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New Distributional Records and Conservation Implications for the Critically Endangered Greater Bamboo Lemur *Prolemur simus*

Laingoniaina Rakotonirina[a, b] Andry Rajaonson[a, b]
Tianasoa Ratolojanahary[e] Jean Rafalimandimby[e]
Prosper Fanomezantsoa[e] Bellarmin Ramahefasoa[c]
Tovonanahary Rasolofoharivelo[b, d] Maholy Ravaloharimanitra[a]
Jonah Ratsimbazafy[b, c] Rainer Dolch[e] Tony King[a]

[a]The Aspinall Foundation, [b]Groupe d'Etude et de Recherche sur les Primates de Madagascar (GERP), [c]Durrell Wildlife Conservation Trust, and [d]Conservation International, Antananarivo, and [e]Association Mitsinjo, Andasibe, Madagascar

Key Words
Conservation · *Hapalemur aureus* · Local knowledge · Madagascar · Marolambo · Nosivolo · *Prolemur simus* · Species distributions · Zahamena

Abstract
To improve our knowledge of the distribution of the critically endangered greater bamboo lemur *Prolemur simus,* we surveyed 6 sites in eastern Madagascar. We found its characteristic feeding signs at 5 sites and made a direct sighting at one of these. One site represents a northern extension of 45 km of the known extant range of the species. Two sites are located in a forest corridor approximately halfway between the previously known southern and northern populations, therefore suggesting a broadly continuous distribution of the species within its range rather than the previously suspected distribution of two distinct populations separated by a distance of over 200 km. Our results illustrate the benefit of species-focussed surveys in determining the true distribution of endangered species, a realistic measure which is necessary in order to assess their current status and to prioritise long-term conservation interventions.

Introduction

The greater bamboo lemur *Prolemur simus* is classified as critically endangered by the IUCN [2010] and has long been considered to be one of the most endangered primates in the world [Mittermeier et al., 2002; Wright et al., 2008, 2009]. Although

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Tony King
The Aspinall Foundation, BP 7170 Andravoahangy
Antananarivo 101 (Madagascar)
Tel. +261 32 54 664 93
E-Mail tonyk@aspinallfoundation.org

at times placed within the *Hapalemur* genus, it is currently the only recognised species in the genus *Prolemur* [Mittermeier et al., 2010], and a conservation programme to ensure its survival has been identified as a conservation priority for many years [Mittermeier et al., 1992; Ganzhorn et al., 1996/1997]. The development of such a programme was proposed in 2008, bringing together various organisations working directly or indirectly with the species [The Aspinall Foundation, 2008; King and Chamberlan, 2010]. An immediate priority of the programme was to improve our knowledge of the distribution and abundance of the species in the wild in order to refine the current status of the species and to prioritise long-term conservation interventions.

Although subfossil records show that *P. simus* was once widely distributed across Madagascar [Godfrey and Vuillaume-Randriamanantena, 1986; Godfrey et al., 2004], its present-day distribution was thought to be highly restricted, with only 11 sites having been confirmed as supporting the species during surveys at 70 sites over a 21-year period from 1986 to 2007 [Wright et al., 2008]. However, very few of these surveys were focussed primarily on finding *P. simus,* and large areas of the possible range of the species had apparently not been surveyed at all. Therefore various surveys were organised to fill in the gaps in previous survey efforts, using methods focussing on finding bamboo lemurs in general and *P. simus* in particular [King and Chamberlan, 2010]. Whilst the first survey had only limited success [Rajaonson et al., 2010], two subsequent surveys resulted in northern and southern range extensions and a major increase in the known extant range and number of sites supporting the species [Ravaloharimanitra et al., 2011; Rakotonirina et al., in press]. These surveys illustrated that an effective way of finding sites with *P. simus* is to work with locally based partner organisations to systematically gather local knowledge, targeting, where possible, local community associations responsible for management transfer zones, followed by intensive searching of potential sites for the characteristic feeding remains of the species [Ravaloharimanitra et al., 2011].

