The non-volant and non-primate mammals of the Ambatovy-Analamay forest

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Abstract

Biological surveys of small mammals (rodents, shrews, and tenrecs) and carnivorans were conducted in the humid forests of Ambatovy-Analamay, where the Ambatovy project is planning mineral exploitation. Three vegetational types have been recognized by the mining project within the general area of exploitation -- "Azonal", "Zonal", and "Transitional". In total, nine different study habitats were inventoried in these three vegetational types in early 2009. The same survey protocols were used at each site, including live traps (Sherman and National), pit-falls traps with associated drift fences, general observation, and analysis of Carnivora scats. The results of the 2009 inventories indicate that 21 species of small mammal are known from the nine study habitats, 20 of which are endemic to Madagascar and one introduced (*Rattus rattus*). The "Zonal" and "Transitional" forests have notably higher species richness of endemic small mammal (n=20) than the "Azonal" (n=10). There was considerable variation in capture rates of small mammals in the Ambatovy-Analamay region between the different habitats. These sites have notably reduced small mammal abundance, as compared to other forests within the same altitudinal range. The species composition of the Ambatovy-Analamay forest is typical of montane forest habitats within the Central Domain of Madagascar. One notable exception is the discovery of *Microgale jobihely* at Ambatovy-Analamay, a species described in 2006 from the Tsaratanana Massif, 485 km to the northwest and not known from any other site. Additionally, four endemic carnivoran species occur in the Ambatovy-Analamay region, but their relative densities are notably low.

Keywords: Analamay-Ambatovy forest, distribution, Madagascar, small mammals, ultrabasic substrates

Résumé détaillé

Des inventaires des petits mammifères (Ordres Afrosoricida, Soricomorpha et Rodentia) et des carnivores (Ordre Carnivora) ont été effectués aux mois de janvier et février 2009 dans la forêt humide d'Ambatovy-Analamay, couvrant neuf types d'habitat déterminés par le projet minier du projet Ambatovy et représentés par une végétation distincte classée en « Azonal », « Transitional » et « Zonal ». L'objectif principal de ces inventaires est de compléter les informations existantes sur les petits mammifères du complexe Ambatovy-Analamay-Torotofotsy. Un même protocole de techniques de piégeage en utilisant les trous-pièges et les pièges standard (Sherman et National) a été adopté dans tous les sites d'étude. Ces techniques ont été complétées par des observations générales et l'analyse des crottes de carnivores. Les résultats de ces inventaires montrent que 21 espèces de petits mammifères sont connues des neuf types d'habitats dont 20 espèces sont endémiques et une a été introduite. En général, l'ensemble des types d'habitat « Zonal » et « Transitional » abrite une richesse élevée, à savoir 21 espèces (20 endémiques et une introduite), comparé avec celui de « Azonal » qui ne présente que 11 espèces (10 endémiques et une introduite). Parmi ces neuf types d'habitat, le « Zonal Impacted Good Quality » héberge la plus grande diversité en petits mammifères endémiques (13 espèces). Une espèce d'Afrosoricide, *Microgale jobihely* décrite en 2006 et n'a jamais été trouvée dans d'autres endroits que dans sa localité type, la partie sud-ouest du massif de Tsaratanana, a été recensée dans cet habitat. Chaque type d'habitat a sa propre composition spécifique et la distribution des espèces ne correspond pas à la classification donnée pour ces milieux, c'est-à-dire que les types d'habitats considérés comme en bon état n'abritent pas forcement des espèces particulières par rapport aux autres qui sont considérés comme dégradés. La composition de la faune de petits mammifères d'Ambatovy-Analamay est typique de la forêt de

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montagne dans le Domaine du Centre de Madagascar et toutes les espèces trouvées sont analogues à celles recensées dans d'autres sites de ce domaine. Une variation remarquable du taux de capture est obtenue dans les différents types d'habitat dans la forêt d'Ambatovy-Analamay et en comparant les résultats obtenus avec une méthodologie similaire, ce taux est faible par rapport à celui des autres sites de la forêt humide appartenant à la même bande altitudinale. Au vu de nos résultats sur les carnivores, quatre espèces endémiques ont été recensées et leur densité est très faible. Les espèces de carnivores trouvées sont identiques à celles trouvées dans d'autres parties de la forêt humide de l'Est. Le type d'habitat « Zonal Impacted Good Quality » mérite d'être protégée par sa diversité importante et la présence de *M. jobihely* qui est considérée en danger suivant la classification de l'UICN mais cette espèce n'est pas représentée dans les Aires Protégées.

Mots clés : Forêt d'Ambatovy-Analamay, distribution, Madagascar, petits mammifères, substrats ultrabasiques

Introduction

The eastern forests of Madagascar span a nearly continuous latitudinal band of the island from its northern to southern limits. Located within the central eastern portion of this area is the Ambatovy-Analamay-Torotorofotsy forest complex, which is situated to the northeast of Moramanga between 980 and 1125 m elevation. In the classical nomenclature of forest types on the island, this zone is classified as "forêt dense à sous-bois herbacé" of Humbert's (1965) Central Domain or "mid-elevation moist evergreen forest" (Lowry *et al*., 1997). Following recent revisions of the Malagasy flora (Moat & Smith, 2007), this vegetation zone is now referred to as "Humid Forest".

The forest structure and plant species present in the Ambatovy-Analamay-Torotorofotsy complex is strongly influenced by soil type and a considerable portion of the forest occurs on ultrabasic substrates, a formation that is notably uncommon in Madagascar (Du Puy & Moat, 2003). Three principal vegetational types have been recognized by the Ambatovy project in this complex (see Goodman & Raselimanana, pp. 36-37), which include: "azonal", mostly composed of ericoid plants; "zonal", dense humid forest; and "transitional", which is a mixed formation between azonal and zonal formations.

Madagascar holds a considerable number of endemic non-volant small mammals, composed principally of two different monophyletic groups. These comprise the Subfamily Nesomyinae (Family Nesomyidae, Order Rodentia), which include all of the endemic rodents of Madagascar (Musser & Carleton, 2005) and the Family Tenrecidae (Order Afrosoricida, ex Lipotyphla and ex Insectivora) (Bronner & Jenkins, 2005) more commonly referred to as the tenrecs. Within this family, there is the most speciose genus of small mammal on Madagascar, known as *Microgale* or the shrew-tenrec, which represents an extraordinary adaptive radiation with numerous sympatrically occurring taxa (Jenkins, 2003; Olson & Goodman, 2003; Olson *et al.*, 2009; Goodman *et al*., 2008). There are also three rat species of the Subfamily Murinae (Family Muridae, Order Rodentia) on the island, all of which are introduced and include *Rattus rattus*, *R. norvegicus*, and *Mus* "*musculus*". Further, two species of the Family Soricidae (Order Soricomorpha) occur on Madagascar, of which at least one, *Suncus murinus*, was introduced. The Nesomyinae and Tenrecidae are strictly endemic to Madagascar and comprise 59 species (27 and 32 species, respectively) (Goodman *et al*., 2008, 2009; Olson *et al*., 2009). The majority of this diversity is found within the island's eastern humid forests..

