Journal of Natural History

ISSN: 0022-2933 (Print) 1464-5262 (Online) Journal homepage: http://www.tandfonline.com/loi/tnah20

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To cite this article: Dan Blumgart, Julia Dolhem & Christopher J. Raxworthy (2017): Herpetological diversity across intact and modified habitats of Nosy Komba Island, Madagascar, Journal of Natural History, DOI: 10.1080/00222933.2017.1287312

To link to this article: http://dx.doi.org/10.1080/00222933.2017.1287312

Published online: 28 Feb 2017.

JOURNAL OF NATURAL HISTORY, 2017
http://dx.doi.org/10.1080/00222933.2017.1287312

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Herpetological diversity across intact and modified habitats of Nosy Komba Island, Madagascar

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ABSTRACT

A six month herpetological survey was undertaken between March and September 2015 on Nosy Komba, an island off of the north-west coast of mainland Madagascar which has undergone considerable anthropogenic modification. A total of 14 species were found that have not been previously recorded on Nosy Komba, bringing the total island diversity to 52 (41 reptiles and 11 frogs). The species assemblage, richness and abundance of four distinct habitat types were compared: closed-canopy forest, disturbed-canopy forest, shade-grown coffee plantation and mixed open plantation. The anthropogenic habitats on Nosy Komba were found to be of high conservation value for reptile species, where species richness and abundance found during surveys was equal to or higher than closed-canopy forest. By contrast, the abundance and species richness for frogs was reduced in anthropogenic habitats, especially in sun-exposed plantations. The forested areas of Nosy Komba contain twelve IUCN threatened species (9 reptiles and 3 frogs). Of these, *Uroplatus henkeli, Uroplatus ebenaui, Phelsuma seippi, Zonosaurus subuniclor, Stumpffia psologlossa* and *Stumpffia pygmaea* were also found in shade-grown coffee plantations, demonstrating the conservation value of these anthropogenic environments. Five threatened species on Nosy Komba were found exclusively in forested areas: *Brookesia minima, Brookesia ebenaui, Lygodactylus madagascariensis, Rhombophryne testudo and Thamnosophis stumpffi*. Our surveys demonstrate the importance of Nosy Komba for conserving regionally endemic and threatened species, and the often under-appreciated value of anthropogenic environments in species conservation, when also coupled with the protection of primary forest.

ARTICLE HISTORY
Received 16 August 2016
Accepted 17 January 2017

KEYWORDS
Herpetofauna; conservation; Madagascar; Nosy Komba; Sambirano

Introduction

Madagascar is a recognised global hotspot for reptile and amphibian diversity and endemism (Goodman and Benstead 2005; Wilmé et al. 2006; Jenkins et al. 2014). Almost all of the herpetofauna species in Madagascar are endemic and many are in decline; with 39% of reptile species (Jenkins et al. 2014) and 25% of frog species (Andreone et al. 2005) listed as threatened with extinction on the IUCN Red List, with

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many more species lacking sufficient data for assessment. With the growing human population and the expansion of agriculture on Madagascar, human-modified habitats are becoming a more dominant feature of the landscape (Harper et al. 2007). To prioritise conservation objectives, it is important to understand the extent to which endemic species are dependent on primary vegetation, and quantify which species can be sustained in degraded and human modified environments (Irwin et al. 2010).

The island of Nosy Komba, where this study was conducted, is situated within the Sambirano eco-region in the northwest of Madagascar. This unique biome contains elements of both the eastern rainforests and the western dry forests and experiences an intermediate rate of rainfall. The vegetation in the region consists of both evergreen forest and sclerophyllous plants that are adapted to the pronounced dry season (Andreone 2004). Annual rainfall in Nosy Be is 2250 mm with the maximum occurring in January (462 mm) and the minimum in July (37 mm) (Andreone et al. 2003). The area is known to support several threatened and range-restricted herpetofauna species, including both *Stumpffia pygmaea* – a tiny microhylid frog and *Brookesia minima* – the world's second smallest species of chameleon (Glaw et al. 2012).

Nosy Komba (coordinates: −13.468°, 48.347°, area: 2,450 ha) is 3 km south of the larger island of Nosy Be and 4 km north of Ankify, mainland Madagascar (Figure 1). The