To build on the positive results of these previous studies and to further advance our knowledge of the current distribution of *P. simus*, we used a similar methodology to undertake two new surveys in regions where there were no prior confirmed records of the species. The first was undertaken in and around the Marolambo forest corridor at sites situated approximately halfway between the previously known northern and southern populations in or near the Ankeniheny-Zahamena (CAZ) and Ambositra-Vondrozo corridors, respectively [Wright et al., 2008], and the second in the Parc National and Réserve Naturelle Intégrale Zahamena, north of the previously known northern range limit near Didy in the CAZ [Ravaloharimanitra et al., 2011]. We also undertook a brief survey to the northeast of Vatomandry, in the lowland area between the CAZ and the Marolambo forest corridor. In this paper we present the results of these surveys and their implications for understanding the distribution of the species and its conservation.

Methods

In total, we surveyed 6 sites in eastern Madagascar (table 1; fig. 1), searching suitable habitats for the characteristic feeding signs of *P. simus* as described by Dolch et al. [2004, 2008], Rajaonson et al. [2010] and Ravaloharimanitra et al. [2011]. The sites were selected based on local knowledge collected prior to our field surveys. Likewise, areas with high densities of large-

Table 1. Survey sites during this study

Site	Latitude	Longitude	Altitude range, m	Survey dates (in 2010)	Observers
Vohibe	S19°55′	E48°29′	315–387	12 July	Ratolojanahary, Rafalimandimby
Mahalina	S19°04′	E48°51′	63–178	27–30 December	Rasolofoharivelo, Ratolojanahary, Rafalimandimby
Ambohimiadana	S19°54′	E47°53′	945–1,456	17–19 July	Rakotonirina, Fanomezantsoa
Sahanavo	S19°57′	E47°53′	1,023–1,647	22–24 July	Rakotonirina, Fanomezantsoa
Ambohimalaza	S19°58′	E47°53′	887–1,135	26–27 July	Rakotonirina, Fanomezantsoa
Zahamena	S17°43′	E48°46′	751–1,028	13–18 September	Rajaonson, Rasolofoharivelo, Ratolojanahary, Rafalimandimby

culmed bamboo within each site were identified through the participation of local community members.

Vohibe (Rural Commune of Ambinanidilana)

Vohibe represents a very small lowland forest fragment situated just to the north of the Nosivolo River, near its confluence with the Mangoro River (fig. 1). It is surrounded by deforested agricultural land supporting large areas of secondary growth often including high densities of traveller's palm *Ravenala madagascariensis* (Strelitziaceae) and *Valiha diffusa* (Poaceae), a large-culmed lowland bamboo endemic to Madagascar. Both are food plants of *P. simus* in lowland sites further north [Ravaloharimanitra et al., 2011]. Management responsibility for the forest was transferred to a local community association several years ago. One of us (J. Ratsimbazafy) received information in 2006 from a local village elder indicating the presence of *P. simus* in the area and during a site visit the same year saw a large bamboo lemur, but too briefly to confirm its identification. We surveyed this site in July 2010.

Mahalina (Rural Commune of Niherenana)

The site of Mahalina is a private property located in a largely deforested lowland area on the south bank of the Iaroka River (fig. 1). Watercourses have been converted to rice fields, which are surrounded by hills of dense secondary vegetation similar to that around Vohibe, also containing high densities of *R. madagascariensis* and *V. diffusa*. The pantropical large-culmed bamboo *Bambusa vulgaris* and the herbaceous *Aframomum angustifolium* (Zingiberaceae) are also present, and both are food plants of *P. simus* in lowland areas to the north [Ravaloharimanitra et al., 2011]. The area previously supported lowland forest, with forest-dependant lemur species such as *Varecia variegata* still present until at least 1999 [T. Rasolofoharivelo, pers. obs.]. During a brief visit in late September 2010, one of us (T. Rasolofoharivelo) saw 2 large bamboo lemurs which appeared to be *P. simus*. We surveyed the site in December 2010.

Ambohimiadana and Sahanavo (Rural Commune of Ambohimilanja)

A community association based at the village of Ambohimiadana is responsible for the management of a forest area located within the eastern limit of the remaining rainforest corridor west of Marolambo, south of the Onive but north of the Nosivolo Rivers (fig. 1). The site contains mid- and high-altitude rainforest, which typically includes the endemic bamboo *Cathariostachys madagascariensis,* the preferred food plant of *P. simus* in similar sites elsewhere [Tan, 1999; Dolch et al., 2008]. The possible presence of *P. simus* at the site was revealed in 2007 through the gathering of local knowledge during an ornithological survey [J.J. Randriamanindry, unpubl. report for BirdLife International/Asity Madagascar]. We surveyed this site, and the neighbouring site of Sahanavo, which is also community managed and located in the forest corridor, in July 2010.