Recently, the native Carnivora of Madagascar have been shown to represent a monophyletic group (Yoder *et al*., 2003), rather than associated with two different Carnivora families (Wozencraft, 1993), and are now placed in the endemic Family Eupleridae (Wozencraft, 2005). There are three introduced carnivoran species (Goodman *et al*., 2008): domestic dogs (*Canis lupus*, Family Canidae), domestic and wild cats (*Felis silvestris*, Family Felidae), and the Indian Civet (*Viverricula indica*, Family Viverridae).

The pre-2009 work conducted in the Ambatovy-Analamay-Torotorofotsy complex revealed a notable diversity of small mammals in this region. Based on collections housed in the Département de Biologie Animale, Université d'Antananarivo (UADBA), 15 species of Afrosoricida, two species of Soricomorpha, and six species of Nesomyinae have been identified from the Ambatovy forest based on voucher specimens (Table 1). Throughout this paper, the term "Ambatovy" is explicitly meant to refer to the pre-2009 survey data whereas "Ambatovy-Analamay" refers to the sites and habitats inventoried during our early 2009 fieldwork. In 2004, several regions of the complex were re-sampled, including Analamay and Ambatovy, as defined above, as well as the Torotorofotsy forest

Table 1. List of small mammal species previously known from the Ambatovy-Analamay-Torotorofotsy region based on previous small mammal surveys. * = introduced species.

	Sites and periods of inventories		
	Ambatovy	**Analamay**	**Torotorofotsy**
Species	**1997 & 2007-2008**	**1997 & 2004**	**1997, 2004 & 2008**
Afrosoricida			
Hemicentetes semispinosus	+	-	+
Microgale cowani	+	+	+
Microgale dobsoni	+	+	-
Microgale drouhardi	+	-	+
Microgale fotsifotsy	+	-	+
Microgale gymnorhyncha	-	+	-
Microgale jobihely	+	-	-
Microgale longicaudata	+	-	+
Microgale majori	+	+	+
Microgale parvula	+	-	-
Microgale principula	-	-	+
Microgale taiva	+	+	-
Microgale talazaci	+	+	+
Microgale thomasi	+	+	+
Oryzorictes hova	+	-	+
Setifer setosus	+	+	+
Tenrec ecaudatus	+	+	+
Total number of Afrosoricida	15	9	12
Soricomorpha			
Suncus madagascariensis	+	-	-
*Suncus murinus**	+	+	+
Total number of Soricomorpha	2	1	1
Rodentia			
Brachytarsomys albicauda	+	-	-
Eliurus minor	+	-	+
Eliurus tanala	+	-	+
Eliurus webbi	+	-	+
Gymnuromys roberti	+	-	+
Nesomys audeberti	-	-	+
Nesomys rufus	+	-	-
*Rattus rattus**	+	+	+
*Mus musculus**	+	-	+
Total number of endemic rodents	**6**	**0**	**5**
Total number of endemic small mammals	**22**	**9**	**17**
Total number of small mammals	**25**	**11**	**20**

and marsh system. In the context of an impact study, the area of Torotorofotsy, including the forest and marsh ecosystem, was re-inventoried in 2008. Furthermore, other field studies, focusing on the impacts of deforestation, have been conducted since 2007. These studies and the associated reference collections resulted in the identification of 25 locally occurring endemic small mammal species, 22 of which were found at Ambatovy, nine at Analamay, and 17 at Torotorofotsy (Table 1).

This current study focused on conducting a detailed inventory of the small mammals and carnivorans at Ambatovy-Analamay to help increase information available on the species occurring in the Ambatovy-Analamay-Torotorofotsy complex. The vegetation of the remaining forested portions of the study area are composed of eastern humid forest, often on particular soil substrates, which have been subjected to various human pressures such as slash and burn agriculture and selective logging of hardwoods. In order to encapsulate differences in the small mammals and carnivorans across different vegetational zones, nine different study habitats were inventoried (eight within the forest and one in a scrub habitat dominated by *Erica* (see Goodman & Raselimanana, pp. 36-37).

Methodology

Systematics and taxonomy

The taxonomy of endemic Malagasy small mammals has been extensively reviewed and modified over the past 15 years. These changes are largely a direct result

of new specimens, with associated tissue samples, collected during the course of biological inventories conducted in the past two decades. For rodents of the subfamily Nesomyinae, the revisions of Carleton & Schmidt (1990), Carleton (1994), Goodman & Carleton (1996, 1998), Carleton *et al*. (2001), and Goodman *et al*. (2005) have been followed. For the Afrosoricida, particularly the genus *Microgale*, the work of Jenkins (1992, 1993, 2003), Jenkins *et al*. (1997), Goodman & Jenkins (1998), Olson *et al*. (2004) and Goodman *et al*. (2006) have been used.

Trapping

During our inventories of the different localities within the Ambatovy-Analamay region, the same methods were used within each habitat, as well as sites outside this zone integrated herein for different biogeographic analyses. At each site, two techniques were adopted for live trapping of small mammals (pit-fall traps and two types of standard traps). These devices were left in place for a minimum of six consecutive nights. At a given site, traps were installed in different ecological settings to better estimate the utilization of various microhabitats by small mammals and to have a robust estimate of the local species richness.

Pit-fall traps

Each pit-fall trap line consisted of 11 buckets (15 l capacity, with internal depth measuring 275 mm and internal lower diameter 220 mm) that were installed on a largely straight trail measuring 0.75-1 m in width. The buckets were dug into the ground, with the rim flush to the soil level, placed 10 m distance from one another, and configuring a line of 100 m. Black plastic, known as “drift-fencing”, approximately 110 m in length and 0.80 m in height was stapled to a series of wooden stakes that bisected the center of each bucket. About 0.70 m of the plastic fence was attached to the stakes and the balance buried in the ground and covered with soil litter. This fencing forms a barrier to small animals moving on the ground and that subsequently fall into the buckets. The bottom of each bucket had small holes to allowed rainwater drainage.

In each habitat type, three pit-fall lines were generally installed in different microhabitats; the coordinates and specific details of each are given in Raselimanana (see pp. 102-103, Table 1). This style of trap is largely intended to capture different members of the Family Tenrecidae and, secondarily, rodents. One bucket in place for 24 hours (dawn to dawn the following day) is the quantified unit of one “pit-fall night”. Supplementary pit-fall lines were also installed at a few sites to better evaluate the small mammal species occurring in other microhabitats.

Standard live traps for small mammals

Two different types of standard live traps were used; Sherman traps (22.5 x 8.6 x 7.4 cm) and National (Tomahawk) traps (39.2 x 12.3 x 12.3 cm). A total of 100 standard traps were installed in a variety of settings within the studied habitats, in the ratio of 1 National: 4 Sherman traps. The geographical coordinates and other details of each standard trap line are presented in Table 2. During the course of a sampling session, each trap had a fixed location, which was marked with a uniquely numbered flag.

The traps were placed in a variety of different microhabitats to increase the probability of capturing small mammals and having robust estimates of local species diversity. Approximately 20% of the devices were placed off the ground (e.g., on tree trunks or lianas) and the other 80% in terrestrial positions (e.g., below inclining tree trunks, along trunks resting on the ground, in front of holes in the ground and within roots or tree trunks). Each trap was visited twice per day, just after dawn and in the late afternoon. These standard traps were baited with peanut butter, which was replaced on a daily basis in the late afternoon. One trap in place for 24 hours (dawn to dawn on the following day) is considered the quantified unit of one “trap-night”. These types of traps are principally intended to capture rodents and secondarily tenrecs, particularly the larger species. Supplementary lines of 50 standard live traps, at the same ratio as mentioned above, were also installed at a few sites to better evaluate the small mammal species occurring in a range of different microhabitats.

