Chapter 4.4
Reptile and Amphibian Communities along the Humidity Gradient and Fragmentation Effects in the Littoral Forests of southeastern Madagascar

Jean-Baptiste Ramanamanjato[1]

Abstract

The littoral forests of the Anosy region in southeastern Madagascar present an interesting amphibian and reptile community, both in terms of diversity and conservation interest. In order to assess the importance of a humidity gradient on the species richness across the region, as well as the effects of fragmentation, surveys were carried out at three different sites over a 14-year period. Species richness increases with increasing precipitation, particularly in amphibians. The ongoing fragmentation of the remaining littoral forests has severe effects on species richness, which declines substantially in fragments smaller than 200 to 300 ha. Extinction with declining fragment size is non-random and mainly occurs in forest-dependent species in smaller fragments. Therefore, conservation actions should focus on the larger fragments. Every species occurring in any of the littoral forest fragments were found within eight days of survey. Thus, inventories of eight days are sufficient as basis for long-term monitoring of the amphibian and reptile communities of littoral forest fragments less than 400 ha in size.

Résumé

Communautés de reptiles et d'amphibiens sur un gradient d'humidité et effets de la fragmentation dans les forêts littorales du sud-est de Madagascar. Les forêts littorales de la région de l'Anosy dans le sud-est de Madagascar abritent une communauté de reptiles et d'amphibiens intéressante aussi bien en matière de diversité que pour la conservation. Afin d'estimer l'importance que peut avoir le gradient de l'humidité pour l'ensemble de la région sur la richesse spécifique ainsi que les effets de la fragmentation de l'habitat, des inventaires ont été réalisés dans trois stations au cours d'une période de 14 ans. La richesse spécifique augmente avec le volume des précipitations et plus particulièrement pour les amphibiens. La fragmentation en cours des dernières forêts littorales a un effet marqué sur la richesse spécifique qui baisse de façon significative dans les fragments dont la superficie est inférieure à 200 ou 300 ha. La relation entre extinction et diminution de la taille des fragments n'est pas aléatoire et est surtout liée aux espèces dépendantes de la forêt dans les plus petits fragments. Par conséquent, les efforts en matière de conservation devraient s'orienter en priorité vers les plus grands fragments. Quelque soit le fragment de forêt littorale considéré, l'ensemble des espèces ont été trouvées en moins de huit jours d'inventaire, de sorte qu'un effort de huit jours est suffisant pour procéder à un suivi à long terme des communautés des amphibiens et des reptiles dans les fragments forestiers de forêt littorale d'une superficie inférieure à 400 ha.

Introduction

The Anosy Region in southeastern Madagascar is remarkable because of the exceptional diversity of natural habitats. Within a 50 km radius, the Anosy Region contains montane areas, littoral forests, and marine zones. Additionally, a climatic ecotone occurs on the western flank of the Anosy Mountains (Goodman *et al.* 1997, Ramanamanjato 2000), resulting in a markedly decreasing humidity gradient from east to west within an extraordinarily narrow scale.

The region is of special interest due to the notable degree of endemism in its herpetofauna, and the presence of many amphibian and reptile species of high conservation priority (e.g., Blanc 1985, Blommers-Schlösser and Blanc 1991). In 1989, a

[1] QIT Madagascar Minerals, BP 225, Tolagnaro 614, Madagascar. Email: jeanbaptiste.ramanamanjato@riotinto.com

