2013). *Hoolock tianxing* occurs east of the Nmai Hka River, and its geographic range and conservation status in Myanmar is unknown (Fan *et al*. 2017). More robust data on the sizes and conservation status of the different subpopulations of *H. tianxing* are needed to guide conservation efforts on its behalf.

The Hong Kong-based NGO Kadoorie Farm & Botanic Garden (KFBG) has been collaborating with the Gaoligongshan National Nature Reserve Tengchong Bureau (TC-GLGS) on biodiversity surveys and conservation initiatives since 2014. In 2016, we launched a project to protect and study the resident gibbon population, and organized a gibbon population census in order to clarify the current population size, distribution and status of *H. tianxing*. The TC-GLGS gibbon population is of particular interest to enhance our understanding of the species as it is the northernmost subpopulation of the species in China, and comparative historical data are available, creating an opportunity to examine the population trend of the species there. Here we report on the results of our survey.

## Methods

### *Study area*

Gaoligongshan, a rugged, north-south running mountain range in southwestern Yunnan, stretches about 600 km from the Tibetan Plateau to Myanmar. It is the watershed of the Salween and Irrawaddy basins in China, and the southwest monsoon from the Indian Ocean brings plentiful rainfall to this low-latitude, high-altitude massif, making it a hotspot for biological discovery (Yang *et al*. 2016; Fan *et al*. 2017). Chaplin (2005) considered it to be "one of the world's most significant biodiversity hotspots outside of the tropics", and provided detailed analysis of its geography in relation to its rich and unique biodiversity. The administration of the Gaoligongshan National Nature Reserve (405,500 ha) is divided into four management sections under three distinct administrative bureaus. *Hoolock tianxing* is restricted to the southern portion (81,443 ha) that is managed by the Baoshan Administrative Bureau. The Baoshan Administrative Bureau manages TC-GLGS that covers 42,418 ha of the western slope of Gaoligongshan, and 90% of TC-GLGS is under well-preserved forest cover. The highest peak in TC-GLGS reaches 3780 m asl, but the elevation drops abruptly to 1800 m in the river valley. Elevational vegetation zonation is well-defined. From the summit to the river valley, one can find sub-alpine bamboo-rhododendron dwarf forest interspersed with mixed coniferous forest at 2700–3200 m, humid evergreen broad-leaved forest at 1800–2800 m, and monsoon humid evergreen broad-leaved forest below 1800 m. Old-growth forest outside the reserve below about 2000 m has, however, been cleared over generations of human settlement, and gibbons are restricted to the lower belt of the protected humid evergreen broad-leaved forest. The tree canopy there averages 25 m.

The survey area was in the northern portion of TC-GLGS, directly adjoining Myanmar's Kachin State. It was divided into two management units; namely Zizhi on the west and Datang on the east (Fig. 1). The forest of Datang and Zizhi is well-protected and contiguous, so the gibbons can be considered as a single population. The gibbon population of TC-GLGS declined dramatically during the 1990s, and they appear to have been extirpated from the southern portion of the reserve (Fan *et al*. 2011). Fan *et al*. (2011) reported 3–4 groups in Datang and two groups in Zizhi in 2009, but were unable to provide detailed population numbers. Since the upper altitudinal limit of *H. tianxing* is 2600 m, we focused our survey effort between 2100 and 2600 m asl. The forest there was old-growth humid evergreen broad-leaved forest dominated by Fagaceae, Lauraceae and Theaceae.

### *Gibbon survey*

We have been monitoring the gibbon groups in the Zizhi and Datang survey areas (Fig. 1) every month since April 2016. We selected and trained 10 reserve wardens to form a gibbon monitoring team. They spent the first few months exploring the forest and familiarizing themselves with the gibbons' ranging patterns. We visited the reserve several times to train the wardens and determine the best listening posts for the population censuses.

A full gibbon population census was conducted from 23 to 27 November 2016. Forty-six people participated. All received training in identifying gibbons and their calls, and in the use of standardized record sheets provided prior to the survey. Most teams had at least one member with experience in surveying wild gibbons. We followed the survey method of Fan *et al*. (2011) that is otherwise widely used in hoolock gibbon surveys (Brockelman *et al*. 2009; Geissmann *et al*. 2013). There were 22 listening posts on hilltops and ridges, each separated by at least 450 m. The time, type, and duration of all gibbon vocalizations were recorded from pre-dawn (i.e. *c*. 07:00 h) to 12:00 h on four consecutive mornings (24–27 November). When gibbons were close to the listening posts, the team would track and directly observe the gibbons to record group size and composition. One team member would remain to continue obtaining vocalization data. All teams also conducted biodiversity fieldwork each afternoon in the gibbon forest during the survey period, our survey therefore covered the full active hours of gibbons. Minimum population size and density were estimated by triangulation of the vocalization data and confirmed with direct observation (Brockelman and Ali 1987; Brockelman and Srikosamatara