Carnivora traps

At sites representing the different habitats within the Ambatovy-Analamay region, a line of 20 National (Tomahawk) traps (39.2 x 12.3 x 12.3 cm) was installed to capture small carnivorans. During the course of a trapping session, each trap was established in a fixed location, given a unique number, and marked with a numbered flag. These trap lines were placed along existing forest trails, but away from the sites with the pit-fall and standard trap lines. The Carnivora traps were staked down in the four corners to keep animals from turning the traps while attempting to extract the bait. Further, the traps were covered with moss,

Table 2. Geographic coordinates of the Sherman and National trap lines in the Ambatovy-Analamay region. ABE = Azonal Benchmark, AIG = Azonal Impacted Good Quality, AID = Azonal Impacted Degraded, TBE = Transitional Benchmark, TIG = Transitional Impacted Good Quality, TID = Transitional Impacted Degraded, ZBE = Zonal Benchmark, ZIG = Zonal Impacted Good Quality, ZID = Zonal Impacted Degraded (see Goodman & Raselimanana, pp. 36-37 for a definition of these vegetational types).

Type of vegetational formation	Habitat	Lines	Total length (m)	Orientation	Coordinates (Latitude, Longitude)	
					Start	End
Azonal	ABE	Line 6	350	NE	18°48'28''S 48°20'11''E 1044 m	18°48'29"S 48°20'19"E 1075 m
		Line 7	600	SE	18°48'30"S 48°20'26"E 1090 m	18°48'41"S 48°20'38"E 1077 m
		Line 8	120	SW	18°48'30"S 48°20'14"E 1048 m	18°48'36"S 48°28'16"E 1035 m
	AIG	Line 13	400	SW	18°49'26"S 48°20'01"E 1055 m	18°49'20"S 48°20'07"E 1081 m
	AID	Line 9	640	SW	18°48'26"S 48°19'47"E 1098 m	18°48'27"S 48°20'02"E 1089 m
Transitional	TBE	Line 4	400	SE	18°47'44"S 48°19'56"E 1130 m	18°47'36"S 48°20'03"E 1104 m
		Line 5	740	SE	18°47'36"S 48°20'03"E 1104 m	18°47'37"S 48°20'20"E 1031 m
	TIG	Line 1	300	NW	18°47'57"S 48°19'36"E 1088 m	18°47'55"S 48°19'23"E 1106 m
		Line 2	250	NW	18°47'55"S 48°19'23"E 1106 m	18°47'55"S 48°19'17"E 1065 m
		Line 3	450	NW	18°47'55"S 48°19'13"E 1063 m	18°47'55"S 48°19'09"E 1050 m
	TID	Line 14	550	NE	18°49'18"S 48°20'08"E 1090 m	18°48'46"S 48°20'13"E 1049 m
Zonal	ZBE	Line 10	525	SE	18°48'25"S 48°21'33"E 1001 m	18°48'10"S 48°21'47"E 1006 m
		Line 11	400	NE	18°48'25"S 48°21'33"E 1001 m	18°48'13"S 48°21'45"E 988 m
	ZIG	Line 15	500	NE	18°49'33"S 48°18'53"E 1181 m	18°49'17"S 48°18'58"E 1110 m
	ZID	Line 12	480	SW	18°48'25"S 48°21'27"E 1020 m	18°48'36"S 48°21'18"E 1021 m

branches, and soil litter, except for the portion with the entrance, to create a tunnel guiding the animals into the device. The Carnivora traps were baited with grilled dried meat mixed with dehydrated fish. During a trapping session, which lasted for a minimum of six nights, the bait was not replaced. The intent was to allow the bait to become odiferous, providing a greater olfactory attraction to carnivorans.

Standard traps for small lemurs

Another set of standard traps were installed at each site for the capture of small lemurs, principally of the family Cheirogaleidae (see Ralison, pp. 179-180), and provided supplementary information on locally occurring small mammals (rodents and tenrecs). At each site a line of 40 traps (30 Sherman and 10 National), of the same dimensions mentioned above

for the standard small mammal trap lines were placed in arboreal sets (1-2 m off the ground), such as on tree trunks, lianas, and horizontal tree branches. The lemur traps were baited with fresh banana, which was replaced each late afternoon. One trap in place for 24 hours (dawn to dawn the following day) is considered the quantified unit of one “trap-night”.

Other inventory methods

Other than the different trapping methods, direct observations were also made, particularly for Carnivora and small mammals, including spiny tenrecs (Subfamily Tenrecinae), such as *Tenrec ecaudatus* and *Setifer setosus*, and crepuscular rodents (Subfamily Nesomyinae), specifically the genus *Nesomys*. Further, local people were questioned about the different non-primate mammals occurring in the study areas, based on local vernacular names or diagnostic external morphological characters. Finally, bone and fur remains found in the scats of Carnivora collected within the study habitats provided supplementary information on locally occurring mammals.

Specimens

A portion of the small mammals captured during this survey were prepared as voucher specimens, in the form of museum study skins with associated skulls or formalin preserved carcasses. These specimens, following the specifications of permit n°328/08/MEEFT/SG/DGEF/DSAP/SE dated 22 December 2008, are housed and cataloged in the UADBA. Standard external measurements (total length, head and body length, tail length, ear length, and hindfoot length) and body mass were taken from each animal before preservation. Tissue samples of each collected individual were placed in EDTA for ongoing and future genetic research. Furthermore, ectoparasites (fleas, ticks, and mites) were conserved in 90% ETOH.

Data analysis

As this study is largely concerned with the endemic small mammals of the Ambatovy-Analamay area, other than presenting information on the presence-absence of introduced species and capture rates, specifically *Rattus rattus*, we have not included introduced animals in any of the diversity and biogeographic analyses. Given the low densities of small mammals in the Ambatovy-Analamay forest, information on taxa represented from the site in the UADBA collections were used in the biogeographic analyses. Even though trapping techniques associated with these other field surveys and collections were not necessarily in parallel with our 2009 work in the region, these specimens allow for a better estimation of the different taxa represented at the site.

Similarity Analysis

The Jaccard Index is calculated to establish faunal relationships between the different sites inventoried in the Ambatovy-Analamay region, as well as other surveyed sites in Ambatovy, Torotorofotsy, and the central eastern portions of the island, including the Central Highlands. This index was chosen as the effects of sample size are less important than with some other coefficients (Shi, 1993) and it is widely used in the style of biogeographic analyses presented here (Magurran, 1988). The Jaccard Index is calculated between pairs of sites based on species presence-absence data and following the formula:

$$I_{Jacquard} = \frac{C}{(N_1 - N_2) - C}$$

with N_1 = specific richness at site 1, N_2 = specific richness at site 2, and C = number of species occurring at both sites.

The associated coefficients were entered into the Cluster Analysis program (Hierarchical Clustering, Linkage complete, distance Euclidean) of SYSTAT to produce a branching diagram illustrating the biogeographic affinities of forest-dwelling mammals at the different sites.