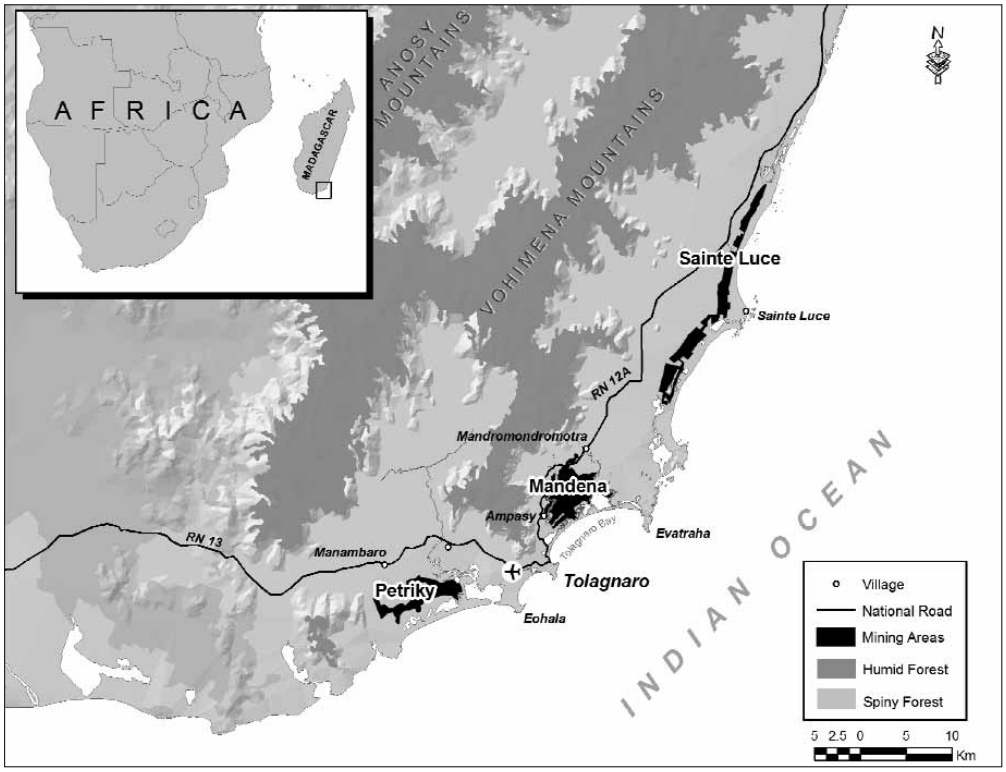

Figure 1. Location of the project area in extreme southeastern Madagascar, which is delineated in the inset map of Africa and Madagascar.

study was initiated by QIT Madagascar Minerals (QMM) to assess the effects of an ilmenite project on the regional herpetofauna. Numerous subsequent zoological expeditions have led to new insights into the herpetofauna of the Anosy Region, including the discovery of new species (e.g., *Phelsuma*: Raxworthy and Nussbaum 1993, Raxworthy and Nussbaum 1994a; *Uroplatus*: Nussbaum and Raxworthy 1995; *Boophis*: Andreone *et al.* 2005) and the taxonomic revision of several genera (e.g., Raxworthy and Nussbaum 1994a, 1994b).

The remaining forests of Madagascar are subject to a diverse range of threats (e.g., Green and Sussman 1990, Smith 1997). The lowland rain forests, including those of the Anosy Region, have been classified as one of the more threatened habitats on the island (Ganzhorn *et al.* 1997), and only a small fraction of the original cover remains (Du Puy and Moat 1996, see Vincelette *et al.* Chapter 2.4). At the beginning of the last century, approximately 60% of the Anosy region was forested, but by 2005 remaining forest cover had been reduced to just more than 100 fragments. Grasslands and extensive anthropogenic heath are important barriers between the large block of remaining humid forest stretching along the eastern flank of the Anosyenne Mountains and the littoral forest on the coastal plain.

Due to their high potential as indicators for habitat change and habitat conditions, amphibians and reptiles have played a prominent role in the environmental impact assessment studies and monitoring programs of QMM. The distributional data compiled from 1989 to 1999 have been summarized in previous papers (Ramanamanjato 2000, Ramanamanjato *et al.* 2002). These results indicate that the amphibian and reptile communities become impoverished in fragments smaller than about 200 ha. Extinction processes in fragments of declining size were non-random.

Herein, the data on species occurrence and habitat preferences of amphibian and reptile species in

Table 1. Number of 24-hour pitfall days used in amphibian and reptile surveys.

	Petriky	Mandena	Sainte Luce
1990	561	915	1110
1992	561	915	1429
1996	0	0	0
1998	462	1848	1232
2000	462	924	616
2002	462	924	616
2004	462	924	616

the three mining zones (Petriky, Mandena, and Sainte Luce) are updated and linked to local and regional biogeographic aspects. These data can serve as the baseline to assess the efficiency of conservation efforts within the mining zone, and to evaluate, in a faunistic sense, the importance of different regional environmental gradients, as well as the effects of habitat degradation.

Methods

The reptile and amphibian communities in the littoral forests of Petriky, Mandena, and Sainte Luce were studied (Fig. 1). Petriky is an 800 ha block of continuous forest. It is surrounded by brackish-water lakes, agricultural fields, and *Eucalyptus* plantations. With a mean annual precipitation of about 880 mm, it is the driest of the three sites. Mandena and Sainte Luce consist of a series of evergreen littoral forest fragments, and these sites receive 1600 mm and 2700 mm of rain per year, respectively. Apart from abiotic conditions, the three sites differ in tree species composition, forest structure, and levels of habitat degradation (see Vincelette *et al*. Chapter 2.1, Rabenantoandro *et al*. Chapter 3.1).

The new distributional data presented here are based on inventories of six fragments in Mandena and five fragments in Sainte Luce ranging from 10 to 340 ha. Fragments are separated by grassland, heath, bare sand, or denuded marshes, and most have been isolated for at least 50 years. For comparison of the species composition to that of relatively intact sites, the nearby Parc National (PN) d'Andohahela (63 100 ha +) was used as a control (Nussbaum *et al*. 1999). However, this comparison, particularly for zones of higher elevation, may not be completely ideal, as the coastal forests grow mainly on poor sandy soils while the forest of parcel 1 of Andohahela grows mainly on lateritic soils (Goodman *et al*. 1997, Goodman 1999). Furthermore, for the amphibian communities of the littoral forests, broad-scale comparisons indicate that communities along Madagascar's east coast are more similar to one another than to the amphibian communities of the montane forests on nearby lateritic soils (Ganzhorn *et al*. 2000).