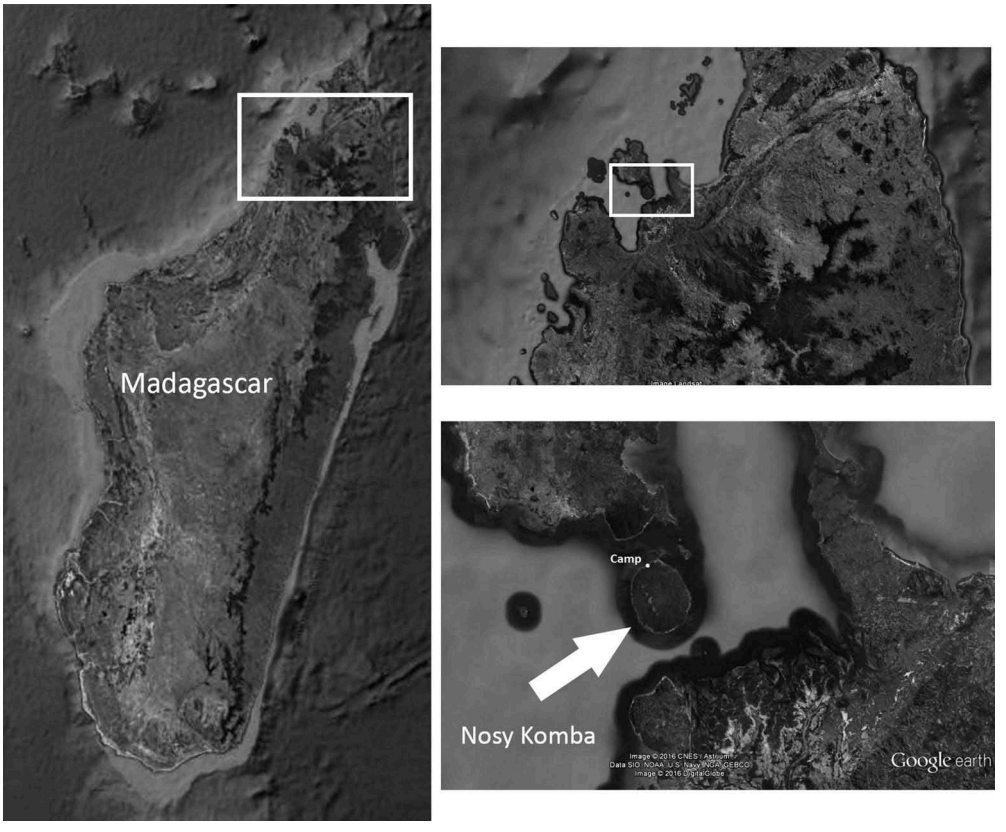

Figure 1. Map showing the location of Nosy Komba in relation to mainland Madagascar. The research camp is marked with a white dot. Map sourced from Google EarthTM. © 2016 Google, Image © 2016 CNES/Astrium Data SIO, NOAA, U.S. Navy, NGA, GEBCO, US Dept of State Geographer, Image © 2016 Digital Globe.

vegetation cover on both Nosy Komba and Nosy Be is almost completely altered by human activities with the notable exception of Lokobe National Park on Nosy Be – a 740 ha reserve which protects one of the last remaining fragments of lowland Sambirano forest. Nosy Komba is dominated by a mosaic of secondary forest, scrub, shade-grown coffee plantations, cacao plantations and mixed open plantations featuring mainly cassava, banana, pineapple, chilli and vanilla. Much of the forested areas are dominated by young Facaceae trees and non-native fruit trees such as mango and jackfruit (*Artocarpus heterophyllus*) with only small fragments of forest dominated by large indigenous trees. Additionally, on the plateau on the top of the island, there are large expanses of bamboo scrub. Currently Nosy Komba receives no recognised or legal environmental protection.

Building on the most recent herpetological survey of Nosy Komba (Roberts and Daly 2014a), the island now has 41 confirmed species of reptile (9 of which are classified as threatened) and 11 confirmed species of frog (3 of which are threatened). For comparison, a 2003 review on the Herpetofauna of Nosy Be (Andreone et al. 2003) combined with two subsequently recorded species: *Furcifer petteri* (Roberts and Daly 2014b) and *Pseudoacontias unicolor* (Sakata and Hikida 2003) and the synonymisation of *Madagascarophis colubrinus* with *M. citrinus* (Nagy et al. 2007) revealed a total of 61 herpetofauna species in Lokobe National Park (46 reptiles and 15 frogs) and a total of 76 herpetofauna species for Nosy Be as a whole (58 reptiles and 18 frogs). Lokobe National Park contains 83% of the frog species and 79% of the reptile species found on Nosy Be – with the remaining species being more generalist species that have adapted to anthropogenic environments (Andreone et al. 2003).

The aim of this study was to measure the conservation value of the human-modified habitats on Nosy Komba, based on estimates of herpetological diversity, and the presence of threatened species in these habitats. It is estimated that Nosy Be was connected to Nosy Komba and to the mainland roughly 8000–15000 years ago when sea levels were significantly lower (Colonna et al. 1996). As the herpetofauna occurring on Nosy Komba represents a subset of the more species-rich fauna on Nosy Be it is likely that the forest would have supported a similar community of species when the two islands were joined.

Methods

Between March 16th – September 9th 2015 (representing the end of the wet season and most of the dry season), we conducted 237 sampling trials of 20 minutes each. Of these, there were 205 daytime surveys and 32 night-time surveys. Surveys were conducted within measured quadrats of 20 m x 20 m in pre-chosen sites across four different habitat types (closed canopy forest, disturbed canopy forest, shade-grown coffee plantation and mixed open plantation). All survey sites were on the north side of the island within a 1.5 km radius of 13.457665°, 48.338048°, with elevations ranging from 20–505 m; with the research camp at −13.446909°, 48.336063° (see map, Figure 1).

Quadrat sites were chosen so that there were representatives of all four habitats at low (0–150 m,) medium (150 –350 m) and high (350–505 m) elevations. During the 6 months, each site was surveyed between 1 and 13 times for daytime surveys with a mean (± SD) of

4.8 (±4.6) and between 1 and 3 times for night time surveys with a mean (± SD) of 1.3 (±0.5). Survey sample sizes for the four habitat types were as follows: closed canopy forest; 52 day and 10 night surveys over 11 sites, disturbed canopy forest; 51 day and 8 night surveys over 11 sites, shade-grown coffee plantation; 51 day and 8 night surveys over 10 sites and mixed open plantation; 51 day and 6 night surveys over 10 sites.

Each survey involved a search of all micro-habitats (leaf litter, crevices in bark and rocks, understory and observable parts of the canopy) by 4–6 observers, mean (±SD) = 5.1 (±0.6) within the pre-defined quadrat. For each individual observed, the vertical height of the animal was recorded. If a specimen could not be identified in the field, it was photographed and identified later. Daytime surveys were conducted between 08:00 and 16:00, and night surveys between 19:30 and 22:50. For each survey, temperature, humidity, cloud cover and rain during the previous night/day was recorded.

Species were also recorded opportunistically (outside of timed quadrat observations) during the 6-month survey time. These observations, combined with observations within timed surveys, were used to estimate overall species richness across habitat types (see Table 1, Figures 2 and 3). For estimations of abundance, only data from the timed surveys were used – the opportunistic data were not included.

Species were identified by the authors using Glaw and Vences (2007) and difficult species were confirmed photographically by Raxworthy. We did not take any voucher specimens or conduct any genetic analysis. We based our identification of specimens on the Nosy Be species pool and assumed there were no potential candidate new species. Two species were recorded at genus level only due to difficulties in identification – these were *Paracontias sp* and an *Amphiglossus sp*.

The four habitat types were defined as follows:

Closed canopy forest – Areas where the canopy is continuous within at least a 20 x 20 m area. The canopy is of a height between 15 and 25 m. Dominant trees are mostly native non-cultivated species but can include mango and jackfruit. The leaf-litter is deep and there is very little light reaching the forest floor.

Disturbed canopy forest – The canopy height is <15 m with significant gaps. Dominant trees are usually mango, jackfruit and young Fabacaea trees. Understory can include cultivated coffee, pineapple, chilli, black pepper and vanilla.

