Population structure, activity pattern, and microhabitat use of *Phelsuma klemmeri* at Mandrozo, Madagascar

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Abstract

We carried out a research on the yellow-headed day gecko, *Phelsuma klemmeri*, in the Mandrozo protected area, a recently reported new locality for this species, to assess its population status and propose conservation measures. Visual encounter surveys and bamboo excavation along six transects provided information on population structure, daily activity patterns, and microhabitat use. A total of 93 individuals were recorded, 65 being adults, 23 immatures, and five hatchlings. Species abundance was positively correlated with the number of dead bamboo stems. The sex ratio is largely skewed in favor of males. *P. klemmeri* is a sexually dimorphic species with males being significantly larger than females. In addition, this gecko showed a bimodal pattern of activity. It would appear that thermoregulatory behavior and predation are determinant factors influencing microhabitat use. These results confirmed the importance of bamboo as a microhabitat to this gecko. Bamboo is widely harvested by villagers in this region of Madagascar, resulting in a decrease of habitat for this gecko.

Key words: activity, bamboo, microhabitat, *Phelsuma klemmeri*, Mandrozo

Résumé détaillé

Une investigation rapide de *Phelsuma klemmeri* a été menée dans sa nouvelle localité récemment reporté qui est l'Aire Protégée de Mandrozo. Cette étude a pour but d'évaluer l'état actuel de cette population afin de fournir des bases de données nécessaires pour une étude de suivi de cette espèce et de proposer des mesures appropriées pour sa conservation. Les méthodes d'observation directe et de fouille systématique des bambous le long de six transect de 10 x 100 m ont permis de mettre en exergue la structure de la population, le rythme d'activité journalière, ainsi que le mode d'utilisation du microhabitat.

Au total, 93 individus ont été recensés, le long du 600 m de transect dont 65 adultes, 23 subadultes et cinq nouvels éclos. Les résultats ont montré que la répartition spatiale de cette espèce est conditionnée par la répartition des bambous. L'abondance relative de ce gecko est aussi positivement corrélée avec le nombre de bambous morts. La sex-ratio est fortement biaisée en faveur des mâles. *Phelsuma klemmeri* possède un dimorphisme sexuel puisque les mâles sont plus grands que les femelles. En outre, son rythme circadien est en deux modes : l'animal est très actif le matin et vers l'après-midi, alors que vers le midi il réduit son rythme d'activité. Il semble par conséquent que le comportement thermorégulateur et la prédation pourraient constituer des facteurs déterminants qui influencent le mode d'utilisation du microhabitat. En effet, cette espèce a été fréquemment observée sur des bambous morts de taille variée munis de fissures. Dès qu'un danger se présente, elle s'incruste facilement à l'intérieur des fissures grâce à son corps aplati. Elle utilise également les bambous verts de grande taille pour effectuer différentes activités. En étalant son corps, ce gecko pourrait rapidement se réfugier vers le côté opposé du tronc de bambou car ce support est assez grand pour qu'il puisse se cacher des prédateurs. Tous ces points montrent l'importance des bambous comme microhabitat de ce gecko endémique de Madagascar. Dans cette région, les bambous de grande taille sont fortement récoltés par les villageois, causant une vulnérabilité importante de l'espèce étudiée.

Bien que ce site appartienne à la catégorie V du classement IUCN, il n'y a pas de conservation appropriée pour cette espèce En danger. Il y a un déclin continu de la couverture forestière dans son aire de répartition due aux activités anthropiques. En revanche, ces dernières semblent favoriser la prolifération des bambous. La transformation continue des bordures de forêts en zone d'agriculture entraine la formation des forêts de bambous. Par conséquent, *P. klemmeri* bénéficie de ce phénomène

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car cette plante constitue un habitat clé pour cette espèce de gecko.

Mots clés: activité, bambou, microhabitat, *Phelsuma klemmeri*, Mandrozo

Introduction

The day-geckos of the genus *Phelsuma* are colorful, attractive lizards and among the most popular Gekkonidae group for terrarium keepers (McKeown, 1999). The majority of *Phelsuma* spp. are endemic to Madagascar and nearby islands, including Comoros, Mascarenes, and Seychelles (Glaw & Vences, 2007; Glaw & Roesler, 2015). All *Phelsuma* spp. are listed on the CITES Appendix II. The international pet-trade has led to the introduction of this genus into several countries of the world (Meshaka, 2011).