**Table 1.** Observation records of *Hoolock tianxing* during the present survey, Yunnan Gaoligongshan National Nature Reserve Tengchong Bureau, China. Group composition: AM = Adult male; AF = Adult female; SJ =Subadult/juvenile; IN = Infant. Coordinates were recorded using hand-held GPS.

| **Date 2016** | **Time and duration** | **Distance between observers and gibbons** | **Group composition (number of individuals)** | **Coordinates** |
|---|---|---|---|---|
| 24 November | 08:05–08:13 | 40 m | AM (1) | 25°45’03.49”N<br>98°42’05.98”E |
| 24 November | 09:36–09:54 | 300 m | AM (1) | 25°47’51.65”N<br>98°41’41.31”E |
| 25 November | 9:37 | 30 m | AM (1), AF (1) | 25°48’12.22”N<br>98°40’07.66”E |
| 25 November | 10:14–10:23 | 30 m | AM (1) | 25°45’03.49”N<br>98°42’05.98”E |
| 26 November | 08:39–09:28 | 480 m | AM (1), AF (1) | 25°47’28.67”N<br>98°40’56.30”E |
| 26 November | 08:41–09:28 | 500 m | AM (1), AF (1), SJ (1) | 25°47’28.67”N<br>98°40’56.30”E |
| 26 November | 10:15–10:34 | 15 m | AM (1), AF (1), SJ (2) | 25°45’92.05”N<br>98°41’27.18”E |
| 26 November | 08:21–08:55 | 200 m | AM (1), AF (1), SJ (1) | 25°44’13.68”N<br>98°42’04.04”E |

**Table 2.** Group composition of *Hoolock tianxing* recorded in the present survey, Yunnan Gaoligongshan National Nature Reserve Tengchong Bureau, China. * = group could be a double-count of DT-B and result is preliminary.

| **Group** | **Group composition** | | | | **Total** |
|---|---|---|---|---|---|
| | **Adult male** | **Adult female** | **Subadult/ Juvenile** | **Infant** | |
| DT-A | 1 | 1 | 1 | 0 | 3 |
| DT-B | 1 | 1 | 1 | 0 | 3 |
| DT-C | 1 | 1 | 1 | 0 | 3 |
| ZZ-A | 1 | 1 | 0 | 0 | 2 |
| ZZ-B | 1 | 1 | 2 | 0 | 4 |
| ZZ-C* | 1 | 1 | 1 | 0 | 3 |
| ZZ-D | 1 | 1 | 0 | 0 | 2 |
| Total | 6–7 | 6–7 | 5–6 | 0 | 17–20 |

1993). The area covered by our survey was 3,320 ha, covering the potential gibbon habitat between 2100 and 2600 m (Fig. 1).

## Results

The weather was sunny but cold during the survey period, with night time temperatures dropping below freezing. Gibbons were observed directly on eight occasions, the earliest contact time was 08:05 h on 24 November, and the latest was 10:15 h on 26 November (Fig. 2). We observed the gibbons from as close as 15 m on 26 November, but had no direct contact with gibbons on 27 November (Table 1).

### *Vocalizations*

During the survey, mean dawn time was 07:26 h. *Hoolock tianxing* duet, and a total of 19 song bouts were heard. The gibbon groups produced morning song bouts on all four days of the survey. Calls were most frequently heard within the first hour after dawn (57.9% of total song bouts), and we recorded 73.7% of all song bouts within 1.5 h after dawn. The earliest song bout started at 07:44 h on 25 November, and the latest one at 10:15 h on 26 November (Fig. 3). Average song bout duration was 25.7 min (n = 19), and varied from 4 min (between 08:08–08:12 on 26 November) to an exceptionally extended bout of 63 min (between 08:20–09:23 on 26 November). One of the gibbon groups called up to 3 times a day (24 and 26 November, respectively).