Shade-grown coffee plantation – Coffee trees are the dominant tree forming a canopy of roughly 5 m. Medium to large isolated trees are present and provide shade (usually Fabacaea trees but can also include other native trees such as *Dypsis* or *Ravenala* and non-native trees such as mango and jackfruit). The plantations usually also contain pineapple, vanilla and pepper.

Open plantation – No canopy but sometimes isolated large trees and palms. Dominant plants include cultivated banana, pineapple, chilli, cassava and sugar cane with areas of self-seeded grasses and forbs. The leaf-litter is generally thin and dry with areas of exposed dry soil and rock.

Statistical analysis

Data was analysed using the statistics package R (version i386 3.1.0). Where possible, data was normalised using a log + 1 transformation. In these cases a one-way ANOVA

Table 1. Species encountered on Nosy Komba across 4 habitat types during both timed surveys and opportunistic observations between March and September 2015. + = encountered, – = not encountered. Highlighted species are classified as Threatened on the IUCN Red List (IUCN 2017). LC = least concern, VU = vulnerable, EN = endangered, NT = near threatened, NE = not evaluated. * = Not previously recorded on Nosy Komba. † = Found only on coastal rocks and not in one of the 4 habitat types. ‡ = Found only once in June 2016 at the mouth of a stream by the coast.

		Found from March – September 2015				
	Previously recorded on Nosy Komba	Closed canopy forest	Disturbed canopy forest	Shade-grown coffee plantation	Open plantation	IUCN rating
AMPHIBIANS						
HYPEROLIIDAE						
Heterixalus tricolor	+	-	-	-	-	LC
MICROHYLIDAE						
Rhombophryne testudo	+	+	+	-	-	EN
Stumpffia pygmaea	+	+	+	+	+	EN
Stumpffia psologlossa*	-	+	+	+	+	EN
Cophyla phyllodactyla	+	+	+	+	+	LC
MANTELLIDAE						
Boophis tephraeomystax	+	-	+	+	+	LC
Blommersia wittei	+	+	+	-	-	LC
Mantella ebenaui	+	+	+	+	+	LC
Gephyromantis pseudoasper	+	+	+	+	-	LC
Gephyromantis granulatus*	-	-	-	+	-	LC
Mantidactylus ulcerosus	+	+	+	+	+	LC
Total (out of 11)	9	8	9	8	6	
REPTILES						
CHAMAELEONIDAE						
Brookesia ebenaui*	-	+	+	-	-	VU
Brookesia minima	+	+	+	-	-	EN
Brookesia stumpffi	+	+	+	+	+	LC
Calumma boettgeri	+	+	+	+	+	LC
Calumma nasutum	+	-	+	+	-	LC
Furcifer pardalis	+	+	+	+	+	LC
GECKONIDAE						
Ebenavia inunguis	+	+	+	+	-	LC
Geckolepis maculata	+	+	+	+	+	LC
Hemidactylus frenatus*	-	-	-	-	+	LC
Hemidactylus mercatorius*	-	-	-	-	+	LC
Hemidactylus platycephalus	+	+	+	+	+	LC
Lygodactylus madagascariensis	+	+	+	-	-	VU
Paroedura oviceps	+	-	+	-	-	NT
Paroedura stumpffi	+	+	+	+	+	LC
Phelsuma abbotti	+	+	+	+	+	LC
Phelsuma dubia	+	-	-	-	-	LC
Phelsuma laticauda	+	-	+	+	+	LC
Phelsuma grandis	+	+	+	+	+	LC
Phelsuma quadriocellata	+	-	-	+	+	LC
Phelsuma seippi	+	+	+	+	-	EN
Uroplatus ebenaui	+	+	+	+	-	VU
Uroplatus henkeli	+	+	+	+	-	VU

(*Continued*)

Table1. (Continued).

	Previously recorded on Nosy Komba	Found from March – September 2015				IUCN rating
		Closed canopy forest	Disturbed canopy forest	Shade-grown coffee plantation	Open plantation	
GERRHOSAURIDAE						
Zonosaurus madagascariensis	+	+	+	+	+	LC
Zonosaurus subunicolor	+	+	+	+	+	EN
SCINCIDAE						
Amphiglossus mandokava‡	-	-	-	-	-	VU
Amphiglossus sp*	-	-	+	-	-	-
Paracontias sp*	-	-	+	-	-	-
Cryptoblepharus boutonii†	+	-	-	-	-	NE
Madascincus stumpffi*	-	-	+	-	+	NT
Trachylepis gravenhorstii	+	+	+	+	+	LC
BOIDAE						
Sanzinia madagascariensis	+	+	-	+	-	LC
Acrantophis madagascariensis*	-	-	+	-	-	LC
TYPHLOPIDAE						
Indotyphlops braminus*	-	-	+	+	-	NE
COLUBRIDAE						
Pseudoxyrhopus microps*	-	+	-	-	-	LC
Thamnosophis stumpffi*	-	+	+	-	-	VU
Dromicodryas quadrilineatus	+	-	+	+	+	LC
Ithycyphus miniatus	+	-	+	-	+	LC
Leioheterodon madagascariensis	+	+	+	+	+	LC
Liophidium torquatum*	-	-	+	-	-	LC
Madagascarophis colubrinus	+	+	+	+	+	LC
Lycodryas granuliceps	+	+	+	-	-	LC
Total (out of 41)	30	24	33	23	20	
Total herpetofauna species (out of 52)	39	32	42	31	26	

test was used to test for significant differences between groups. Where data could not be normalised, a non-parametric Kruskal-Wallis test was used instead.