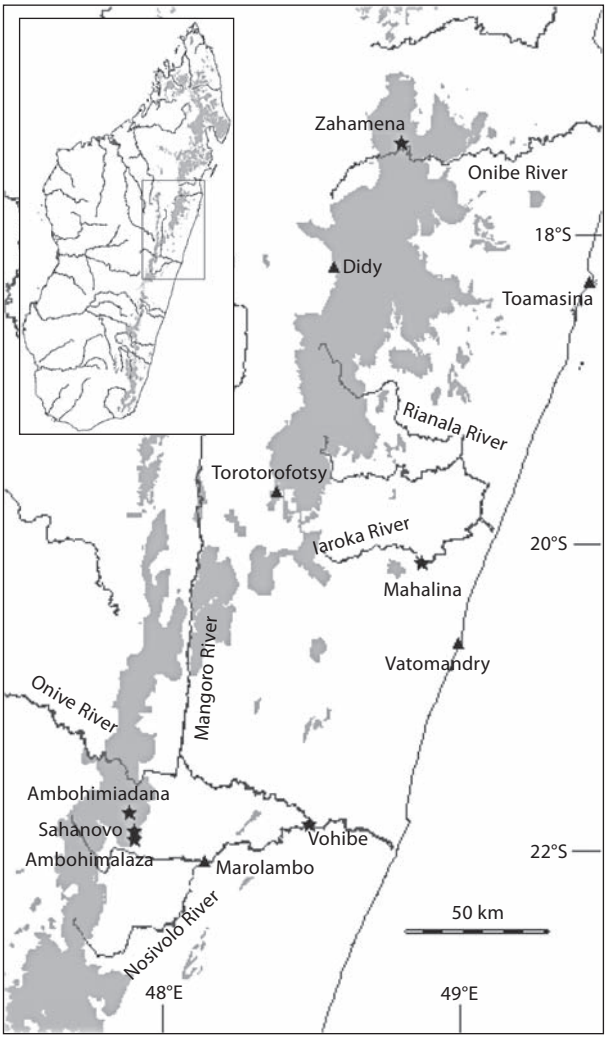

Fig. 1. Map of the study area in eastern Madagascar showing approximate forest cover (light grey), selected rivers (dark grey), survey sites (stars) and selected localities mentioned in the text (triangles).

Ambohimalaza (Rural Commune of Ambalapaiso II)

This is a mid-altitude rainforest site located just to the south of the previous sites (fig. 1) and managed since 2004 by a community association based in the village of Ambatomitsangana. One of us (B. Ramahefasoa) received information in 2010 from a village elder who confirmed the presence of *P. simus* in this forest after being shown photos of various lemur species. We surveyed this site in July 2010.

Zahamena (Rural Commune of Manakambahiny Est)

The Parc National and Réserve Naturelle Intégrale Zahamena incorporate 64,000 hectares of low- to high-altitude rainforest, located to the north of the Onibe River (fig. 1), which separates the area from the previously known most-northerly extant populations of *P. simus* located in the CAZ [Ravaloharimanitra et al., 2011]. Both protected areas are managed by Madagascar National Parks (MNP). Observations of large bamboo lemurs in the area were reported in the

Table 2. Lemur species recorded at each survey site

Site	*P. simus*	Other species
Vohibe	2 fresh and 2 old feeding signs, faeces	None
Mahalina	direct sighting of 5 individuals, plus feeding signs and faeces	*H. griseus* (faeces and 1 direct sighting)
Ambohimiadana	2 fresh feeding signs	*H.* cf. *aureus*[1] (10 fresh feeding signs), *H. griseus* (9 fresh feeding signs and 1 direct sighting)
Sahanavo	–	*H.* cf. *aureus*[1] (13 fresh feeding signs), *H. griseus* (5 fresh feeding signs), *Eulemur* sp.[2] (heard)
Ambohimalaza	1 very old feeding sign	*H.* cf. *aureus*[1] (3 fresh feeding signs)
Zahamena	2 old feeding signs, faeces	*H. occidentalis* (feeding signs and direct sighting), *Eulemur fulvus*, *Varecia variegata*, *Propithecus diadema*, *Indri indri* (all direct), *Daubentonia madagascariensis* (feeding signs)

[1] Feeding signs were identical to those of *H. aureus* in the Parc National Ranomafana, but in the absence of a direct sighting the presence of this species remains unconfirmed.