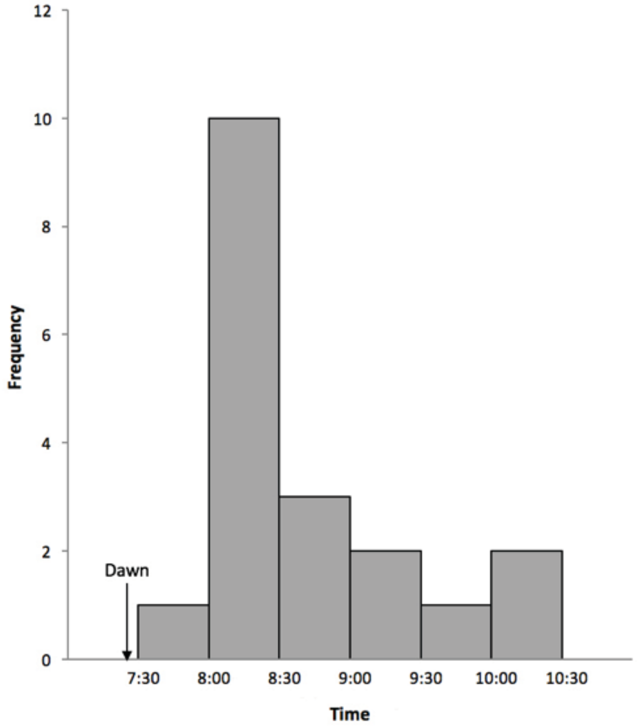

**Figure 3.** Frequency distribution of the onset of vocalization for *Hoolock tianxing*, Yunnan Gaoligongshan National Nature Reserve Tengchong Bureau, China. N = 19 song bouts.

### *Population and group size*

Based on locations of observation and vocalization, timing of song bouts, and group composition observed, we confirmed there were 6–7 gibbon groups with a total of 17–20 gibbons in TC-GLGS, including three or four groups of three individuals, two groups of two individuals, and one group of four individuals. The mean group size was 2.8–2.9 with a population density of 0.18–0.21 groups/km$^2$. Three of the groups live in the Datang unit (groups prefixed with "DT-") and the other three groups in the Zizhi unit (groups prefixed with "ZZ-"). All groups observed were socially monogamous, with four of the six groups having immatures (Table 2). A fourth gibbon group, consisting of a breeding pair and a juvenile, was detected in the Zizhi unit on 25 November, close to the home range of DT-B which had the same group composition; unfortunately, DT-B was not detected on the same date. Subsequent regular monitoring also detected the same gibbon group in Zizhi, but never in the same time span when DT-B was detected, and therefore we cannot discount the possibility that DT-B either shifted its home range or has a particularly large home range.

### *Sympatric primates*

The primate community sympatric with *H. tianxing* has rarely been reported. Four other primates—*Macaca arctoides*, *M. assamensis*, *M. mulatta*, and *Trachypithecus phayrei*—were identified on camera traps or recorded during casual encounters in the survey area. *Trachypithecus phayrei* was the rarest amongst the four, and has probably been extirpated in the Datang unit. *Macaca arctoides* and *M. assamensis* are widespread and common. *Macaca mulatta* largely occurs at lower elevations, and is more frequently encountered in rocky forest near human habitation.

## Discussion

As far as we are aware, our population census was the most intensive field survey ever conducted for *H. tianxing*. We recorded 17–20 individuals in 6–7 family groups of *H. tianxing* in TC-GLGS. Comparing our findings with those of Fan *et al.* (2011), the Datang population remained stable, while the population in Zizhi increased. The population of *H. tianxing* in TC-GLGS is of particular research and conservation importance because it is both the northernmost (up to c. 25°48'13"N), and the largest subpopulation known in China (see Fan *et al.* 2011).

The mean group size in TC-GLGS was 2.8–2.9 individuals (range 2–4), which is lower than the national estimate of 3.9 reported by Fan *et al*. (2011). Average group sizes for eastern hoolock gibbon *sensu lato* in Myanmar is 2.4 (Geissmann *et al*. 2013). The population density in TC-GLGS was 0.18–0.21 groups/km$^2$, which is substantially lower than values reported for the Gaoligong hoolock gibbon from the eastern slopes of Gaoligongshan (0.5 groups/km$^2$; Yin *et al*. 2016) or eastern hoolock gibbon *sensu lato* in Myanmar (>1 to 2.3 groups/km$^2$; Geissmann *et al.* 2013). The average gibbon density from the Northern Kachin Forest Complex adjacent to TC-GLGS was 2.07 groups per km$^2$, which is lower than the national average of Myanmar; the authors attributed the low gibbon density in Kachin to loss of lower elevation forest, colder climate and high hunting pressure. It is of note that the gibbon density of Kachin is still several orders of magnitude higher than what we found in TC-GLGS, indicating the TC-GLGS population has been severely impacted by anthropogenic threats, especially hunting (Fan *et al.* 2011).

The gibbon groups produced morning songs on all days during the survey period, confirming the suggestion of Zhang *et al*. (2011) that November is a good month to survey for the species, as they produce frequent morning calls. *Hoolock tianxing* in TC-GLGS had an average song bout duration of 25.7 min (range 4–63 min, n = 19), which is similar to a study from another Gaoligongshan site (Yin *et al.* 2016), but longer than those reported outside China (Geissmann *et al.* 2013). Our record of a song bout lasting 63 min seems exceptional, but an even longer song bout (75 min 50 s) was reported in a previous study in the same area (Zhang *et al.* 2011). Despite the more northerly location and freezing mornings during the survey, we recorded the highest frequency of calling within an hour after dawn, and a single gibbon group sang three times in a day on two occasions. These differ from the results of two studies from Gaoligongshan, which reported their study groups called on average 2–3 h after dawn, and their groups rarely if ever sang three times a day (Zhang *et al.* 2011; Yin *et al.* 2016). Yin *et al.* (2016) suggested that low temperatures were the reason for the low calling frequency and delayed onset of calling, but frequent and early calling during our cold mornings (consistently <10ºC) appears to contradict this.