Shannon-Weaver Diversity Index

Given the limited number of data obtained, descriptive statistics have been preferred, and are here limited to the estimation of specific diversity. In order to characterize the specific diversity of small mammals at sites within or between different ecosystems, it is critical to have quantified information on species richness and relative abundance. Herein, we have employed the Shannon-Weaver Index, which provides a measure of different aspects within a biological community: an estimation of species richness and the level of evenness in the distribution of species between the different habitats and sites. This index was used to measure the diversity of small mammal communities within the forests of Ambatovy-Analamay. Only data from animals captured in the pit-fall traps and standard traps were used. The following formula was employed

Table 3. List of non-volant and non-primate mammal species recorded in the Ambatovy-Analamay forest. All of this information is based on captured animals. The exceptions are those marked with "[+]" which were observed or reported to occur by local people. The utilization of "(+)" indicates that this species was documented based on remains found in the forest or scats of the animal were located and "*" an introduced species. ABE = Azonal Benchmark, AIG = Azonal Impacted Good Quality, AID = Azonal Impacted Degraded, TBE = Transitional Benchmark, TIG = Transitional Impacted Good Quality, TID = Transitional Impacted Degraded, ZBE = Zonal Benchmark, ZIG = Zonal Impacted Good Quality, and ZID = Zonal Impacted Degraded. IUCN status (IUCN, 2009), LC = Least Concerned, NT = Near Threatened, Vu = Vulnerable, and EN = Endangered.

	IUCN Status	Azonal			Transitional			Zonal		
		ABE	AIG	AID	TBE	TIG	TID	ZBE	ZIG	ZID
Afrosoricida										
Hemicentetes semispinosus	LC	-	-	-	+	-	-	-	-	-
Microgale cowani	LC	+	-	-	-	-	-	+	+	+
Microgale drouhardi	LC	-	-	-	+	-	-	-	+	-
Microgale fotsifotsy	LC	-	-	-	+	-	-	-	-	+
Microgale jobihely	EN	-	-	-	-	-	-	-	+	-
Microgale longicaudata	LC	+	-	-	+	-	-	-	+	-
Microgale majori	LC	+	+	-	+	-	+	+	+	+
Microgale principula	LC	-	-	-	-	-	-	-	-	+
Microgale taiva	LC	+	-	-	-	-	+	-	-	-
Microgale talazaci	LC	-	+	-	+	+	+	-	+	-
Microgale thomasi	LC	-	-	-	+	+	-	-	+	-
Oryzorictes hova	LC	-	+	-	+	+	-	+	+	+
Setifer setosus	LC	+	+	-	+	+	+	+	+	+
Tenrec ecaudatus	LC	+	+	-	+	+	+	+	+	+
Rodentia										
Gymnuromys roberti	LC	-	-	-	-	-	+	+	-	-
Eliurus grandidieri	LC	-	-	-	-	-	-	-	+	-
Eliurus minor	LC	-	-	-	-	+	-	-	-	-
Eliurus tanala	LC	-	+	-	+	-	+	-	+	-
Eliurus webbi	LC	-	-	-	-	-	+	+	+	+
Nesomys rufus	LC	+	-	-	+	+	-	+	-	+
*Rattus rattus**		+	+	+	+	+	+	-	+	-
Total number of endemic small mammals		**7**	**6**	**0**	**12**	**7**	**8**	**8**	**13**	**9**
Total number of small mammals		**8**	**7**	**1**	**13**	**8**	**9**	**8**	**14**	**9**
Carnivora										
Cryptoprocta ferox	Vu	-	-	(+)	-	-	-	-	-	-
Galidia elegans	LC	-	-	-	-	-	-	[+]	-	[+]
Galidictis fasciata	NT	-	-	-	-	-	+	-	-	-
Fossa fossana	NT	-	-	-	-	-	-	+	-	+
Total number of endemic carnivorans		0	0	1	0	0	1	2	0	2
Total number of carnivorans		0	0	1	0	0	1	2	0	2
Artiodactyla										
*Potamochoerus larvatus**		(+)	-	-	-	(+)	-	(+)	-	(+)
Total number of artiodactyls		**1**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**1**
Total endemic mammal species		**7**	**6**	**1**	**12**	**7**	**9**	**10**	**13**	**11**
Total mammal species		**8**	**7**	**2**	**13**	**9**	**10**	**11**	**14**	**12**
Total mammal species per habitat groups			**13**			**19**			**21**	

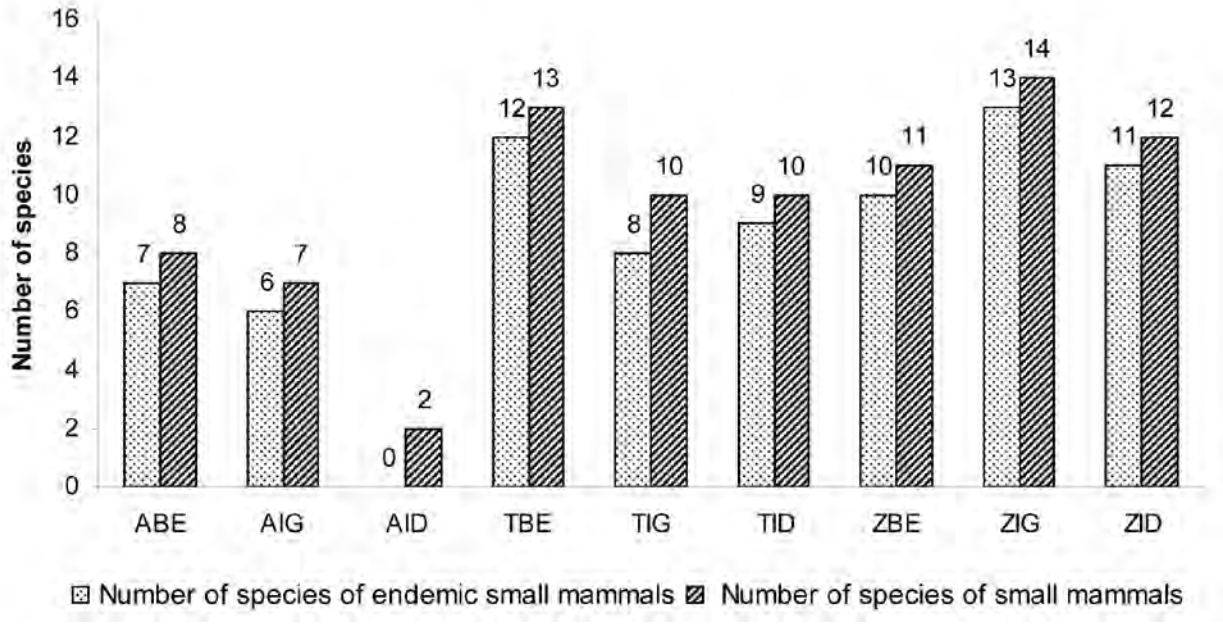

Figure 1. Graphic representation of the number of small mammals in the different habitat types in the Ambatovy-Analamay region. ABE = Azonal Benchmark, AIG = Azonal Impacted Good Quality, AID = Azonal Impacted Degraded, TBE = Transitional Benchmark, TIG = Transitional Impacted Good Quality, TID = Transitional Impacted Degraded, ZBE = Zonal Benchmark, ZIG = Zonal Impacted Good Quality, and ZID = Zonal Impacted Degraded.

in the calculation of the Shannon-Weaver H' Diversity Index:

$$H' = -\Sigma (ni/N)\log10(ni/N)$$

where ni = number of a given species; N = total number of individuals captured.