[2] *Eulemur rufifrons* based on the species distributions of the '*E. fulvus*' group given by Mittermeier et al. [2010].

1990s [Goodman and Ganzhorn, pers. commun.; Godfrey et al., 1997; Dolch et al., 2010], and during a visit in 2010 by one of us (T. Rasolofoharivelo) local MNP staff talked of bamboo lemurs larger than *Hapalemur* spp. being present around the eastern (lowland) boundary of the park. We surveyed Zahamena in September 2010, accessing the area from the southwest and therefore surveying principally mid-altitude rainforest.

Results

We found the characteristic feeding signs of *P. simus* at 5 of the 6 sites surveyed (tables 2, 3). They occurred at low altitudes in Vohibe and Mahalina (63–387 m), mid-altitudes at Ambohimalaza and Zahamena (910–937 m) and high altitudes at Ambohimiadana (1,394–1,405 m). Of a total of 11 feeding signs recorded, 8 were on large-culmed bamboo species including *V. diffusa* and *C. madagascariensis*, 2 on *Dypsys* sp. and 1 on a flower of *R. madagascariensis* (table 3). These feeding signs were fresh at Vohibe, Mahalina and Ambohimiadana, several months old at Zahamena and very old at Ambohimalaza. We found faeces at 3 sites (fig. 2), and at Mahalina we observed 1 group of at least 5 *P. simus,* which fled almost immediately, giving their characteristic alarm call.

We also found fresh feeding signs of the grey bamboo lemur *Hapalemur griseus* at Mahalina, Sahanavo and Ambohimiadana at altitudes of 80 and 1,034–1,577 m, with direct sightings at two of these sites, and we found feeding signs of the northern bamboo lemur *Hapalemur occidentalis* at Zahamena at altitudes of 815–948 m, with a single direct sighting (table 2). Additionally, at the three sites in the Marolambo

Table 3. Observations of *P. simus* made at the survey sites

Site	Observation	Plant	Coordinates	Altitude, m
Vohibe	Faeces		S19°55′32″ E48°29′11″	323
Vohibe	Fresh feeding sign	Bamboo sp. 1	S19°55′32″ E48°29′10″	354
Vohibe	Old feeding sign	Bamboo sp. 1	S19°55′23″ E48°29′04″	374
Vohibe	Old feeding sign	Bamboo sp. 1	S19°55′21″ E48°29′01″	375
Vohibe	Fresh feeding sign	*Ravenala* flower	S19°55′19″ E48°29′00″	387
Mahalina	Fresh feeding sign	Bamboo sp. 1	S19°04′15″ E48°51′23″	178
Mahalina	5 individuals		S19°04′05″ E48°51′18″	94
Mahalina	Faeces		S19°04′11″ E48°51′11″	63
Mahalina	Faeces		S19°04′16″ E48°51′24″	155
Ambohimiadana	Fresh feeding sign	Bamboo sp. 2	S19°53′27″ E47°52′50″	1,398
Ambohimiadana	Fresh feeding sign	Bamboo sp. 2	S19°53′25″ E47°52′45″	1,394
Ambohimiadana	Very old feeding sign	Bamboo sp. 2	S19°53′25″ E47°52′44″	1,405
Ambohimalaza	Very old feeding sign	Bamboo sp. 3	S19°58′37″ E47°53′34″	910
Zahamena	Old feeding sign	*Dypsys* sp.	S17°42′07″ E48°46′03″	910
Zahamena	Old feeding sign	*Dypsys* sp.	S17°42′39″ E48°46′16″	922
Zahamena	Old faeces		S17°42′38″ E48°46′17″	937

Bamboo sp. 1 = *V. diffusa;* Bamboo sp. 2 = *C. madagascariensis*; Bamboo sp. 3 = unidentified species known locally as 'Volojatsy' or 'Volo lagnana'.

Color version available online

Fig. 2. Faeces of *P. simus* from Vohibe (**a**), Mahalina (**b**) and Zahamena (**c**).

forest corridor at altitudes of 1,022–1,647 m, we observed fresh feeding signs identical to those made by the golden bamboo lemur *Hapalemur aureus* in the Parc National Ranomafana [L. Rakotonirina, pers. obs.] but made no direct sightings of this species (table 2).