Phelsuma klemmeri, the so-called neon day gecko or yellow-headed day gecko, is a small (body length up to 90 mm) and colorful arboreal lizard endemic to Madagascar. This species is currently assessed as Endangered by IUCN (2016) because it has an extremely restricted distribution and the population is severely fragmented, known only from two separate and highly isolated locations, which are the Ampasindava Peninsula (northwestern Madagascar) and Mandrozo (Razafimahatratra *et al*., 2008). On the Ampasindava Peninsula this species appears threatened by forest exploitation and harvesting of bamboo (Van Heygen, 2004), and from its newly documented site, the Mandrozo protected area in western dry forest, two individuals were recently reported (Razafimahatratra *et al*., 2008). Therefore, it was deemed important to assess the current population status of the Mandrozo population in order to provide baseline information on this gecko for future monitoring effort and to suggest appropriate measures for its conservation.

In this study, we aimed to determine for this species (i) the population structure, including abundance, sex ratio and, age classes, and (ii) the daily activity pattern and microhabitat use in order to identify its ecological requirements and the level of dependency on bamboo. We also provided general considerations of threats affecting this species and indications for its conservation.

Materials and methods

Study site

Mandrozo protected area is a low-altitude dry deciduous forest, located in western Madagascar (Figure 1). It is a category V protected area, following the IUCN classification, and is a Ramsar Site since 5 June 2012 (Razafimanjato *et al.*, 2012). The area is managed by The Peregrine Fund and situated at 60 km north of Maintirano, in the Melaky Region. It is administratively included within the rural communes of Tambohorano (in the west), Andranovao (in the south) and Veromanga (in the east). The protected area covers 15,145 ha of which 1800 ha is freshwater habitat (17°32'S, 44°05'E, 73 m a.s.l.). This area belongs to the ecoregion of western dry forest, and is represented by a mosaic of ecosystems: Lake Mandrozo, swamps, dry patches of dense forests, palm forests, and savannas (The Peregrine Fund, 2009). The Mandrozo dry forest is highly fragmented and forms several different blocks. The climate is characterized by a warm and sub-humid bioclimate (Koechlin *et al*., 1974) and is divided into dry season from May to October and a rainy season from October to April. The annual precipitation ranges between 500 and 2200 mm with maximum of rainfall in January. The average annual temperature is between 18 and 32° C (The Peregrine Fund, 2009).

Bamboo description and distribution

In the Mandrozo protected area, *Phelsuma klemmeri* uses the bamboo *Dendrocalamus* sp. (family Poaceae, subfamily Bambusoideae), an introduced species, as its preferred microhabitat (Razafimahatratra *et al.*, 2010). This bamboo is commonly found in areas of high humidity (Bitariho & Mosango, 2005), along forest edges, open areas or cleared land for cultivation, as well as along riverbanks. This bamboo species is characterized by straight and smooth green culms, becoming yellow when dry. This bamboo was characterized into two types:

- Green live bamboo without cracks but holes, which contain rainwater, and form phytotelms for frogs. The holes are presumably made by insects and rain probably aids in the development of insect larvae and frog tadpoles (Duckworth, 1993).
- Yellow dead bamboo with many cracks and without water that provide refuge and shelter for *P. klemmeri*.

Dendrocalamus sp. is heliophilous in nature and therefore competes for light and soil nutrients with trees in the mixed bamboo thickets (Bitariho & Mosango, 2005). This is probably the reason why its density in the mixed bamboo thickets often decreases from the periphery to deeper within the forest.