Results

A total of 2,343 individuals of 41 species were recorded over the course of 237 surveys. For daytime surveys, 2,041 individuals of 34 species were recorded during 205 surveys and for night-time surveys, 302 individuals of 28 species were recorded during 32 surveys. The following species were also encountered by us on Nosy Komba but not within the timed

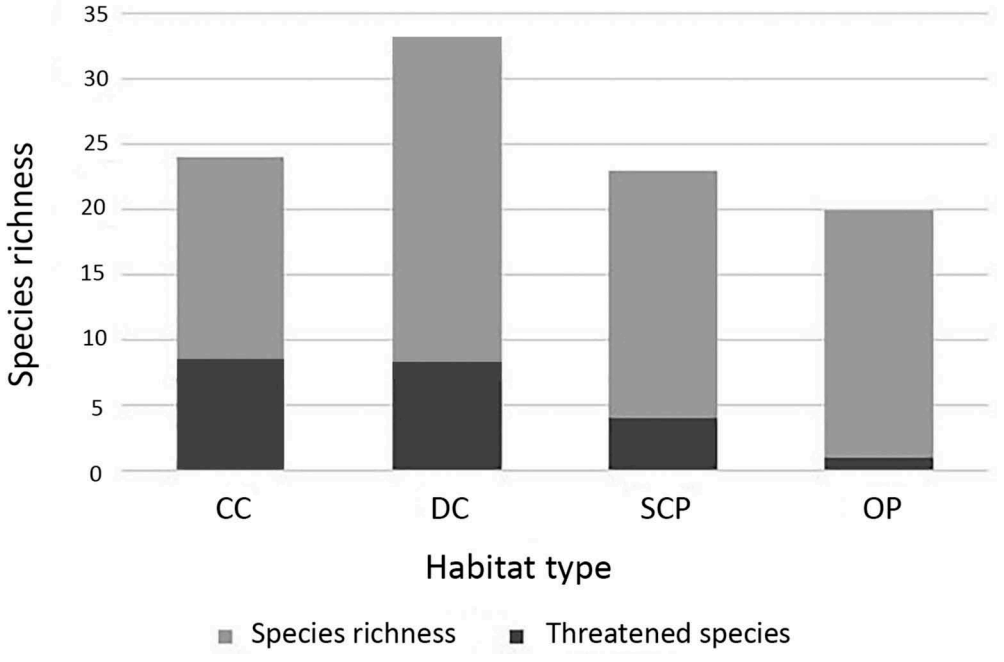

Figure 2. Reptile species richness in different habitats including all species encountered both within timed surveys and opportunistic sightings. Darker bars represent the proportion of species classified as Threatened on the IUCN Red List. Habitat types are as follows: CC = closed canopy forest, DC = disturbed canopy forest, SCP = shade-grown coffee plantation, OP = open plantation.

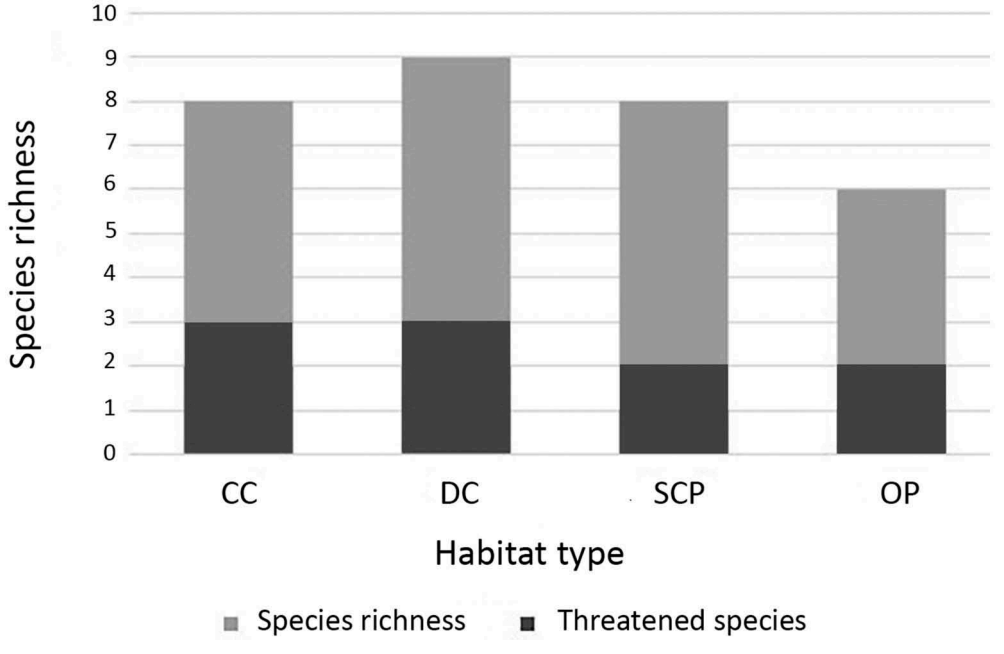

Figure 3. Amphibian species richness in different habitats including all species encountered both within timed surveys and opportunistic sightings. Darker bars represent the proportion of species classified as Threatened on the IUCN Red List. Habitat types are as follows: CC = closed canopy forest, DC = disturbed canopy forest, SCP = shade-grown coffee plantation, OP = open plantation.

surveys. Reptiles: *Acrantophis madagascariensis, Amphiglossus mandokava, Amphiglossus sp, Cryptoblepharus boutonii, Hemidactylus frenatus, Paracontias sp and Sanzinia madagascariensis*. Amphibians: *Blommersia wittei, Gephyromantis granulatus and Gephyromantis pseudoasper*.

We encountered 14 species that had not previously been recorded on Nosy Komba (12 reptiles and 2 frogs). These were the frogs: *Gephyromantis granulatus and Stumpffia psologlossa*, and the reptiles: *Acrantophis madagascariensis, Amphiglossus mandokava, Amphiglossus sp, Brookesia ebenaui, Hemidactylus frenatus, Hemidactylus mercatorius, Liophidium torquatum, Madascincus stumpffi, Paracontias sp, Pseudoxyrhopus microps, Indotyphlops braminus* and *Thamnosophis stumpffi* (Figures 4 and 5). Four of these species are listed as Threatened on the IUCN Red List: *A. mandokava* (Vulnerable), *B. ebenaui* (Vulnerable), *S. psologlossa* (Endangered) and *T. stumpffi* (Vulnerable). The snake *I. braminus* is unevaluated. All the others are listed as Least Concern.