Herpetological surveys were carried out every two years from 1989 through 2004, with the exception of 1994 (Table 1). Survey methods consisted of pitfall traps and direct searching (Ramanamanjato 1993, 2000, Raselimanana 1993). Pitfall traps were composed of 15 l buckets that were dug into the ground at 10 m intervals along 100 m drift fences. In most cases, four pitfall lines were installed at each site and were monitored twice a day for seven consecutive days. Direct searching included walking transects designed to intersect representative habitats during the day and at night. Possible refuges were excavated. Additionally, opportunistic observations were included starting in 1998. The total sampling effort with pitfall traps is summarized in Table 1.

Voucher specimens were collected for taxonomic identification and these are deposited at the Museum of Zoology, University of Michigan, and at the Département de Biologie Animale, Université d'Antananarivo.

Species composition at each site was analyzed using the presence and absence of amphibian and reptile species. The data for the fragments in Mandena and Sainte Luce were pooled when comparing species richness between the three sites, and analyzed separately when considering the community composition of each fragment associated with the effects of fragmentation. Similarities of species communities between the sites were assessed using Jaccard's index. The classification for habitat associations and measures of commonality herpetofauna associations follow Goodman *et al*. (1997).

Table 2. Species list and distribution between study sites (P = Petriky, M = Mandena, S = Sainte Luce; numbers indicate fragment numbers); 0 = absence, 1 = presence. For the analysis of herpetofauna associations, the following categories were used (Goodman *et al.* 1997): Specialization: Forest (F) – species restricted to continuous tracts of disturbed or relatively intact forest; Generalist (G) – species that use forest and open habitats; Aquatic (A) – species that are found in wetland habitats in littoral zone; Lifestyle: t = terrestrial, a = arboreal, b = fresh water, m = marine. Activity: N = nocturnal, D = diurnal, C = crepuscular, U = unknown.

Species	Petriky	Mandena	Sainte Luce	P1 800 ha	S9 340 ha	M15/16 230 ha	S17 240 ha
Amphibians							
Aglyptodactylus madagascarensis		1	1		1	1	1
Anodonthyla boulengeri		1	1		1	1	
Boophis madagascarensis			1		1		
Boophis opisthodon		1	1		1	1	
Boophis tephraeomystax		1				1	
Heterixalus boettgeri	1	1	1	1	1	1	1
Madecassophryne truebae			1		1		
Mantidactylus betsileanus		1	1		1	1	1
Mantidactylus bicalcaratus		1	1		1	1	1
Mantidactylus biporus		1	1		1	1	
Mantidactylus decaryi		1	1		1	1	
Mantidactylus depressiceps		1	1		1	1	1
Mantidactylus domerguei		1	1		1	1	1
Mantidactylus majori			1		1		
Mantidactylus punctatus		1	1		1	1	1
Mantidactylus pulcher		1	1		1	1	1
Mantidactylus ulcerosus	1	1	1	1	1	1	
Mantidactylus wittei		1	1		1	1	1
Paradoxophyla palmata			1		1		
Plethodontohyla alluaudi		1	1		1	1	1
Plethodontohyla bipunctata		1	1		1	1	1
Plethodontohyla notosticta		1	1		1	1	1
Ptychadena mascarenensis	1	1	1	1	1	1	
Scaphiophryne brevis		1				1	
Scaphiophryne calcarata	1	1		1		1	
Stumpffia tridactyla		1	1		1	1	1
Tomopterna labrosa	1	1		1		1	
Number of amphibian species	**5**	**23**	**23**	**5**	**23**	**23**	**13**
Reptiles							
Acrantophis dumerili	1	1	1	1	1	1	1
Amphiglossus astrolabi		1	1		1	1	
Amphiglossus macrocercus		1	1		1	1	1
Amphiglossus melanopleura	1	1	1	1	1	1	1
Amphiglossus melanurus			1		1		1
Amphiglossus ornaticeps	1	1	1	1	1	1	1
Androngo trivittatus delphinensis			1		1		
Androngo trivittatus	1			1			
Blaesodactylus sakalava	1			1			
Boa manditra		1	1		1	1	1
Brookesia nasus		1	1		1		
Calumma nasuta			1		1		
Caretta caretta	1		1	1			1
Chalarodon madagascariensis	1			1			
Chelonia mydas			1				1
Crocodylus niloticus		1	1			1	1
Dromicodryas bernieri	1		1	1	1	1	1
Ebenavia inunguis	1	1	1	1	1	1	1
Erethmochelys imbricata	1		1	1			1
Furcifer lateralis	1	1	1	1	1	1	