The Shannon-Weaver Index is frequently used to examine the relative abundance of a given group within a zone and their distribution across communities. The values of this index augment with increasing diversity and faunal homogeneity. In cases where two sites hold the same number of species, this index helps to differentiate cases where the relative abundance is largely similar or certain taxa dominate the local community.

Results

Small mammals (rodents and tenrecs)

Species composition and richness

On the basis of the combined results of the early 2009 small mammal inventories in the Ambatovy-Analamay forest, 21 species were documented (Table 3). These include 14 species of Afrosoricida and seven species of rodents (six Nesomyinae and one introduced Murinae, *Rattus rattus*). Amongst the nine habitats inventoried, the Zonal Impacted Good Quality held the highest small mammal diversity with 13 endemic species (Figure 1). The other habitats contained between seven and 12 endemic species, with the exception of the Azonal Impacted Degraded habitat, which contained only *R. rattus*. In general, the zonal and transitional habitat types hold a greater number of small mammal species, in total 21 (20 endemic and one introduced), in comparisons to the azonal type, which has 11 species (10 endemic and one introduced).

Amongst the Afrosoricida, *Setifer setosus* and *Tenrec ecaudatus* were commonly captured and observed in all eight forest habitats. Several other species of Afrosoricida were broadly distributed across the zone, while *Microgale jobihely* was captured only in the Zonal Impacted Good Quality habitat, *Hemicentetes semispinosus* only found in the Transitional Benchmark habitat, and *M. majori* and *M. drouhardi* only obtained in two habitat types. Amongst rodents, *Eliurus tanala*, *E. webbi*, and *Nesomys rufus* were found in four different habitat types, while the other two endemic species, *E. grandidieri* and *E. minor*, were captured on single occasions, in the Zonal Impacted Good Quality and Transitional Benchmark habitats, respectively. The introduced *R. rattus* was trapped in six of the nine different habitats.

Relative abundance of small mammals

The specific details on the small mammals captured in the nine different habitat types are presented in Tables 4, 5, and 6. Capture rates of Afrosoricida based on the

Table 4. Summary of pit-fall trap results for small mammals in the different habitat types of the Ambatovy-Analamay region. ABE = Azonal Benchmark, AIG = Azonal Impacted Good Quality, AID = Azonal Impacted Degraded, TBE = Transitional Benchmark, TIG = Transitional Impacted Good Quality, TID = Transitional Impacted Degraded, ZBE = Zonal Benchmark, ZIG = Zonal Impacted Good Quality, and ZID = Zonal Impacted Degraded.

	Sites and habitats																						
	Site 1			**Site 2**				**Site 3**				**Site 4**						**Site 5**					
	TIG			**TBE**				**ABE**			**AID**	**ZID**			**ZBE**			**AIG**		**TID**	**ZIG**		
Number of pit-fall line	1	2	3	7	4	5	6	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Number of pit-fall nights	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66
Afrosoricida																							
Hemicentetes semispinosus	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Microgale cowani	-	-	-	-	-	-	-	-	-	1	-	-	-	4	-	-	-	-	-	-	2	-	-
Microgale drouhardi	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1
Microgale fotsifotsy	-	-	-	1	1	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Microgale longicaudata	-	-	-	2	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Microgale jobihely	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Microgale majori	-	1		1	1	1	1	-	-	-	-	-	-	1	-	-	-	1	-	1	1	-	1
Microgale principula	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Microgale taiva	-	-	-	-	-	-	-	-	1	2	-	-	-	-	-	-	-	1	4	1	-	-	-
Microgale talazaci	1	3	3	9	3	5	2	-	-	-	-	-	2	5	1	2	6	-	1	1	-	1	4
Microgale thomasi	-	-	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Oryzorictes hova	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	2	-	1	-	3	1	-
Setifer setosus	1	-	-	-	-	1	-	-	1	1	-	-	-	-	-	1	1	-	-	-	2	-	-
Tenrec ecaudatus	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	10	1	5	2	13	-	14
Number of species of Afrosoricida captured	**2**	**3**	**2**	**5**	**4**	**6**	**2**	**1**	**3**	**3**	**0**	**0**	**3**	**3**	**1**	**2**	**4**	**3**	**4**	**4**	**6**	**4**	**5**
Number of individuals of Afrosoricida captured	**2**	**5**	**4**	**15**	**6**	**11**	**3**	**1**	**3**	**4**	**0**	**0**	**4**	**10**	**1**	**3**	**19**	**3**	**11**	**5**	**22**	**5**	**22**
Capture rate (%)	**3.0**	**7.6**	**6.0**	**22.7**	**9.0**	**16.6**	**4.5**	**1.5**	**4.5**	**6.0**	**0**	**0**	**6.0**	**15.5**	**1.5**	**4.5**	**28.8**	**4.5**	**16.6**	**7.6**	**33.3**	**7.6**	**33.3**
Number of individuals captured during six nights of trapping	**11**			**32**			**3**	**8**			**0**	**14**			**23**			**19**			**49**		
Capture rate (%) during six nights of trapping	**5.5**			**16.1**			**4.5**	**4.0**			**0**	**7.0**			**11.6**			**9.6**			**24.7**		

Table 4. (cont.)

	Sites and habitats																						
	Site 1			Site 2				Site 3				Site 4						Site 5					
	TIG			TBE				ABE			AID	ZID			ZBE			AIG		TID	ZIG		
Number of pit-fall line	1	2	3	7	4	5	6	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Number of pit-fall nights	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66
Rodentia																							
Gymnuromys roberti	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-
*Rattus rattus**	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Number of individual rodents captured	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Capture rates (%)	0	0	0	0	0	3.0	0	0	0	0	0	0	0	0	0	0	1.5	0	0	1.5	0	0	0
Summary statistics																							
Number of endemic small mammals captured during six nights of trapping	**11**			**32**			**3**	**8**			**0**	**14**			**24**			**20**			**49**		
Total number of small mammals captured during six nights of trapping	**11**			**34**			**3**	**8**			**0**	**14**			**24**			**20**			**49**		
Capture rate (%) of small mammals during six nights of trapping	**5.5**			**17.1**			**4.5**	**4.0**			**0**	**7.0**			**12.1**			**10.1**			**24.7**		

pit-fall traps varied from 4.0 to 24.7%. These same trap types resulted in the capture of two individuals of the endemic rodent *Gymnuromys roberti* in the Zonal Benchmark and Transitional Benchmark habitats and two individuals of the introduced rodent *Rattus rattus* in the Transitional Benchmark habitat. Amongst the Afrosoricida, the highest capture rate (24.7%) was in the Zonal Impacted Good Quality habitat, but it is important to note that *Tenrec ecaudatus* represents 54% of the trapped individuals. The lowest capture rate (4.0%) was in the Azonal Benchmark habitat. No animals were captured in the pit-falls installed in the Azonal Impacted Degraded habitat.