Species richness

The highest number of species encountered was in disturbed canopy forest (42 species) and the lowest number of species were encountered in open plantations (26 species) – see Table 1, Figures 2 and 3. Overall, we found 12 threatened species (9 reptiles and 3 frogs) including 6 Endangered species (3 reptiles and 3 frogs) and 6 Vulnerable species (all reptiles). We also found 2 Near-Threatened species: *Madascincus stumpffi* and *Paroedura oviceps*. All of the threatened species were encountered in forest habitats apart from *Amphiglossus mandokava* which was encountered only once by a stream in highly disturbed habitat. We encountered 6 threatened species in shade-grown coffee plantations (4 reptiles and 2 frogs). Open plantations contained the least number of threatened species (3 species: *Zonosaurus subunicolor, Stumpffia psologlossa and Stumpffia pygmaea*). During the survey period we also encountered two individuals of *Paracontias* sp. and one individual of *Amphiglossus* sp. that could not be identified.

Reptile abundance

Daytime surveys: Reptile abundance differed significantly across habitat types (one-way ANOVA, $F_{3,\ 201} = 45.05$, $p > 0.001$), with a higher abundance in more altered habitats – the highest abundance was found in open plantations and the lowest in closed-canopy forest (see Figure 6(a)). Night-time surveys: Habitat type was found to have no effect on either reptile abundance (one-way ANOVA, $F_{3,\ 28} = 0.60$, $p = 0.62$), see Figure 6(b).

Frog abundance

Daytime surveys: Frog abundance differed significantly across habitats (Kruskal-Wallis test, $X^2 = 20.01$, $df = 3$, $p > 0.001$) – with a lower abundance in more altered habitats and an especially low abundance in open plantations (see Figure 7(a)). Night-time surveys: Habitat type was found to have no effect either on frog abundance (Kruskal-Wallis test, $X^2 = 2.28$, $df = 3$, $p > 0.516$) Kruskal-Wallis test, $X^2 = 2.40$, $df = 3$, $p > 0.498$), see Figure 7(b).

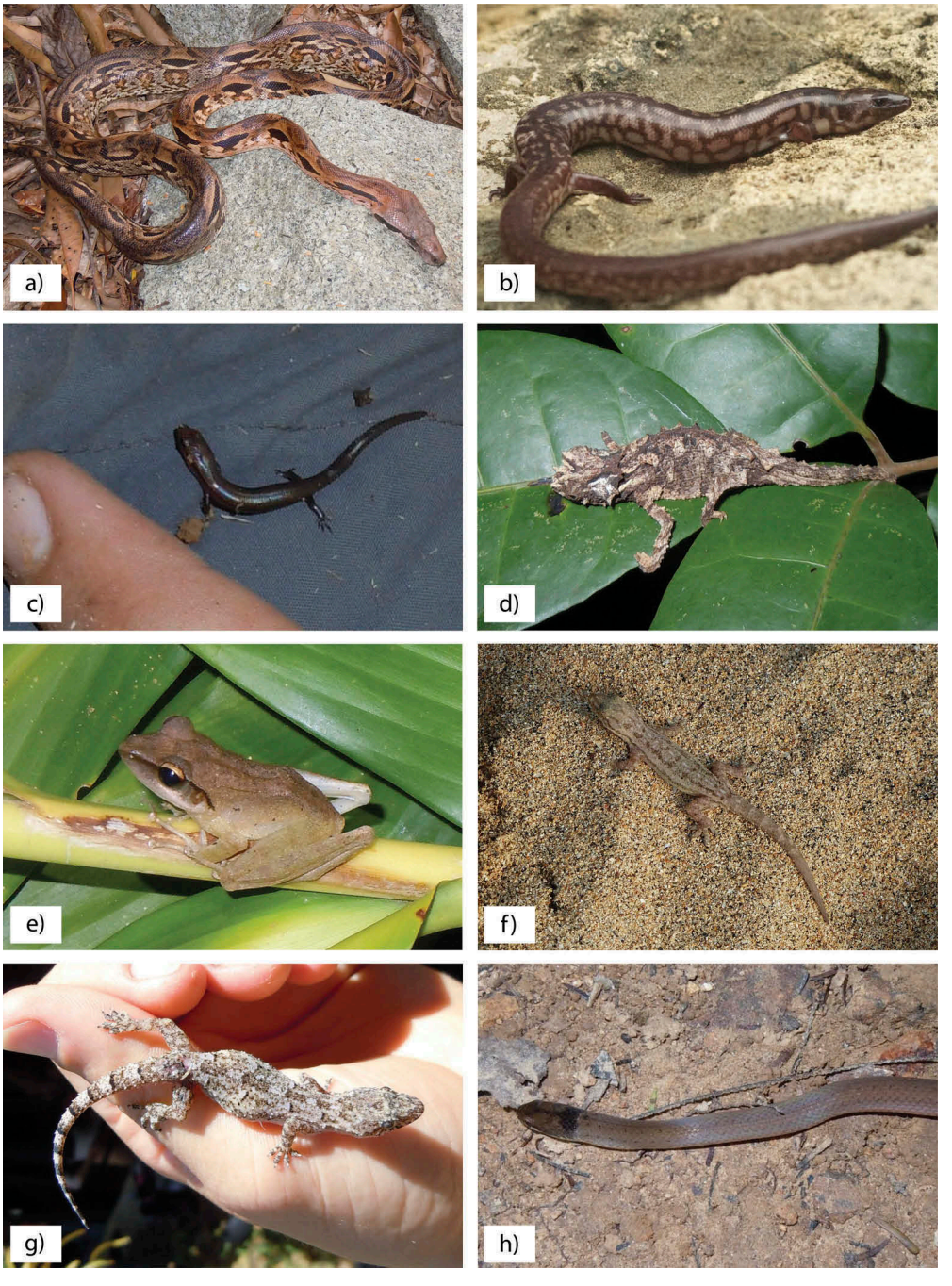

Figure 4. Newly recorded species on Nosy Komba: (a) *Acrantophis madagascariensis*, (b) *Amphiglossus mandokava*, (c) *Amphiglossus sp.*, (d) *Brookesia ebenaui*, (e) *Gephyromantis granulatus*, (f) *Hemidactylus frenatus*, (g) *Hemidactylus mercatorius*, (h) *Liophidium torquatum*.

Figure 5. Newly recorded species on Nosy Komba: (a) *Indotyphlops braminus*, (b) *Indotyphlops braminus* detail, (c) *Madascincus stumpffi*, (d) *Pseudoxyrhopus microps*, (e) *Paracontias sp*., (f) *Paracontias sp*. detail, (g) *Thamnosophis stumpffi*, (h) *Stumpffia psologlossa*.