S1/2 212 ha	S7 206 ha	S8 91 ha	M4 41 ha	M5 28 ha	M6 20 ha	M7 10 ha	Specialization	Life-style	Activity
							F	t	C
	1		1				F	a	C
							F	a	N
							G	a	N
			1	1	1	1	G	a	C
	1	1	1	1	1		G	a	C
							F	t	C
1	1	1	1				G	b	C
1	1	1					F	a	D
							G	t	C
1		1					F	T	C
1	1	1					F	a	C
1	1	1	1	1			G	t	C
							F	t	C
1	1	1					F	a	C
1	1	1					F	a	C
1	1	1	1	1			G	b	C
1	1				1	1	G	b	C
							F	b	U
							F	t	U
1	1						F	t	C
1							F	a	C
1	1	1	1	1	1	1	G	b	C
							G	t	C
							F	t	C
1							F	t	C
							G	t	C
13	**12**	**1**	**7**	**5**	**4**	**3**			
							F	t	N
							F	b	U
1	1	1	1				F	t	D
1	1	1	1	1	1		F	t	D
							F	t	D
	1	1					F	t	D
							F	t	U
							F	t	U
							G	t	N
1							G	a	N
							F	a	D
							F	a	D
							A	m	U
							G	t	D
							A	m	U
	1						A	b	U
1	1	1	1	1	1	1	G	t	D
		1					F	a	N
							A	m	U
1	1	1	1	1	1	1	G	a	D

Table 2. Continued

Species	Petriky	Mandena	Sainte Luce	P1 800 ha	S9 340 ha	M15/16 230 ha	S17 240 ha
Furcifer oustaleti	1	1	1	1	1	1	1
Furcifer verrucosus	1	1		1		1	
Geckolepis maculata		1	1		1	1	1
Geckolepis typica	1			1			
Hemidactylus mercatorius	1	1	1	1	1	1	1
Ithycyphus goudoti			1		1		1
Ithycyphus oursi		1	1			1	
Langaha madagascariensis	1	1		1		1	
Leioheterodon madagascariensis	1	1	1	1	1	1	1
Leioheterodon modestus	1	1	1	1		1	
Liophidium rhodogaster		1	1		1	1	1
Liophidium torquatus	1	1	1	1	1	1	
Liophidium vaillanti		1				1	
Liopholidophis epistibes			1		1		
Liopholidophis lateralis	1	1	1	1	1	1	1
Liopholidophis sexlineatus		1				1	
Lycodryas arctifasciatus	1		1	1	1		
Lycodryas betsileanus			1		1		
Lycodryas gaimardi	1	1	1	1	1		1
Lygodactylus miops			1		1		
Lygodactylus tolampyae	1	1		1		1	
Lygodactylus tuberosus	1			1			
Mabuya elegans delphinensis	1	1	1	1	1	1	1
Mabuya gravenhorstii	1	1	1	1	1	1	1
Mabuya vato	1			1			
Madagascarophis colubrinus	1	1	1	1	1	1	1
Microopistodon ochraceus			1		1		
Mimophis mahfalensis	1	1	1	1	1	1	1
Oplurus quadrimaculatus	1	1		1		1	
Paroedura androyensis	1			1			
Paroedura bastardi	1			1			
Pelomedusa subrufa		1					
Phelsuma antanosy			1				
Phelsuma lineata		1	1		1	1	1
Phelsuma modesta	1	1	1	1	1	1	1
Phelsuma quadriocellata		1	1		1	1	1
Pseudoxyrhopus kely	1	1	1	1		1	1
Pseudoxyrhopus microps			1		1		
Pseudoxyrhopus sokosoko		1				1	
Ramphotyphlops braminus	1			1			
Typhlops arenarius	1	1		1		1	
Typhlops decorsei	1			1			
Uroplatus sikorae		1	1		1		
Voeltzkowia lineata	1			1			
Zonosaurus aeneus			1				1
Zonosaurus karsteni	1			1			
Zonosaurus laticaudatus	1	1		1	1	1	1
Zonosaurus maximus		1	1			1	1
Number of reptile species	**40**	**40**	**46**	**40**	**37**	**37**	**31**
Total number of species	**45**	**63**	**69**	**45**	**60**	**60**	**44**

S1/2 212 ha	S7 206 ha	S8 91 ha	M4 41 ha	M5 28 ha	M6 20 ha	M7 10 ha	Specialization	Life-style	Activity
1	1	1	1	1	1		G	a	D
							G	a	D
1	1	1	1	1			F	a	N
							F	a	N
1	1	1	1	1		1	G	a	N
							F	a	D
1		1	1	1			F	a	D
							F	a	U
							G	t	D
1	1	1	1				G	t	D
	1						F	t	D
		1	1	1			F	t	D
				1			G	t	D
							F	t	D
1	1	1	1	1	1		G	t	D
							F	t	D
							F	a	N
							F	a	N
1							F	a	N
							F	a	D
			1	1			F	a	D
							G	a	D
1	1	1	1	1	1	1	G	t	D
1	1	1	1	1	1		G	t	D
							G	t	D
1	1	1	1	1	1		G	t	N
	1						T	a	D
1	1	1	1	1	1	1	G	t	D
		1					G	t	D
							G	t	N
							G	t	N
			1				A	b	U
1	1	1					F	a	D
1	1	1	1	1	1		G	a	D
1	1	1	1	1	1	1	G	a	D
1	1	1	1	1			F	a	D
							F	t	N
							F	t	N
							F	t	N
							F	t	N
			1	1			F	t	U
							F	t	U
							F	a	N
							F	t	N
							G	t	D
							F	t	D
1	1	1					F	t	D
							G	t	D
21	**22**	**23**	**21**	**19**	**11**	**6**			
34	**34**	**33**	**28**	**24**	**15**	**9**			

Table 3. Jaccard indices for similarities between amphibian and reptile communities. Reptiles are above the diagonal in plain font, amphibians are below the diagonal in italics.