In the case of the standard traps (Sherman and National), trap success varied considerably during six nights of trapping – the Azonal Impacted Good Quality, the Transitional Impacted Degraded and the Zonal Benchmark habitats had the greatest trap success at 0.3%. However, it is important to note that these figures only include endemic rodents, and at certain sites, such as the Transitional Benchmark, Transitional Impacted Degraded habitat and Transitional Impacted Good Quality, the trap success for introduced *R. rattus* was notably high.

A few small mammals were captured in the trap lines put in place for small nocturnal lemurs (see Ralison, p. 184) and the results are presented in Table 7. Amongst the Azonal Impacted Good Quality and Zonal Impacted Good Quality habitats, the capture rate was the highest at 3%. The only examples of the rodent *Eliurus grandidieri* within the study area were captured using these trap sets in the Zonal Impacted Good Quality habitat. Of considerable interest was the capture of an individual of *Microgale talazaci* in an arboreal position, a species of Afrosoricida generally considered to be terrestrial.

Collection effort

The species accumulation curves based on trapping effort are presented in Figure 2. In general, the pit-fall traps (Figure 2a) show a relatively rapid approach towards a flat curve, particularly in the Transitional Impacted Good Quality and Azonal Benchmark habitats. In a few cases, one or two additional species were trapped in a given habitat towards the end of the trapping session. This would indicate that other species of small mammals not recorded during these surveys might exist at these sites. In the case of the standard trap lines (Figure 2b), not including those set for nocturnal lemurs (Table 7), the notably low rodent species richness at the six sites where these devices were in place make the interpretation of the accumulation curves difficult. Based on this caveat, in most cases no new species was captured after 300 trap nights in a given habitat.

Diversity Index

The Shannon-Weaver Diversity Indices for the native small mammals documented in the different habitats of the Ambatovy-Analamay region are presented in Table 8. On the basis of the calculated indexes for Afrosoricida, the Transitional Benchmark habitat has an elevated value (0.706), while the figures for the majority of other sites are reduced (0.702 to 0.501). The lowest values (0.311) were in the Azonal Impacted Good Quality and Transitional Impacted Degraded habitats, which are explained by the abundance of *Tenrec ecaudatus* in these forests. For rodents, where in most cases a single species was captured in a given habitat, it is not possible to calculate this index. The exception is the Zonal Benchmark, which has an index value of 0.301. In comparison with measures of species richness in the Lakato and Maromiza forests (Soarimalala & Goodman, unpublished) using identical survey methodologies, the Ambatovy-Analamay region has low diversity (see Table 8).

Faunal similarity between sites

Separate analyses for Afrosoricida and Rodentia are presented in Figure 3 associated with the faunal similarity of the endemic small mammals at the nine different habitats inventoried in the Ambatovy-Analamay region. The Jaccard values are presented for the different sites and separately for endemic Afrosoricida and Rodentia (Table 9). Based on these analyses, there is considerable similarity in the Afrosoricida fauna amongst these sites, with the exception of the Azonal Impacted Degraded habitat for which no endemic species was captured. The large grouping made up of eight of the nine habitats, forms three sub-groups, with the first comprising the Transitional Benchmark, Transitional Impacted Good Quality, and Azonal Impacted Good habitats; the second the Transitional Impacted Degraded, Azonal Benchmark, and Zonal Impacted Good Quality habitats; and the third Zonal Benchmark and Zonal Impacted Degraded habitats. In the third subgroup, the species represented were very similar with the exception of *Microgale principula*, which was only found in the Zonal Impacted Degraded habitat.

In the case of the Rodentia, the level of similarity is notably less, but given the low capture rates and species richness in the nine different habitats, these

Table 5. Summary of standard traps (Sherman and National) results for small mammals in the different habitat types of the Ambatovy-Analamay region. ABE = Azonal Benchmark, AIG = Azonal Impacted Good Quality, AID = Azonal Impacted Degraded, TBE = Transitional Benchmark, TIG = Transitional Impacted Good Quality, TID = Transitional Impacted Degraded, ZBE = Zonal Benchmark, ZIG = Zonal Impacted Good Quality, and ZID = Zonal Impacted Degraded.

Number of trap line	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Habitats	**TIG**	**TIG**	**TIG**	**TBE**	**TBE**	**ABE**	**ABE**	**ABE**	**AID**	**ZBE**	**ZBE**	**ZID**	**AIG**	**TID**	**ZIG**
Number of trap-nights	280	280	240	240	560	320	400	80	300	300	300	300	300	300	300
Afrosoricida															
Microgale talazaci	-	-	-	1	-	-	-	-	-	-	-	-	2	-	-
Setifer setosus	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Tenrec ecaudatus	1	4	1	-	-	-	-	-	-	4	2	-	2	4	-
Number of individual Afrosoricida captured	**1**	**4**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**4**	**2**	**0**	**4**	**4**	**1**
Capture rate (%) of Afrosoricida	**0.3**	**1.4**	**0.4**	**0.4**	**0**	**0.3**	**0**	**0**	**0**	**1.3**	**0.6**	**0**	**1.3**	**1.3**	**0.3**
Rodentia															
Eliurus minor	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eliurus webbi	-	-	-	-	-	-	-	-	-	-	1	-	-	2	-
Nesomys rufus	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-
*Rattus rattus**	1	6	-	1	1	-	1	-	1	-	-	-	2	4	-
Carnivora															
Galidictis fasciata	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Number of captured endemic rodent species	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**1**	**0**
Number of individual endemic rodents captured	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**2**	**0**
Capture rates (%) of endemic rodents	**0.3**	**0**	**0**	**0.5**	**0**	**0**	**0**	**0**	**0**	**0.3**	**0.3**	**0**	**0**	**0.6**	**0**
Total number of captured rodents	**2**	**6**	**0**	**2**	**1**	**0**	**1**	**0**	**1**	**1**	**1**	**0**	**2**	**6**	**0**
Capture rates (%) for rodents	**0.7**	**2.0**	**0**	**0.8**	**0.1**	**0**	**0.2**	**0**	**0.3**	**0.3**	**0.3**	**0**	**0.6**	**1.6**	**0**
Total number of captured mammals	**3**	**10**	**1**	**3**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**0**	**2**	**11**	**1**
Capture rate (%) of mammals	**1.0**	**3.5**	**0.4**	**1.3**	**0.1**	**0.3**	**0.2**	**0**	**0.3**	**0.3**	**0.3**	**0**	**0.6**	**3.6**	**0.3**

Table 6. Summary of standard trap (Sherman and National) results for small mammals in the different habitat types of the Ambatovy-Analamay region during six nights of trapping. ABE = Azonal Benchmark, AIG = Azonal Impacted Good Quality, TID = Transitional Impacted Degraded, TBE = Transitional Benchmark, TIG = Transitional Impacted Good Quality, and ZBE = Zonal Benchmark.