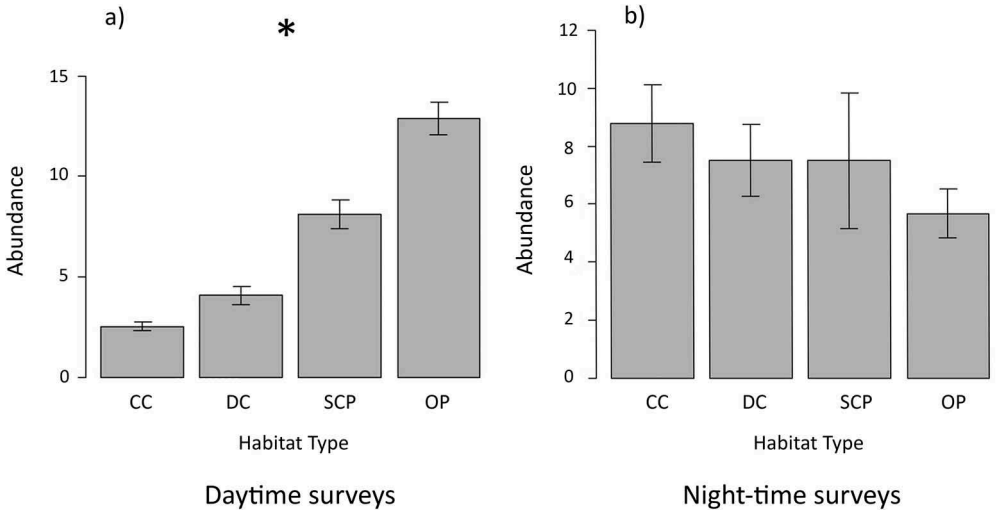

Figure 6. Reptile abundance during daytime surveys (a: n = 205) and night-time surveys (b: n = 32). Bars show standard error. Abundance was measured in individuals encountered per 20 minute survey conducted within a 20 x 20 m quadrant. Habitat types are as follows: CC = closed canopy forest, DC = disturbed canopy forest, SCP = shade-grown coffee plantation, OP = open plantation. Figures marked with * were found to be statistically significant ($p < 0.05$).

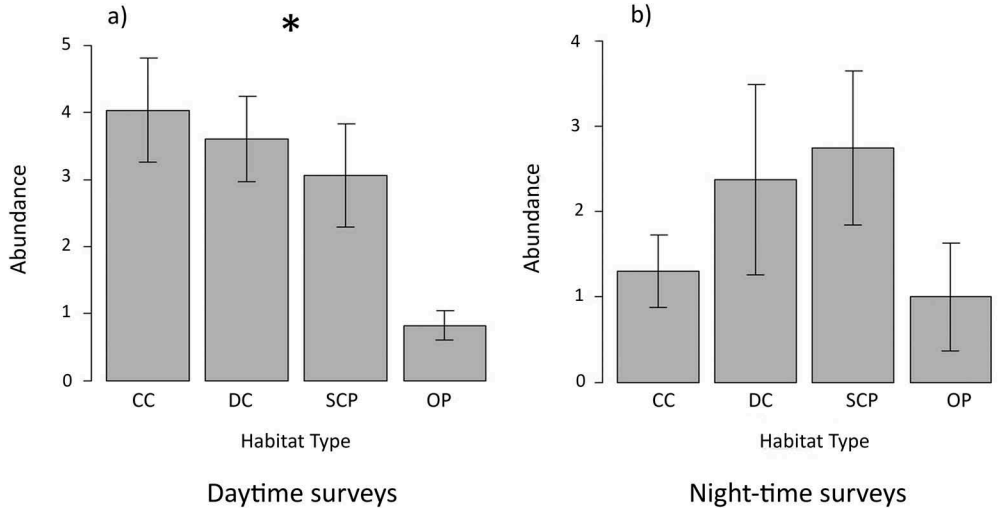

Figure 7. Amphibian abundance during daytime surveys (a: n = 205) and night-time surveys (b: n = 32). Bars show standard error. Abundance was measured in individuals encountered per 20 minute survey conducted within a 20 x 20 m quadrant. Habitat types are as follows: CC = closed canopy forest, DC = disturbed canopy forest, SCP = shade-grown coffee plantation, OP = open plantation. Figures marked with * were found to be statistically significant ($p < 0.05$).

Discussion

Nosy Komba has a surprisingly diverse herpetofauna, especially considering its small size, and the anthropogenic impact on its natural habitats. Our results show that Nosy Komba contains 68% of the herpetofaunal species found on neighbouring Nosy Be, yet its size is only 10% of that of the larger island (Nosy Be = 25,200 ha, Nosy Komba = 2,450 ha). Nosy Komba has 61% of Nosy Be's frog species (11 compared to 18) and 71% of reptile species (41 compared to 58). The only species found on Nosy Komba that has not been recorded on Nosy Be was *Amphiglossus mandokava*. It was found only once, in June 2016 after heavy rains by the side of a stream next to the coast at the research camp. The individual was perched on a rock in the shade at 6:30am (see Figure 4(b)) and was in an area of highly modified habitat and sparse tree-cover. This rarely found species is endemic to the far north of Madagascar and is associated with undisturbed humid forest (Raxworthy 2011). It is possible that the heavy rains during the night washed the individual down from more intact forest higher up the island. Its presence on Nosy Komba suggests it may yet be undiscovered in Lokobe National Park. Apart from *A. mandokava*, there were no other species found on Nosy Komba that were not present on Nosy Be.

There are 27 species on Nosy Be that were not found on Nosy Komba. These are: the frogs *Hoplobatrachus tigerinus, Ptychadena mascareniensis, Boophis brachychir**, Boophis jaegeri***, Gephyromantis horridus**, Cophyla milloti**** and *Cophyla occultans***, and reptiles: *Crocodylus niloticus, Furcifer petteri**, Gehyra mutilata, Lygoodactylus heterurus, Zonosaurus boettgeri**, Zonosaurus rufipes*, Paracontias hildebranti, Pseudoacontias unicolor***, *Trachylepis lavarambo**, Amphiglossus elongates*, one unknown *Amphiglossus* species, *Typhlops madagascariensis, Typhlops mucronatus, Typhlops reuteri*, one unkown *Typhlops* species, *Alluaudina bellyi, Dromicodryas bernieri, Langaha madagascariensis, Micropisthodon ochraceus* and *Pararhadinaea melanogaster***. Of these, 11 species are listed as either Near Threatened (marked *), Vulnerable (**) or Endangered (***). All these threatened species are associated with intact forest habitat and several of them are quite rare. This may help explain why they are absent from the highly modified habitats of Nosy Komba. It is likely that before human influence, Nosy Komba would have supported a higher proportion of the species present on Nosy Be.