	Petriky	Mandena	Sainte Luce
Petriky	-	0.40	0.26
Mandena	*0.21*	-	0.62
Sainte Luce	*0.13*	*0.70*	-

Results and Discussion

Species composition of amphibian and reptile communities

Within the three sites, 96 amphibian and reptile species were recorded (27 amphibian, 69 reptile, Table 2). Species richness is highest at Sainte Luce (69 species), followed by Mandena (63) and Petriky (45, Fig. 2). Species accumulation curves reached a plateau after ten years of survey, and therefore, the herpetofauna of the littoral forests of the Anosy Region can be assumed to be comprehensively sampled (Fig. 3).

In general, there was considerable variation in the species composition of the three communities. The greatest similarity was between Mandena and Sainte Luce, the lowest between Petriky and Sainte Luce (Table 3). These results are consistent for both amphibians and reptiles. No amphibian, but 11 reptile species were found exclusively at Petriky. Two amphibian and three reptile species were found exclusively at Mandena, and four amphibian and 11 reptiles were only recorded at Sainte Luce.

Petriky is poor in amphibians, but relatively rich in reptile species. The herpetofauna of Petriky has a strong affinity for the southern domain of Madagascar, including *Chalarodon madagascariensis*, *Zonosaurus karsteni*, and *Androngo t. trivittatus*, although there are only a few taxa with affinities for the eastern humid forests, such as *Pseudoxyrhopus kely* and *Heterixalus boettgeri*. The climatic ecotone between the dry west and the humid east falls between the sites of Petriky and Mandena (Ramanamanjato *et al.* 2002). Hence, the herpetofauna of Petriky is more similar to that of the western part of PN d'Andohahela (parcels 2 and 3) than to that of Mandena and, especially, Sainte Luce (Tables 2, 3).

Mandena constitutes a contact zone between the dry west and the eastern humid forests. Indeed, it has species in common with both Petriky to the west and Sainte Luce to the north (Table 2). For several species with eastern humid forest affinities, Mandena represents the southern limit of their distribution (e.g., *Brookesia nasus*, *Lycodryas* (*Stenophis*) *betsileanus*, *Zonosaurus maximus*, *Amphiglossus astrolabi*, *Plethodontohyla notosticta*, *Mantidactylus domerguei*, *M. depressiceps*). The opposite is the case for several taxa found in the drier portions of the island to the west and for whom Mandena constitutes the eastern limit of their distribution (e.g., *Aglyptodactylus madagascariensis*, *Laliostoma labrosum*, *Scaphiophryne brevis*, *Furcifer verrucosus*, *Phelsuma modesta*). This pattern is also found in other animal groups, such as the cheirogaleid lemurs (see Ganzhorn *et al*. Chapter 4.8).

The herpetofauna of Sainte Luce shows close affinities for the eastern humid forests, including taxa such as *Microopistodon ochraceus*,*Uroplatus sikorae*, *Calumma nasuta*, *Pseudoxyrophus microps*, and *Liopholidophis stumpfii* (Ramanamanjato 2000, Ramanamanjato *et al.* 2002). Sainte Luce constitutes the southern boundary of the distribution of these species, as well as the northern limit for species that are endemic to the humid part of southeastern Madagascar.

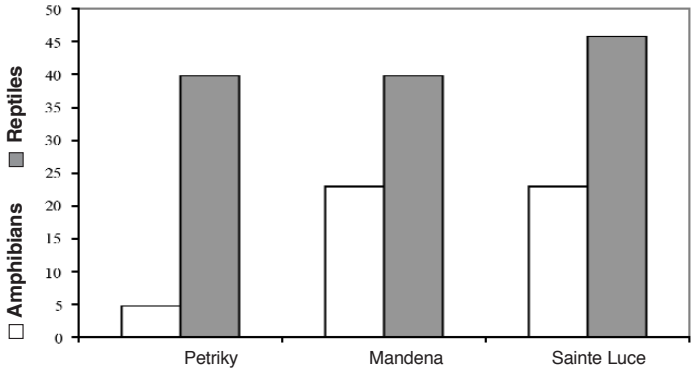

Figure 2. Number of species of amphibians (open bars) and reptiles (gray bars) in three littoral forests of the Anosy Region.