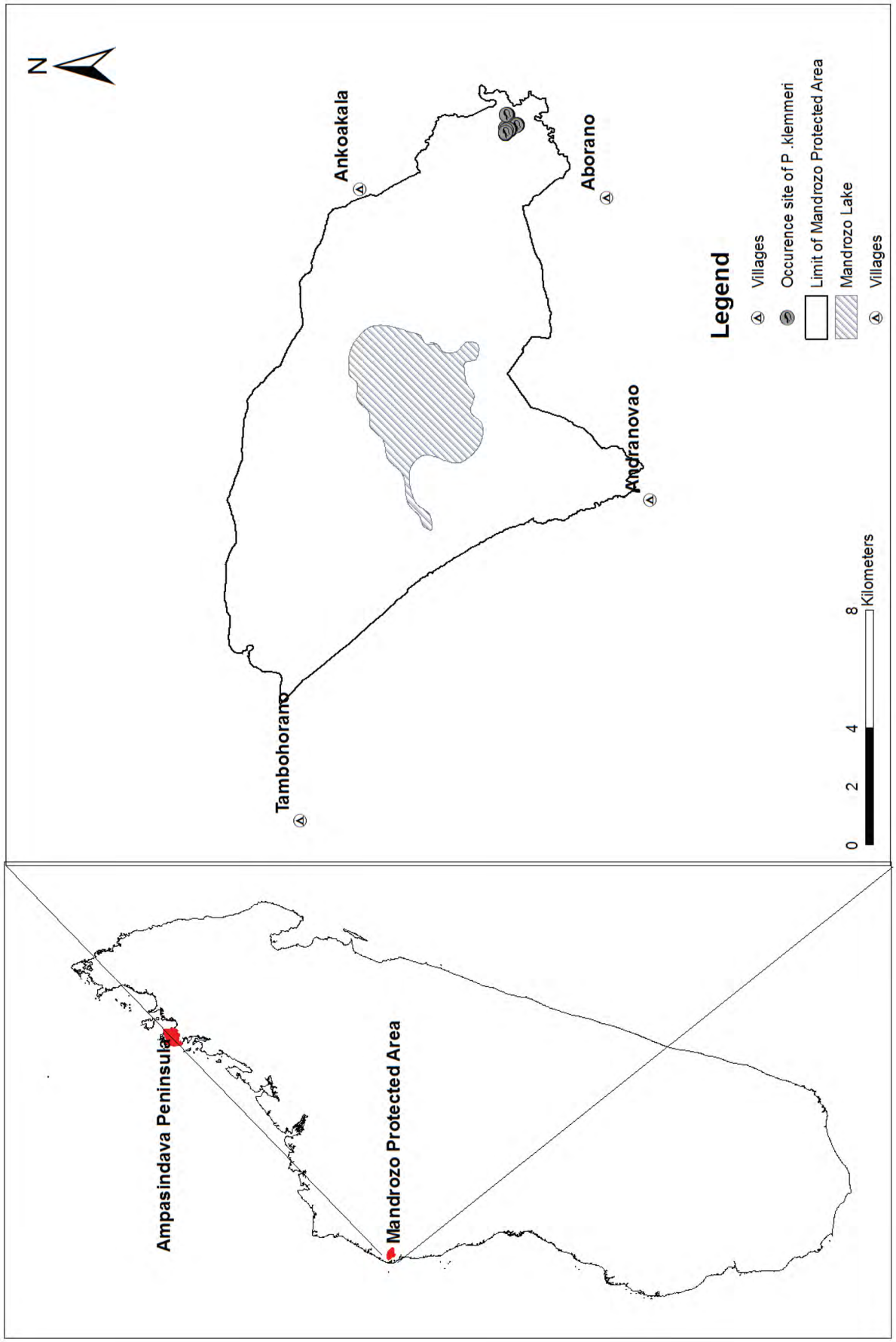

Figure 1. Location of the study area in Mandrozo protected area.

Data collection and field sampling

A survey was conducted from 18 October to 2 November 2015 in the vicinity of Androy (17°34'23,9" S, 44°11'15,5''E, 36 m.a.s.l.). Six transects of 10 x 100 m each, established from the edge to the middle of the bamboo thickets were made and surveyed bamboos were carefully checked for the presence of the gecko. Each transect was searched twice during the period this day gecko is most active: in the morning (07:30 a.m. to 11:30 a.m.) and in the afternoon (2:30 p.m. to 5:30 p.m.) by three observers. Only individuals observed within a 10 m band of habitat (5 m on each side of the transect) were recorded. When a gecko was spotted, data on activity, type of microhabitat where the gecko was initially sighted (dead or live bamboo), perch height, diameter at the breast height (DBH) of the substrate, light condition (sun or shade) of the specific site, and their size were recorded. The following measurements from each individual were taken with a dial calipers: snout-vent length (SVL), tail length (TL), and body length (BL) to the nearest 1 mm, and body mass (BM) with a balance with a precision of 0.1 g.