We identified several anthropogenic threats at each site, which could be broadly categorised as hunting, habitat destruction, or habitat degradation (table 4). Lemur traps were particularly common at Ambohimalaza and Zahamena. Ambohimalaza also appeared to be the most threatened site through habitat destruction and degradation.

Table 4. Anthropogenic threats recorded at each survey site

	Vohibe	Mahalina	Ambohi-miadana	Sahanavo	Ambohi-malaza	Zahamena
Hunting						
Lemur traps		y			y	y
Fruit bat nets	y					
Habitat destruction						
Forest clearance for agriculture					y	
Habitat degradation						
Bamboo cutting for local use	y		y	y	y	
Selective tree cutting for local use			y	y	y	y
Illegal logging			y		y	
Illegal gold mining	y	y	y	y	y	y
Cattle grazing inside the forest	y		y	y	y	

Discussion

Distribution of P. simus

Our discovery of feeding signs of *P. simus* in the Parc National Zahamena represents a northern extension of the known extant range of the species. These new records are located 45 km north of the sites at Didy reported by Ravaloharimanitra et al. [2011] and previously considered to represent the northern distributional limit (fig. 1, 3).

The southern distributional limit of the species was also recently extended, with old feeding signs discovered near the Parc National Midongy du Sud [Rakotonirina et al., in press]. The distance between the northern Zahamena site and the southern Midongy sites is approximately 670 km, spanning several rainforest corridors. Our discovery of feeding signs at 2 sites in the forest corridor west of Marolambo, 120 km south and 140 km north of the closest previously known sites (fig. 3), suggests that there is (or at least was) a broadly continuous distribution of the species through these corridors, rather than the previously suspected distribution of two distinct southern and northern populations separated by a distance of over 200 km [Wright et al., 2009]. Within this generally continuous distribution, however, further research is required to ascertain the level of connectivity between known sites and to clarify whether, on a finer scale, the species is as patchily distributed as records suggest.

In addition to the sites within rainforest corridors, we also found feeding signs at Vohibe and Mahalina, two sites situated in a largely deforested lowland landscape, 60 and 30 km east of the remaining forest corridor, respectively (fig. 1, 3). Similar degraded or secondary forest sites supporting the species have also been found to the east of the CAZ [Ravaloharimanitra et al., 2011] and Ambositra-Vondrozo corridor [Wright et al., 2008], although none of the previously known sites is located more than 40 km from a forest corridor. The increasingly frequent discovery of *P. simus* groups in lowland deforested regions suggests that the species has a broader longitudinal distribution than previously thought, therefore significantly

Fig. 3. Map of Madagascar showing survey sites where we found evidence of *P. simus* during this study (black diamonds), previous records of *P. simus* (white diamonds), approximate rainforest cover (light grey) and large rivers (dark grey, with names for those within the range of *P. simus*). Previous *P. simus* records include those given by Meier and Rumpler [1987], Andriaholinirina et al. [2003], Wright et al. [2008], Delmore et al. [2009], Rajaonson et al. [2010], Ravaloharimanitra et al. [2011] and Rakotonirina et al. [in press].

increasing the area of its possible extant range. However, within this expanded potential range, evidence suggests that the species is very patchily distributed, and it appears to be absent from many sites supporting apparently suitable habitat and the grey bamboo lemur *H. griseus* [Rajaonson et al., 2010; Ravaloharimanitra et al., 2011]. Many of these lowland sites, therefore, appear to support small isolated populations which are unlikely to be viable and are probably at a high risk of extinction. Further research is urgently required to ascertain the true level of isolation of these lowland sites, the consequent impacts on the viability of the populations at these sites and the implications for the effective total population size of the species in the wild.

Distribution of Other Bamboo Lemurs Hapalemur *spp.*

Our observations of *H. griseus* and *H. occidentalis* are unremarkable considering their currently known distributions [Mittermeier et al., 2010]. However, our observations of feeding signs thought to be attributable to *H. aureus* at Ambohimiadana, Sahanavo and Ambohimalaza appear to corroborate a previous observation in that area and suggest a northern range extension for this species. Although these sites lie 140 km north of the nearest confirmed locality for the species in the Parc National Ranomafana, they are only 10 km east of Mt. Jangajilo, from where Lehman and Wright [2000] reported presumed feeding signs and vocalizations of *H. aureus*. Should our records be substantiated, they would almost double the known latitudinal range of the species, usually considered to incorporate the rainforest corridors from the Manampatrana River in the south to the Namorona River in the north [Rakotondravony and Razafindramahatra, 2004; Irwin et al., 2005; Mittermeier et al., 2010]. Based on our observations, we tentatively suggest that the Onive River could be considered the northern limit of the range of *H. aureus* (fig. 4). Recent observations based on an unconfirmed sighting [P. Rabeson in Delmore et al., 2009] and feeding signs [Rakotonirina et al., in press] additionally imply that the southern latitudinal range limit of *H. aureus* should be extended to or even beyond the Mananara River (fig. 4).