There were also some widespread generalist species found on Nosy Be that were absent from Nosy Komba. The crocodile *C. niloticus* and the freshwater turtle *P. castanoides* are most likely absent due to the lack of any large bodies of fresh water on Nosy Komba. The frogs *H. tigerinus* and *P. mascareniensis* are associated with wetland habitats and rice paddies which are also absent from Nosy Komba. The *Typhlops* and *Amphiglossus* species are small and elusive and it is possible that some of these species could have been missed during surveys.

There were two species recorded from Nosy Komba (Roberts and Daly 2014a) that we did not encounter – these were the gecko *Phelsuma dubia* and the frog *Heterixalus tricolor*. *H. tricolor* breeds in permanent or temporary standing water so the absence of this species in our surveys could be because the majority of our study took place in the dry season when this species is less likely to be active. The apparent rarity of *Phelsuma dubia* on Nosy Komba is curious as it is common in buildings and degraded areas on Nosy Be (Andreone et al. 2003 and personal obs.).

The value of man-made environments is often overlooked in discussion of conservation. Shade-grown plantations of tropical tree species such as coffee (Rappole et al. 2003) and cacao (Wanger et al. 2009) have been shown to support a high diversity of herpetofauna species, especially when considered next to more intensive forms of agriculture (Brokerhoff et al 2008). On Nosy Komba, we have found that low-intensity coffee plantations have a high abundance and diversity of herpetofauna and are utilised to varying extents by six threatened species: the leaf-tailed geckos *Uroplatus henkeli* and *Uroplatus ebenaui*, the day gecko *Phelsuma seippi*, the plated lizard *Zonosaurus subuniclor* and the frogs *Stumpffia psologlossa* and *Stumpffia pygmaea*. While *S psologlossa, S. pygmaea* and *Z. unicolor* were regularly encountered in plantation habitats, *U. ebenaui* and *P. seippi* were rarely found outside of forest habitats. *U. henkeli* was encountered only once in a coffee plantation (a juvenile individual) and was not found in open plantations. For comparison, this same species was reliably found on every nocturnal survey in closed canopy forest. This suggests that *U. henkeli* may be unlikely to persist in large coffee plantations without interspersed areas of forest.

When considering the high diversity found in coffee plantations, it should be noted that the land-use pattern on Nosy Komba is highly heterogeneous, where coffee plantations are interspersed with disturbed forest, open plantations and small patches of mature forest. Each habitat type is likely to be affected by edge effects and by adjacency to other habitat types. Edge effects and neighbouring habitats have been noted as a confounding factor when assessing the value of anthropogenic habitats (Barlow et al. 2007). With this in mind, it cannot be assumed that more extensive areas of shade-grown coffee can continue to support the diversity that we currently find here. It could be that the species assemblage found in coffee plantations is at least partly dependent on spill-over from adjoining forest habitats (E.g., Lucey and Hill 2012). Furthermore, there is evidence that local extinction of a species can occur with a substantial delay after habitat degradation has occurred (Krauss et al. 2010). The fragmentation of high-quality habitats is also known to effect species assemblage. For example, Riemann et al. (2015) found that Malagasy frog species richness in small forest fragments was similar to that in large contiguous forest, but the community composition was altered and many species present in contiguous forest were absent in forest fragments. It is important therefore to monitor the populations of species Nosy Komba over a long time-series to assess the true conservation value of coffee plantations and other degraded habitats on the island.

Although plantation forests can provide biodiversity benefits by acting as dispersal corridors between forest remnants (Brockerhoff et al. 2008), the value of mature or primary forests is widely agreed to be irreplaceable (Barlow et al. 2007; Gibson et al. 2011). Our study suggests that there are several species dependent on forest habitat. Two of these, the chameleons *Brookesia ebenaui* and *Brookesia minima* are regional endemics, with *B. ebenaui* only being present in the far north and *B. minima* in the far north-west of Madagascar. The forest areas Nosy Komba therefore represent an important remaining habitat for these threatened species.

During our standardised time-constrained surveys, we found that reptile abundance was especially high in shade-grown coffee plantations and open plantations during the day and was consistently greater than that found in forested areas of Nosy Komba. However, it should be noted that the majority of species found in the highly modified areas are widespread, generalist species, usually of a Least Concern rating on the IUCN

Red List. Our findings corroborate with other studies that have found that communities in degraded habitats become dominated by widespread, generalist species (Barlow et al. 2007, Irwin et al. 2010). Frog abundance and species richness was similar across the two forest habitat types, slightly reduced in coffee plantations but was greatly reduced in open plantations. Of the three threatened species of frog on Nosy Komba (*Rhombophryne testudo, Stumpffia psologlossa* and *Stumpffia pygmaea*), only *S. pygmaea* and *S. psologlossa* were found outside of forested areas and at reduced densities. The only threatened species of reptile found in open plantations was *Zonosaurus subunicolor* (Endangered) which was encountered at a lower rate in comparison to forest habitats. Night-time surveys revealed a more equal distribution of reptile abundance and diversity across habitat types.

Of the twelve threatened species found on Nosy Komba, six of them were found at least once in the shade-grown coffee plantations – these were; *Phelsuma seippi, Stumpffia psologlossa, Stumpffia pygmaea, Uroplatus ebenaui, Uroplatus henkeli* and *Zonosaurus subunicolor*. Although the abundance was lower in coffee plantations in comparison to forested areas, this demonstrates that highly modified woody environments are still valuable in the conservation of threatened species. However, five of the threatened species; *Brookesia ebenaui, Brookesia minima, Lygodactylus madagascariensis, Rhombophryne testudo* and *Thamnosophis stumpffi* were found exclusively in forested areas.