Activity

The activity of *Phelsuma klemmeri* was classified into three categories: (1) moving, which includes an action accompanied by a change of location such as jumping, walking, running, retreating, and hunting (including stalking bamboo flies), (2) basking, active thermoregulation**,** specifically when they were found in the sun on exposed bamboo, and (3) resting**:** when the individual remained in the same position on a shaded bamboo-trunk or inside bamboo canes.

Identification of age and sex

Three age classes were defined based on total length of the gecko and on external sexual characters. Sex was determined by the occurrence of hemipenial bulges and preanofemoral pores for males and developed extracranial endolymphatic calcium sacs for females (Glaw and Vences, 2007). The sex ratio was calculated as the proportion between males and females. Adults were those individuals with BL ≥ 70 mm, in which the external sexual characters were well-developed, immatures were those ranging in size from 30 mm ≥ BL < 70 mm (starting at 60 mm in BL, males are recognizable by not well-developed external sexual characters), hatchlings ranged in size from 22 mm ≥ BL < 30 mm.

To avoid the double counting a given individual, each gecko was painted on its dorsum when first encountered with "white non-toxic paint" and quickly released at the site of capture. To minimize disturbance, marked individuals were not recaptured. In the field, information was collected from informal interviews with local people, particularly information about threats, bamboo, and the study site.

Data analysis

All statistical analyses were performed using SPSS version 17.0 (SPSS Inc., 2008). All variables were tested for normality using Shapiro-Wilk test (Shapiro & Wilk, 1965; Royston, 1982). Non-normal variables were $\log_{10}$ transformed prior to analyses (Neter *et al*., 1996). One-way ANOVA was used to compare measurements taken from males and females (SVL, TL, BL, and BM). The diameters of bamboo and perch heights were also examined to see if these factors are related to the activity patterns of this gecko. Associations were explored between the abundance of *Phelsuma klemmeri* and the different types of bamboo using the Spearman correlation coefficient (*r*).

Results

Population structure

A total of 93 individuals were recorded and were composed of 69.9% adults, 24.7% immatures, and 5.4% hatchlings. The sex ratio (SR = 1.5) was skewed in favor of males and adult males were the most frequently found age-sex group in the population.

For the morphometric analyses, only adults for which data was recorded for SVL, TL, BL, and BM were taken into account. According to the one-way ANOVA result, body size (SVL, TL, and BL) differed significantly between sexes, but not the body mass (Table 1). *Phelsuma klemmeri* is a sexually dimorphic species with males being significantly larger than females.

Vertical movement and microhabitat use

Relationship between perch height and daily activity pattern

In the early morning (8:00 a.m to 9:00 a.m), when sunlight has not yet reached the forest floor, individuals were observed at the upper levels of bamboo canes, in search of basking sites (Figure 2), where they reach their optimal body temperature. Thereafter they usually move to lower sites either to expose themselves to sun-exposed bamboo canes,

Table 1. Morphological measurements with mean ± standard deviation of each mensuration of adult male and adult female of *Phelsuma klemmeri*. *= $p < 0.05$; N.S. = not significant with $p > 0.05$.

Sex	SVL (mm)	TL (mm)	BL (mm)	BM (g)
Male	39.2 ± 1.31	39.10 ± 3.94	78.26 ± 4.60	1.57 ± 0.26
Female	38.13 ± 1.22	36.82 ± 2.06	74,94 ± 2.55	1.55 ± 0.15
***F and P*-value**	$F_{(1,45)} = 7.33$ $p = 0.010$ *	$F_{(1,45)} = 5.35$ $p = 0.025$*	$F_{(1,45)} = 8.12$ $p = 0.007$*	$F_{(1,45)} = 0.07$ $p = 0.715$ N.S.