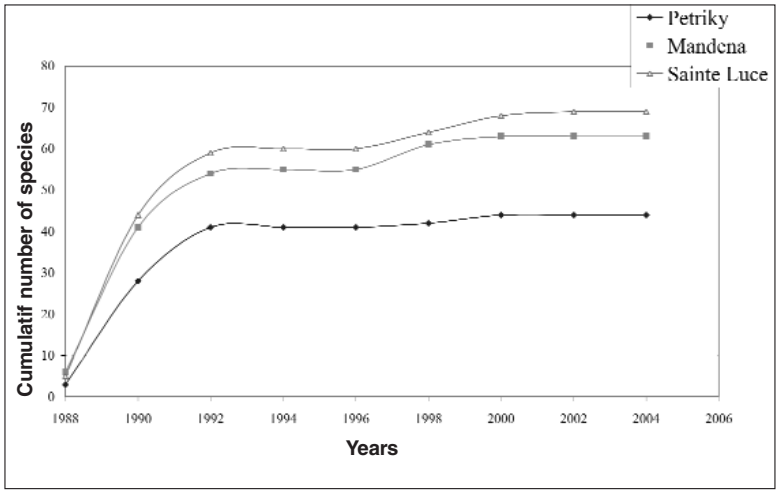

Figure 3. Species accumulation curve of all amphibian and reptile species found in the littoral forests of Petriky, Mandena, and Sainte Luce.

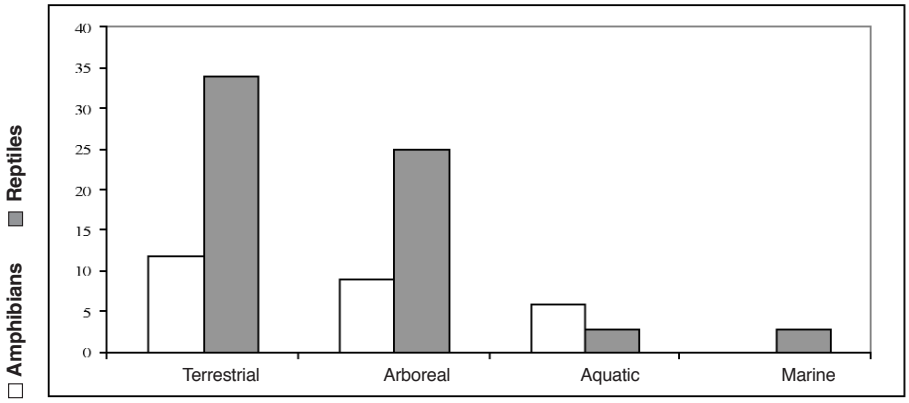

Figure 4. Habitat associations of amphibians (white bars) and reptiles (gray bars) in the littoral forests of the Anosy Region.

Habitat preferences

The vast majority of the local amphibians and reptiles has a terrestrial lifestyle rather than being arboreal (Fig. 4, Table 2), and in several cases, there is considerable habitat specialization. For example, several terrestrial species occur only on sandy substrate (e.g., *Pseudoxyrhopus* spp., *Amphiglossus* spp., *Typhlops* spp.). Moreover, in Mandena and Sainte Luce, all stages of the life cycles of three frog species (*Mantidactylus punctatus, M. bicalcaratus,* and *M. pulcher*) occur exclusively on a single species of *Pandanus*.

Nine freshwater species (six frogs, the turtle *Pelomedusa subrufa*, the crocodile *Crocodylus niloticus*, and an aquatic lizard, *Amphiglossus astrolabi*) and three sea turtles species have been documented at these sites. Since an ongoing monitoring program for marine turtles indicates that nesting activity continuously decreases at other sites around Tolagnaro, Ehoala, and Ambinanibe, the beaches of Sainte Luce constitute an extremely important nesting zone.

Fragmentation effects and minimum size of fragments that might allow persistence of the native amphibian and reptile fauna

The number of amphibian species in Mandena and Sainte Luce declines monotonically with decreasing fragment size. The number of reptile species seems to decline dramatically in fragments smaller than 200 ha, which is where the species number seems to stabilize before dropping again at around 50 ha (Fig. 5; for more

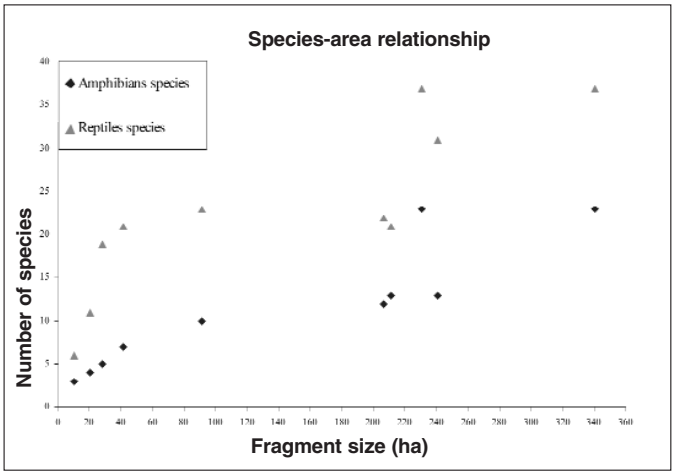

Figure 5. Species-area relationship between the number of amphibian (circles) and reptile species (squares) and fragment size in the littoral forests of southern Madagascar (Mandena and Sainte Luce; updated from Ramanamanjato 2000).