Habitats	ABE	AIG/TID	TBE	TIG	ZBE
Number of trap-nights	600	600	600	600	600
Afrosoricida					
Microgale talazaci	-	2	1	-	-
Setifer setosus	1	-	-	-	-
Tenrec ecaudatus	-	6	-	6	6
Number of individual Afrosoricida captured	**1**	**8**	**1**	**6**	**6**
Capture rate (%) of Afrosoricida	**0.2**	**1.3**	**0.2**	**1.0**	**1.0**
Rodentia					
Eliurus minor	-	-	-	1	-
Eliurus webbi	-	2	-	-	1
Nesomys rufus	-	-	1	-	1
*Rattus rattus**	1	6	2	7	-
Carnivora					
Galidictis fasciata	-	1	-	-	-
Number of captured endemic rodent species	**0**	**1**	**1**	**1**	**2**
Number of individual endemic rodents captured	**0**	**2**	**1**	**1**	**2**
Capture rates (%) of endemic rodents	**0**	**0.3**	**0.2**	**0.2**	**0.3**
Total number of captured rodents	**1**	**8**	**3**	**8**	**2**
Capture rates (%) for rodents	**0.2**	**1.3**	**0.5**	**1.3**	**0.3**
Total number of captured mammals	**2**	**17**	**4**	**14**	**8**
Capture rate (%) of mammals	**0.3**	**2.8**	**0.6**	**2.3**	**1.3**

results are difficult to interpret. The only point worth mentioning is that the Azonal Impacted Degraded habitat shows the lowest degree of similarity, as no endemic taxon was obtained.

In a broader comparison of the different small mammal communities occupying the three different habitat types (azonal, zonal, and transitional), no clear relationship was found in the inter-habitat comparisons and their floristic association. This would indicate a certain level of homogeneity and that the habitat classification proposed for the local forest types within the Ambatovy-Analamay region (Goodman & Raselimanana, pp. 36-37) is not directly related to distribution of small mammals. In this sense, it is important to reiterate that all of the different habitats surveyed have experienced at least some human perturbation.

Comparisons of small mammal communities between the Ambatovy-Analamay-Torotorofotsy complex and other mid-elevation sites in the central east of Madagascar

In Table 10, we present known small mammal faunal lists from a selection of sites at Ambatovy and Torotorofotsy, and several other mid-elevation forests in the central east of Madagascar. In all of these cases, with the exception of Ambatovy and Torotorofotsy, the same trapping effort and protocols were used in the small mammal inventories. The Jaccard's Similarity coefficients for the faunal relationships of these different sites are presented in Table 11.

When other mid-elevation central eastern sites outside of the Ambatovy-Analamay region are included in this analysis for the Afrosoricida, there is a distinct grouping of the nine habitats inventoried in the context of this survey with the other sites part of the Ambatovy-Analamay-Torotorofotsy complex (Figure 4a). The only exception is the Azonal Impacted Degraded habitat, where no Afrosoricidia was captured, and forms an outlying branch of the dendrogram. The Transitional Benchmark habitat, the Torotorofotsy forest, and the Ambatovy forest form a sub-group. The other major group was composed of all of the other central eastern mid-elevation sites, including Maromiza, which is a short distance to the southeast of the Ambatovy-Analamay-Torotorofotsy complex.

In the case of rodents, most sites of the Ambatovy-Analamay-Torotorofotsy complex are divided into two separate and not closely related groups (Figure 4b); this separation is presumed to be biologically unimportant and associated with low species diversity. The Azonal Impacted Degraded habitat did not have a single endemic taxon and forms a separate outlying branch. The exceptions to the above-mentioned groupings are Torotorofotsy and the Transitional Benchmark habitat, which falls within a separate group, composed of the other central eastern mid-elevation sites.

Carnivora

Although 1080 trap-nights were accrued for the National traps installed in the context of the carnivoran lines in nine different habitats, not a single member of this order was captured in these lines. One individual of *Galidictis fasciata*, a member of the endemic family

Table 7. Summary information on trapping success of small mammals in nocturnal lemur trap lines in the different habitat types of the Ambatovy-Analamay forest. TIG = Transitional Impacted Good Quality, TBE = Transitional Benchmark, ZBE = Zonal Benchmark, ZIG = Zonal Impacted Good Quality, and AIG = Azonal Impacted Good Quality.

Habitats	TIG	TBE	ZBE	ZIG	AIG
Trap-nights	**280**	**280**	**280**	**240**	**240**
Afrosoricida					
Microgale talazaci	-	-	-	-	1
Rodents					
Eliurus grandidieri	-	-	-	2	-
Eliurus minor	1	-	-	-	-
Eliurus tanala	-	1	-	-	2
Eliurus webbi	-	-	1	1	-
*Rattus rattus**	-	-	-	-	1
Number of rodent species captured	**1**	**1**	**1**	**2**	**2**
Number of individual endemic rodents captured	**1**	**1**	**1**	**3**	**2**
Total number of individual rodents captured	**1**	**1**	**1**	**3**	**3**
Capture rate (%) of endemic rodents	**0.4**	**0.4**	**0.4**	**1.3**	**1.3**
Capture rate (%) of rodents	**0.4**	**0.4**	**0.4**	**1.3**	**0.8**