SVL: Snout-vent length, TL: Tail length, BL: Body length or total length and BM: Body mass

or rest on those in the shade, or within bamboo. These activities often take place between 10:00 a.m. and 2:30 p.m. Although the activity of *Phelsuma klemmeri* was significantly independent of perch height (ANOVA: $F = 1.01$; $df = 2$; $P = 0.371$; Figure 2), they usually hunt bamboo flies at lower perches.

Frequency histograms of activity were plotted for different periods during the day (Figure 3). The data is segregated into two different substrates: those within cracks in bamboo canes and those on bamboo canes. *Phelsuma klemmeri* showed a bimodal activity pattern, with peak activities in the morning between 8:30 a.m. and 9:30 a.m. and again in the late afternoon between 3:00 p.m. and 4:00 p.m. There was a reduction in activity during the hotter parts of the day (11:00 a.m.-1:30 p.m.).

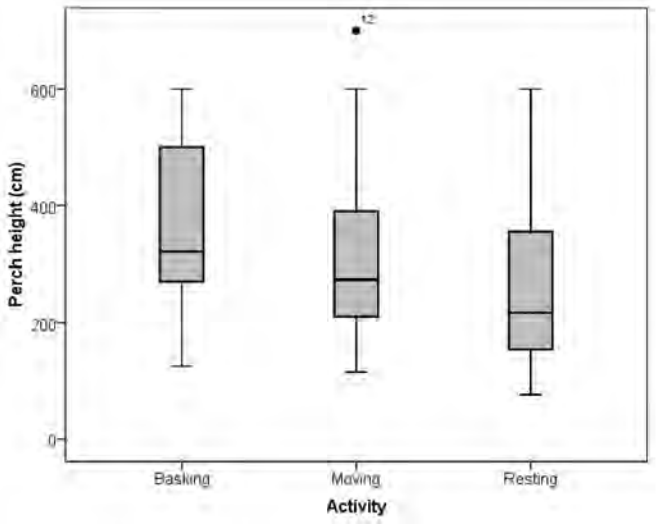

Figure 2. Perch height preference distribution of *Phelsuma klemmeri* according to their activity.

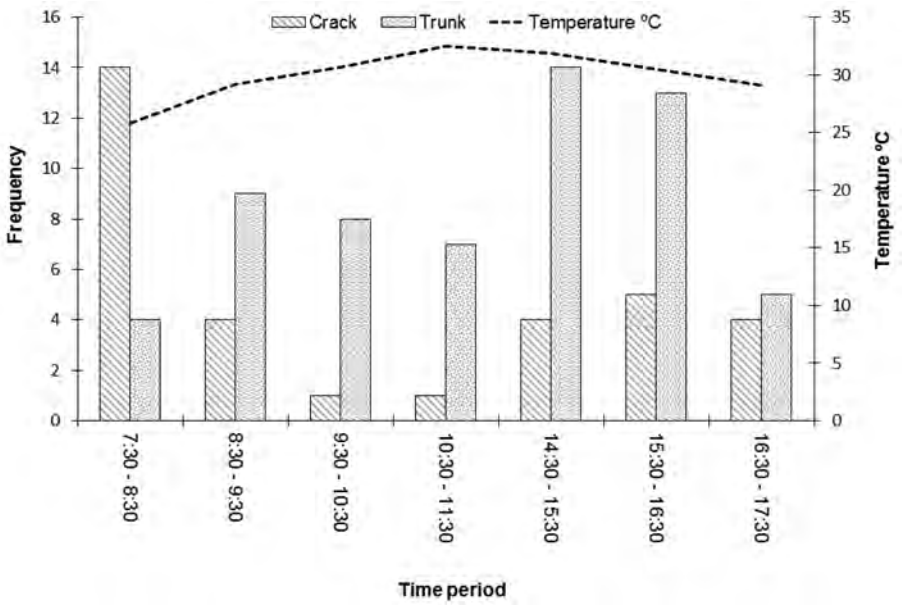

Figure 3. Daily activity pattern of *Phelsuma klemmeri*.