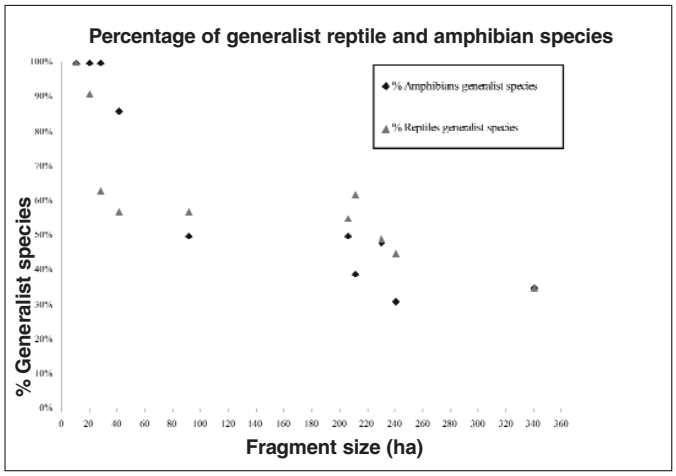

Figure 6. Percentage of generalist reptile and amphibian species in the communities of the littoral forest fragments (taken from Ramanamanjato 2000). The square represents the percentage of generalist species in the large forest (63 000 ha +) of the Parc National d'Andohahela (Parcel 1).

detailed information see Ramanamanjato 2000).

Accordingly, littoral forest fragments smaller than 200-300 ha cannot retain a substantial proportion of the original herpetofauna, as fragments below that size are clearly impoverished. Moreover, the loss of species with declining fragment size is not random, but strongly deterministic. This means that, from a conservation point of view, one or two large forest fragments cannot be replaced by several smaller ones. It seems crucial that the ratio of forest area to edge remains high, as many species seem to react negatively to the opening of the forest canopy and edge effects.

Species groups at particular risk

The decline of reptile and amphibian species that accompanies decreasing fragment size is in tandem with a shift in the representation of forest dependent species. The proportion of forest dependent species decreased from 67% in the 340 ha fragment to 0% in the 10 ha fragment (Fig. 6; for more detailed information see Ramanamanjato 2000). Therefore, the loss of species dependent on forest habitat is principally responsible for the decreased total number of species in smaller fragments. In the smallest fragment (10 ha), only five species of reptiles and one amphibian species were documented, and all were Malagasy endemics that can be found in degraded forests and open areas. Small fragments and larger forest blocks in Mandena are more degraded than those in Sainte Luce. Since forest size and degradation are correlated, degradation might also contribute to the decline of reptile and amphibian species. Thus,

the vulnerability of a given species due to forest fragmentation is related to its tolerance to habitat change and its ability to use or bridge the new anthropogenic habitat matrix around the remaining forest fragments (Laurance and Bierregaard 1997, Gascon and Lovejoy 1998).

Among the categories of species predicted to be most vulnerable due to fragmentation are the following: (1) species with limited or patchy geographic distributions, and species with low population densities; (2) animals requiring very specific habitats for different phases of their life cycles, such as amphibians; (3) species with poor dispersal abilities, which may not stray far from natal zones, or may be stopped by barriers; (4) species with low fecundity; (5) species with short life cycles; (6) species depending on patchy or unpredictable resources, or for other reasons have highly variable population sizes; (7) nesting on or near the ground, which is ill suited to the ecological conditions in fragmented landscapes; (8) species that are absent from small patches with little or no true interior habitat; and (9) species vulnerable to human exploitation or persecution.

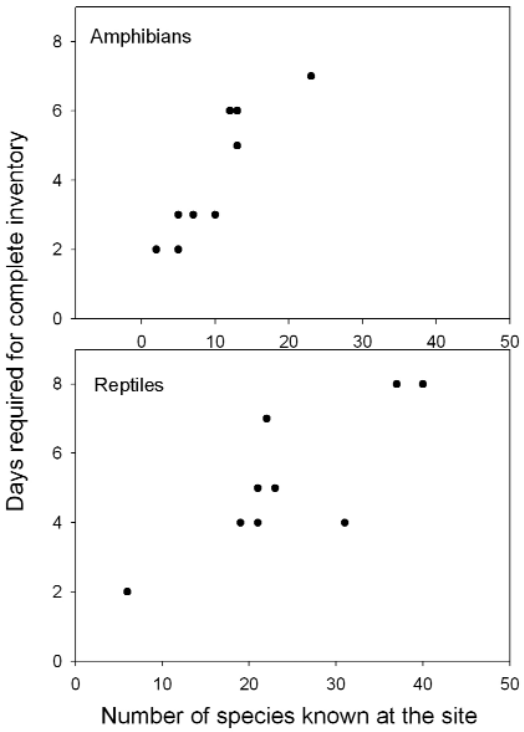

Figure 7. Number of days required to largely complete inventories for amphibians and reptiles at sites with different number of species.