Contrary to *P. simus*, however, there are no reports of *H. aureus* occurring in sites outside the remaining forest corridors, and the species appears to be restricted to these corridors [Rajaonson et al., 2010]. Given that these are some of the most fragmented and threatened forest corridors in Madagascar, the viability and future survival of the species likely depend on the implementation of effective forest conservation programmes for these corridors, and *H. aureus* appears to be an ideal candidate to be regarded as a flagship species for such programmes.

Conservation Implications for P. simus

The results of our surveys contribute significantly to improving our understanding of the distribution of *P. simus*. Only 11 sites supporting *P. simus* were identified in the 21-year period from 1986 to 2007 [Wright et al., 2008]. Combined results from this study and recent similar surveys [Ravaloharimanitra et al., 2011; Rakotonirina et al., in press] have yielded over 20 new sites for this critically endangered primate in just 2 years from 2009 to 2010. This illustrates the benefits of species-focussed surveys when trying to establish the distribution of endangered species, using the methods most appropriate for finding the target taxon.

As direct sightings from many of the new sites are still scant or absent, data on abundance are lacking. Community-based monitoring has been initiated at most of the sites reported by Ravaloharimanitra et al. [2011]. This will facilitate the collection of baseline demographic and ecological data, improve local awareness of lemur and forest conservation issues and stimulate further interventions to help local community associations improve the management of their forest zones. Since numerous threats to the habitat in general, and to the *P. simus* populations in particular, exist at all sites reported in this study, we recommend that similar programmes be initiated there (although Zahamena, as a site managed by MNP rather than local communities, has a different context). Local communities at each site require educational, technical and financial assistance to address these threats; otherwise the sites and the biodiversity that they support will gradually disappear. Further sites supporting

Fig. 4. Map of Madagascar showing survey sites where we found feeding signs identical to those of *H. aureus* (black diamonds), previous records of *H. aureus* (white diamonds), approximate rainforest cover (light grey) and large rivers (dark grey, with selected names). Previous *H. aureus* records include those given by Meier and Rumpler [1987], Wright et al. [1987], Lehman and Wright [2000], Goodman et al. [2001], Arrigo-Nelson and Wright [2004], Rakotondravony and Razafindramahatra [2004], Delmore et al. [2009], Rajaonson et al. [2010] and Rakotonirina et al. [in press]. Note that records south of the Manampatrana River are considered unconfirmed [Delmore et al., 2009; Mittermeier et al., 2010; Rakotonirina et al., in press], as is the record from Jangajilo given by Lehman and Wright [2000], represented on this map by the white diamond just west of our observations.

P. simus need to be identified to build a clearer understanding of the true distribution of the species and its habitat. Connectivity between sites needs to be assessed and, where possible, assured.

The discovery in recent years of numerous new sites supporting *P. simus* has provided encouragement for the survival prospects of this species, but at the same time it has provided new challenges. The development of conservation programmes at every known site was proposed prior to the recent surveys [The Aspinall Foundation, 2008; Wright et al., 2008; King and Chamberlan, 2010]. However, if resources limit the number of sites which may benefit from conservation interventions, prioritisation of sites should be made based on objective assessments, which ideally should be consistent across the full distribution range of the species. Given that well-

focussed surveys continue to extend the known limits of the species in almost all directions, it appears that similar surveys should be continued until the true distribution is established [Dolch et al., 2010]. Ideally, research and conservation programmes should be designed for every region where new populations are being discovered. We can only attempt to estimate the greater bamboo lemur's abundance, assess its status, predict future population trends and prioritise long-term conservation interventions once we are confident that we know the real distribution of the species. In the meantime, conservation decisions regarding *P. simus* largely rely on incomplete and rapidly evolving information.

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