Relationship between diameter and nature of bamboo

Of 93 individuals observed, 55 were recorded on dead and 38 on live bamboo. Spearman correlation test showed that the abundance of *Phelsuma klemmeri* was positively correlated with the number of dead bamboo (r_s = 0.22; p = 0.034). Hence, the abundance of *P. klemmeri* was significantly greater on dead than living bamboo.

The diameter of bamboo selected by this gecko as a substrate depends significantly on the type of the bamboo (One-way ANOVA: F = 14.21; df = 1; p < 0.001). When they used dead bamboo, they selected different diameters ranging from small to large, whereas for living bamboo, they mainly used medium sized or large bamboo (≥5 cm) (Figure 4).

Threats faced by Phelsuma klemmeri *and its habitat*

Based on direct field observations and interviews of local people, the principal threat for *Phelsuma klemmeri* is mainly the loss of bamboo stands resulting from direct exploitation of bamboo for human use. This plant is widely harvested by villagers for house and fence construction. Local people also practice selective exploitation of large bamboo by cutting down their lower part, which sections between the nodes are used to collect and store liquids, such as that of the palm *Bismarckia nobilis* to produce an alcoholic drink. Selective cut of bamboo has a direct impact on *P. klemmeri*. Further, over the last decade, lowland forest at the study site has been gradually cleared for rice, tobacco, and vegetable cultivation, with a spontaneous growth of bamboo thickets in cleared areas along forest edges.

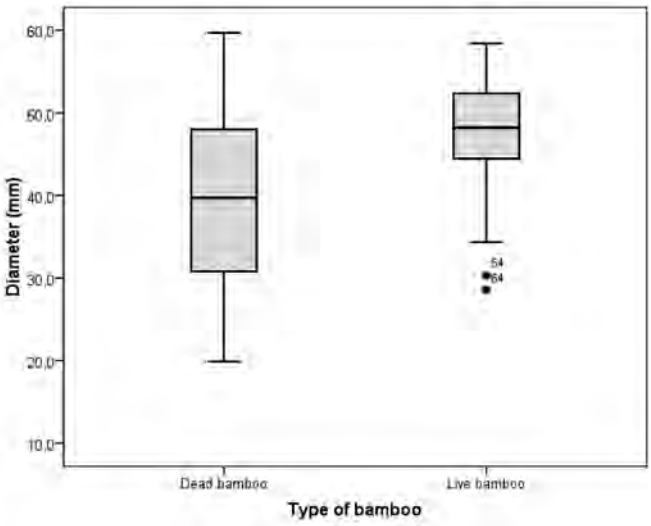

Figure 4. Box plot of the diameter of bamboo per type of bamboo used by the population of *Phelsuma klemmeri*.

Discussion

Population structure

The results of this study indicate that the population of *Phelsuma klemmeri* at Mandrozo shows a male biased sex ratio. This situation may lead to increase male-male competition associated with female sexual selection (Grant *et al*. 1995; Jones *et al*. 2004). According to Mitchel & Janzen (2010), climate change can skew the sex ratio of temperature dependent sex-determination animals and might lead to local extirpation, specifically if the temperature change resulted in a preponderance of males (Dale, 2001; Clout *et al.*, 2002). In reptiles where incubation temperature of eggs determines the sex of the hatchlings (Ferguson & Joanen, 1982), females are produced at lower temperatures. Therefore, an explanation for the skew could be that the ambient temperature in this region would promote the production of males. However, this is a supposition and further work is needed to assess this possible relationship.

On the basis of this study, with both the presence of hatchlings and immatures at different growth stages present between mid-October to early November, female *P. klemmeri* probably have an extended breeding period, including laying eggs during the dry season (August-September).