Endemic species and species at risk

Some naturally rare species are at immediate risk of extinction. These include two forest dwelling, habitat specialist reptile species (*Phelsuma antanosy* and *Pseudoxyrhopus kely*) that have very limited distributions and are presumed to be endemic to the littoral forest of the Anosy Region. *Phelsuma antanosy* was discovered at Petriky and Sainte Luce, and additionally at Ambatotsirorongorongo, a transitional forest about 4-5 km west of Petriky. The species seems to depend on specific tree species, which they use to situate their eggs. Thus, the local exploitation of *Pandanus* and the endemic palm *Dypsis saintelucei* directly affects this species' reproductive biology, and constitutes a possible cause for local extirpation (Ramanamanjato *et al.* 2002). In addition, both species are found only in relatively undisturbed, closed-canopy forest. Between 1990 and 1994, the forest cover of Petriky was considerably reduced and *P. antanosy* accordingly disappeared from this site.

The burrowing snake *Pseudoxyrhopus kely* was previously known at all three sites with closed-canopy forest, and is presumed to be largely endemic to the littoral forests of the Anosy Region. It is only known to inhabit forest parcels greater than 200 ha. Recently, the species has also been found in gallery forest at Berenty, a previously unrecorded habitat for this animal. Nevertheless, it has not been found in smaller fragments or in degraded forests (see Ramanamanjato *et al*. Chapter 4.5).

Among the amphibians, the forest size restrictions apply to the ground dwelling frog *Madecassophrynae truebae*, which was found at Sainte Luce. This species is endemic to the Anosy Region and is considered at risk and endangered (Andreone *et al.* 2005). Other species with specific habitat requirements are also a matter of concern; these include *Mantidactylus punctatus*, *M. depressiceps*, *Paradoxophyla palmata*, and *Amphiglossus astrolabi*. For example, *A. astrolabi* inhabits wetlands, and as such, if wetlands become isolated into a matrix of grasslands or bare soil, this species will not be able to disperse between patches, which will impact its long-term prospects.

Several rain forest species appear to be localized in the largest blocks of the closed-canopy littoral forest. They are absent from small patches with little or no true interior; these include: *Amphiglossus melanurus, Sanzinia madagascariensis, Acrantophis dumerili*,

Brookesia nasus, Calumma nasuta, Ithycyphus goudoti, Langaha madagascariensis, Liopholidophis stumpffi, L. sexlineatus, Lygodactylus miops, Stenophis arctifasciatus, S. gaimardi, and *S. betsileanus* (reptiles), and *Aglyptodactylus madagascariensis, Boophis madagascariensis, B. opisthodon, Mantidactylus majori,* and *Scaphiophryne calcarata* (amphibians). Most of these species are common in the eastern rain forest such as PN d'Andohahela with 63,100 ha (parcel 1), in PN de Ranomafana with 40,000 ha or in PN d'Andringitra with 31,160 ha (Nicoll and Langrand 1989, Raxworthy and Nussbaum 1996, Nussbaum *et al.* 1999).

Monitoring

Given the asymptote in the accumulation of previously unrecorded species at the three sites (Fig. 3), it can be assumed that the sampling has approached completion concerning species richness. Thus, we know how many and which species are present in the various fragments. For monitoring purposes, the question is how much survey effort is required to ensure all species in any given fragment are recorded. To get an idea of the survey effort required to achieve a comprehensive species list, standard surveys were carried out in 10 different fragments (all the sites listed in Table 2 except for M6). These surveys consisted of four pitfall lines with 11 buckets each, and direct searching. The pitfall lines and the inventories were continued until species accumulation curves reached an asymptote.

In the largest and most species-rich fragment, all amphibian species were found within seven days of inventory. In fragments with fewer species, the comprehensive inventory took even less time. The number of days required to theoretically achieve a complete inventory for amphibians is given by the equation: Number of days required = 0.26 x Number of amphibian species at the site + 1.50 ($R^2 = 0.85$; $p < 0.001$). In the largest fragments, all reptile species had been found after eight days of inventory. Again, species lists could be completed for smaller fragments in less time. The number of days required to achieve a comprehensive inventory for this group is given by the equation: Number of days required = 0.17 x Number of reptile species at the site + 1.11 ($R^2 = 0.71$; $p = 0.002$; Fig. 7). Thus, inventories of eight days are sufficient for long-term monitoring of changes in the amphibian and reptile communities of the littoral forest fragments less than 400 ha in size.

Conclusions

The littoral forests of southeastern Madagascar contain notable amphibian and reptile communities, both in terms of diversity and conservation interest. Species richness along a humidity gradient rises with increasing precipitation, particularly in amphibians. However, the ongoing fragmentation of this habitat severely impacts the species richness of the regional herpetofauna. Fragments smaller than 200-300 ha cannot sustain a substantial portion of the original fauna, and, therefore, conservation action needs to focus primarily on maintaining the larger fragments. Furthermore, the ratio of forest area to edge should remain as high as possible since many species react negatively to the opening of the forest canopy and edge effects.

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