Limitations of the quadrat surveys

Species abundance

Despite our standardised methods of sampling across the habitat types using quadrats, there were differences in the habitats that may have biased our results towards finding a higher abundance in plantation areas. Firstly, plantations are structurally less complex than forest areas. The forest areas we sampled had a deeper and more extensive leaf litter, more dead wood and a thicker understory for animals to conceal themselves in. Secondly, the type of herpetofauna found in open areas tended to be more active and more brightly coloured than those found in forest areas. Reptiles most common in plantations included the highly visible geckos from the genus *Phelsuma*, the skink *Trachylepis gravenhorstii* and the plated lizard *Zonosaurus madagascariensis* which all rest in exposed places and run away conspicuously when disturbed. In contrast, species more common in forested areas include the highly localised but abundant frog *Stumpffia pygmaea*, and the pygmy leaf chameleon *Brookesia stumpffi* which is ground-dwelling, highly camouflaged and slow-moving. *Brookesia stumpffi* are much easier to find sleeping at night when they climb onto a leaf 10–50 cm above the ground and become pale. During our day-time surveys of closed-canopy forest on Nosy Komba we found an average of 0.25 *B. stumpffi* per 20 minute survey; but at night in the same areas, we found an average of 3.3. This means that in this location, using these survey techniques, *B. stumpffi* were over 13 times more detectable at night. It can therefore be assumed that there are many individuals within the quadrats going undetected during surveys. In addition to this, it is difficult to sample forest that is over 4–6 m in height. As all our surveys were conducted from ground level, it is likely that individuals in the canopy will be overlooked.

Species richness

It is likely that species richness has been underestimated for closed canopy forest in comparison to other habitat types. The vegetation cover on Nosy Komba is predominantly disturbed forest and coffee plantations. As a result, we spent the most time travelling through these habitat types on route to our sample quadrats and we rarely passed through closed canopy forest, so the likelihood of casually encountering species in disturbed habitats was much greater. As the number of species detected is dependent on sampling effort (Gotelli and Colwell 2001) it follows that we have probably encountered a higher proportion of the total species present in disturbed forest and coffee plantations in comparison to closed canopy forest.

It is possible that the herpetological species list for Nosy Komba is still incomplete. As our surveys were almost entirely conducted on the north side of the island, there may be species that are concentrated on the south side that were not encountered. Furthermore, there may be canopy-dwelling species such as *Zonosaurus boettgeri* that were not detected due to a lack of searching in the canopy layer. There may also be species most active in the rainy season that were not detected as our surveys took place largely in the dry season. A more spatially and temporally thorough survey of Nosy Komba may yet reveal more species.

Conservation

Although mango and jackfruit are not native to Madagascar, they are often the dominant trees in the remaining forested areas on Nosy Komba. These trees provide abundant fruit and therefore an incentive to the local people to leave them standing. These semi-natural forests were found to be of a higher conservation value than plantation areas in terms of overall species richness and the presence of threatened species. We found that open, sun-exposed plantations contained the least number of species overall, especially threatened species. The main crops grown in these areas were cassava, banana and pineapple. Although pineapple and banana plants did often host species such as the day-gecko *Phelsuma laticauda* and the nocturnal frog *Cophylla phyllodacyla* which spent the day hidden within the plants, there were no species utilising cassava plants. Shade-grown coffee plantations hosted a more diverse range of species; overall we encountered almost as many species in coffee plantations as we did in closed-canopy forest (31 and 32 species respectively), although these plantation areas were utilised less by threatened species (6 species) in comparison to closed-canopy forest where we found 11 threatened species.

During our 6 month survey on Nosy Komba we witnessed a slow encroachment of plantations into forested areas – with the understory of the forest first being cleared and then larger trees being felled later. In established coffee and cacao plantations large shade-providing trees were sometimes felled and often used for the construction of dug-out canoes. With only one small traditionally protected area on the island, Nosy Komba is at threat of losing several of its most threatened and charismatic species. The species most at threat are those that were not encountered outside of forested areas: *Acrantophis madagascariensis, Blommersia wittei, Brookesia ebenaui, Brookesia minima, Liophidium torquatum, Lycodryas granuliceps, Lygodactylus madagascariensis, Madascincus*

stumpffi, Paroedura oviceps, Pseudoxyrhopus microps, Rhombophryne testudo, Thamnosophis stumpffi and *Uroplatus henkeli* which was encountered only once outside of forest habitat. However, it is evident that the conservation value of shade-grown coffee plantations should not be overlooked. With observations of six threatened species and a relatively high abundance and species richness of both frogs and reptiles these semi-natural habitats are an important aspect of conservation on Nosy Komba. The areas of lowest conservation value are the open sun-exposed plantations.

Conclusions

Considering its small size, Nosy Komba maintains an extremely rich reptile and amphibian community. It also represents a valuable remaining habitat for threatened range-restricted species such as the frogs *Rhombophryne testudo, Stumpffia pygmaea*, the chameleons *Brookesia minima* and *Brookesia ebenaui* and the leaf-tailed geckos *Uroplatus ebenaui* and *Uroplatus henkeli*. Nosy Komba currently has one traditionally protected area of roughly 40 ha that includes an area of mature indigenous forest. It is essential that the remaining areas of indigenous forest and disturbed forest are protected in order to promote the survival of Nosy Komba's forest-dependent species. In addition, coffee plantations should be managed with their conservation value in mind in order to provide additional habitat for less sensitive forest-specialist species as well as for the diverse assemblage of currently non-threatened amphibians and reptiles.

Acknowledgements

Thank you to Madagascar Research and Conservation Institute (MRCI) for their support, facilities and funding that made the research possible; to our local guides Jimmy Norcien Tongazara and Roby Duchen; to long-term volunteers Aren Armari, Elitsa Penkova, Tess Mulligan, Rosie McTigue and Adam Richards; to forest interns Michael Burrow and Brandon Baxter; to Guillaume Demare for photographing the *A. mandokava*; to Chloe Amoo who got the project started; to loyal friends Phoebe West and Vicky Abbott, and to all other volunteers who supported MRCI and assisted in the data collection.

Geolocation information

The study took place on the northern half of Nosy Komba island, centered around point: -13.450034°, 48.336895°

Disclosure statement

No potential conflict of interest was reported by the authors.

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