### *Conservation*

Currently, the gibbons of TC-GLGS live in an area of about 3,300 ha. Taking the average home range of hoolock gibbons as 100–200 ha (Geissmann *et al.* 2013), this area could theoretically support at least 16 gibbon groups. Comparing population densities of hoolock gibbons elsewhere in and outside China, it is evident that the gibbon population in TC-GLGS is well below the carrying capacity of the extensive and excellent closed-canopy forest of the reserve. Reasons for the extremely low gibbon density in Gaoligongshan—hunting, habitat degradation and population fragmentation—have been discussed by a number of researchers (Fan *et al*. 2011; Zhang *et al.* 2011; Yuan *et al.* 2014; Yin *et al*. 2016; Fan *et al*. 2017). In areas inhabited by the Lisu ethnic group throughout Gaoligongshan and Myanmar's Kachin State, the brain of the hoolock gibbon is considered a cure for headaches and for child epilepsy, and dried skulls of hoolock gibbons are sometimes confiscated or seen for sale in local markets. In fact, it has been reported that hunting wiped out the gibbons in the southern portion of TC-GLGS (Fan *et al*. 2011). Ngwe Lwin *et al.* (2011) similarly reported that hunting was a serious threat in half of the survey sites in the distribution of eastern hoolock gibbon *sensu lato* in northeastern Myanmar. On the contrary, there are cultural taboos against hunting gibbons in the border area of Houqiao and Sudian in China, where remnant groups of *H. tianxing* are living in community forest blocks close to villages (Fan *et al*. 2011; Fan 2016). Luckily, with enhanced enforcement and the financial security for China's protected-area system, anti-poaching efforts have improved, and it can be expected that the poaching of gibbons will continue to decline. Poaching, nevertheless, remains a serious threat to this much-depleted gibbon population in China, and every effort must be made to combat direct killing of gibbons.

Habitat loss and degradation is another major contributing factor for the low gibbon density in TC-GLGS. This threat is two-fold. (1) The fertile lowlands and foothills along the river valley in Tengchong has been settled by humans for hundreds of years, and outside the reserve boundary, below *c*. 2000 m asl, the original forest has been either cleared or is severely degraded (Fan *et al*. 2011). Geissmann *et al*. (2013) reported that Myanmar's hoolock gibbons appear to be more common at elevations of 80–1500 m; the gibbons in Gaoligongshan are therefore forced to live in suboptimal high elevation forest with a lower carrying capacity for gibbons. (2) Partial removal of large trees in lower elevation valleys in the gibbon range for plantations of the understorey herb tsaoko (*Fructus tsaoko*, Zingiberaceae; the fruits are valued in traditional Chinese medicine) increases disturbance in the gibbon's habitat, affects the energy budget of the gibbons, and reduces food density and choices for sleeping trees (Fan *et al.* 2012; Zhang *et al*. 2013; Yuan *et al.* 2014). In addition, the apparently well-conserved forests in TC-GLGS are disturbed not only by understorey agriculture but also in the Zizhi unit by cattle ranching, where the gibbon population appears to be recovering. In 2014, a large cattle farm was established right on the reserve boundary, and hundreds of cattle, horses and pigs are grazing and trampling the regenerating valley-bottom forest of the reserve. This prevents the recovery of the closed-canopy, low-elevation forest to the detriment of the tiny gibbon population. Eastern hoolock gibbons *sensu lato*, however, are evidently able to live in degraded forest (Geissmann *et al.* 2013); and the gibbons in TC-GLGS may be able to occupy these degraded lower elevation forests in the reserve if free-ranging livestock in Zizhi could be excluded.

*Hoolock tianxing* in China is living in three major clusters (Fig. 1). There are 17 isolated forest blocks in these three clusters that support gibbons. While it may be socio-economically too challenging to reconnect the three major clusters, we should make every effort to reconnect fragmented gibbon habitats within each cluster. Fan *et al.* (2011) reported five isolated forest blocks, each one with just a single gibbon group. These isolated groups can be treated as "living dead" on an extinction debt, and although not without risks, the authorities should seriously consider the option of translocation to rescue them by moving them into forest blocks with larger subpopulations, rather than investing limited resources into protecting them for no real future.

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