Vertical movement and microhabitat use

Possible factors that influence microhabitat use in reptiles are thermoregulatory behavior and predation avoidance (Huey, 1974; Gillis, 1991; Sanchez & Parmenter, 2002; Dias & Rocha, 2004). Regarding thermoregulatory behavior, this study indicates that *Phelsuma klemmeri* shows a bimodal activity pattern. Small geckos are highly susceptible to overheating and desiccation (Stevenson, 1985; Steinberg *et al*., 2007; Allen & Powell, 2014). This species has a small body size (up to 90 mm in BL) and seems to reduce its activity during the hottest part of the day to avoid overheating. Thus, using shaded bamboo stems or cracks, both sheltered from direct sunlight might be a tactic to avoid overheating and desiccation. Moving between sun and shade (Cowles & Bogert, 1944) in lizards is one example of behavioral thermoregulation and this may be an important factor in the use of bamboo by *P. klemmeri.*

Predation avoidance is often considered as the most important factor determining differential microhabitat use and activity patterns by many species (Lagos *et al.,* 1995; Kronfeld-Schor & Dayan, 2003). Due to its brightly colorful body and relatively small size, *P. klemmeri* might be subjected to important levels of predation. Throughout all their daily activities, they were found on medium-sized green bamboo. While exposing their bodies, when threatened these geckos could quickly retreat and hide at the opposite side of these bamboo. They also used small-to-large-sized dead bamboo with cracks and could easily retreat into the fissures when threatened. Apparently, this behavior constitutes an anti-predator strategy.

On the Ampasindava Peninsula, *P. grandis,* one of the largest *Phelsuma* spp. on Madagascar, co-occurs with *P. klemmeri*, *P. seippi* and *P. vanheygeni* in the same bamboo thickets, but no aggression was noticed towards smaller species of the genus even when they occupy the same bamboo trunk (Van Heygen, 2004). Nevertheless, *P. kochi*, another large species, can be aggressive towards *P. klemmeri* at Mandrozo. Razafimahatratra *et al*. (2010) reported that *P. kochi* lived in sympatry with *P. klemmeri* but did not occupy the same microhabitat. During this study, direct predation of *P. kochi* upon *P. klemmeri* was observed (Figure 5) and both species were often found on the same bamboo stems.

Pressure and threat

The main threat to endemic Malagasy reptiles is the loss of original habitat from different range of anthropogenic activities including severe fragmentation by fire, illegal logging, and deforestation for agriculture (Ganzhorn *et al.,* 2001; D'Cruze *et al*., 2007; Glaw & Vences, 2007; Rakotondravony, 2007). Primary forests are considered to be the

Figure 5. *Phelsuma kochi* preying upon *P. klemmeri.* (Photo by Lovasoa M.S. Rakotozafy.)

major habitat of geckos. This is not always the case regarding *Phelsuma klemmeri*. On one hand, this bamboo-dwelling species suffers from excessive exploitation of bamboo by villagers, which will likely lead to population decline of this gecko. On the other hand, the species seems to benefit from increased bamboo growth in human-modified habitats. During this study, it was noticed that bamboo thickets are denser in cleared open areas or along forest edges. This finding corroborates Van Heygen's (2004) observation that bamboo thickets are rapidly established in human disturbed areas, which in turns constitute an advantage for *P. klemmeri*. Hence, *P. klemmeri* are also distributed and more abundant in areas where bamboos are very dense.

However, in the Mandrozo protected area no particular regulation is present with respect to the exploitation of bamboo, which leads to overharvesting by local communities, and possibly creates a negative impact on the abundance of *P. klemmeri*. Conservation attention is required to protect this species in the long term.

Conclusion

This study provides the first baseline reference for future monitoring of an endangered gecko, *Phelsuma klemmeri*, in the Mandrozo protected area. This study shows that *P. klemmeri* is dependent on bamboo, which is used for shelter, hunting, basking, resting, and nesting sites. The presence of cracks in dead bamboo could be one of the key factors determining the presence of this gecko, as based on its compressed body is able to use this microhabitat. Hence, the presence and distribution of this bamboo appears to be related to relatively higher population densities of this gecko. Apart from *P. klemmeri*, other gecko species, insects and phytotelm-breeding frogs depend on this plant. This demonstrates the importance of bamboo to Madagascar's highly endemic herpetofauna for the viability of several species.

An extensive survey of non-investigated areas in Mandrozo is crucial to identify the presence of new populations of this gecko and further details on its local distribution. Genetic assessment of the *P. klemmeri* populations from the Ampasindava Peninsula, 600 km northwest of Mandrozo is needed to understand the evolutionary relationship between them.

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