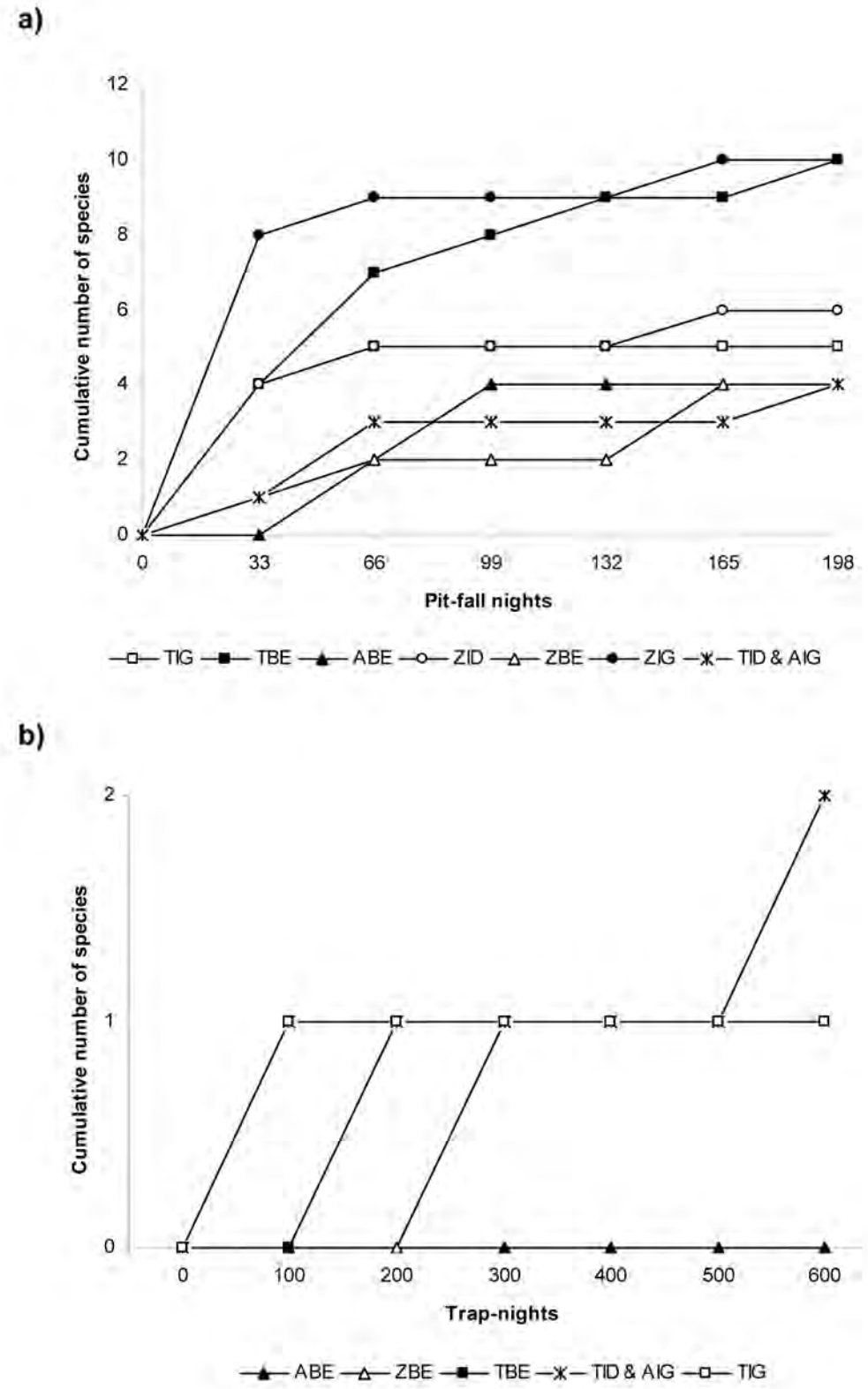

Figure 2. Species accumulation curves based on trapping effort for small mammals in the nine different habitats in the Ambatovy-Analamay region, **a)** Afrosoricida in pit-fall traps and **b)** Rodentia in the standard traps (Sherman and National), excluding the nocturnal lemur lines. TIG = Transitional Impacted Good Quality, TBE = Transitional Benchmark, ABE = Azonal Benchmark, ZID = Zonal Impacted Degraded, ZBE = Zonal Benchmark, AIG = Azonal Impacted Good Quality, TID = Transitional Impacted Degraded, and ZIG = Zonal Impacted Good Quality.

Eupleridae, was obtained in a National trap, which was installed as part of the standard trap lines in the Transitional Impacted Degraded habitat. Combining all of the carnivoran and small mammal traps, 5,580 trap-nights were accrued, giving a trap success for Carnivora of 0.02%. In addition, an individual of *Fossa fossana* was noted at night in the Zonal Impacted Degraded habitat, which was the only

Table 8. Shannon-Weaver Diversity Index for small mammals in the different inventoried sites in the Ambatovy-Analamay region, as well as the Lakato and Maromiza forests (Vahatra, unpublished data). TIG = Transitional Impacted Good Quality, TBE = Transitional Benchmark, ABE = Azonal Benchmark, ZID = Zonal Impacted Degraded, ZBE = Zonal Benchmark, AIG = Azonal Impacted Good Quality, TID = Transitional Impacted Degraded, and ZIG = Zonal Impacted Good Quality.

	TIG	TBE	ABE	ZID	ZBE	AIG&TID	ZIG	Maromiza	Lakato
Afrosoricida	0.504	0.706	0.649	0.552	0.501	0.311	0.702	0.831	0.799
Rodentia	0	0	0	-	0.301	0	-	0.562	0.507

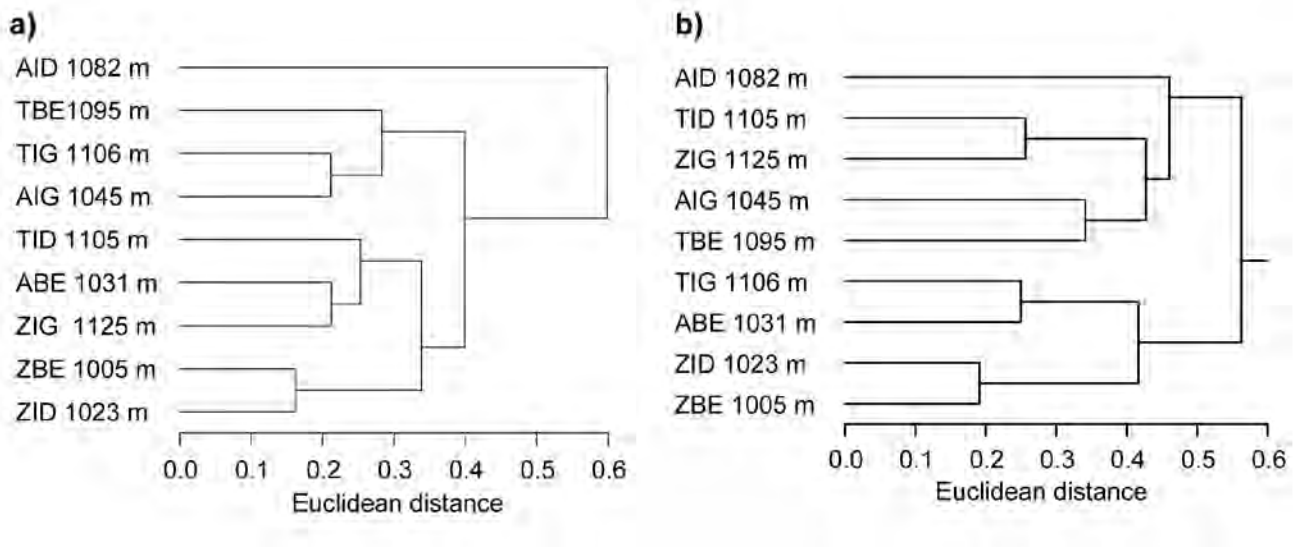

Figure 3. Dendrograms of faunal similarities of endemic small mammals inventoried at the different sites in the Ambatovy-Analamay region based on the Jaccard's index, **a)** Afrosoricida and **b)** Rodentia. ABE = Azonal Benchmark, AIG = Azonal Impacted Good Quality, AID = Azonal Impacted Degraded, TBE = Transitional Benchmark, TIG = Transitional Impacted Good Quality, TID = Transitional Impacted Degraded, ZBE = Zonal Benchmark, ZIG = Zonal Impacted Good Quality, and ZID = Zonal Impacted Degraded.

other direct observation of a native carnivoran during the early 2009 field surveys. On the basis of scats characteristic of *Cryptoprocta ferox* recovered in the Azonal Degraded habitat, it could be determined that this species also occurs locally. People living in the immediate vicinity of the Ambatovy-Analamay region mentioned that *Galidia elegans* probably occurs in the Zonal Benchmark and Zonal Impacted Degraded habitats. Finally, one other species of carnivoran described by local villagers is almost certainly the introduced carnivoran *Viverricula indica* (Family Viverridae). Scats of a carnivoran found in the Azonal Degraded habitat and composed mostly of insects are probably of this taxon.

Table 9. Jaccard Similarity indices for Afrosoricida (below the diagonal) and Rodentia (above the diagonal) in the nine different habitats in the Ambatovy-Analamay region. ABE = Azonal Benchmark, AIG = Azonal Impacted Good Quality, AID = Azonal Impacted Degraded, TBE = Transitional Benchmark, TIG = Transitional Impacted Good Quality, TID = Transitional Impacted Degraded, ZBE = Zonal Benchmark, ZIG = Zonal Impacted Good Quality, and ZID = Zonal Impacted Degraded.

Habitats	ABE	AIG	AID	TBE	TIG	TID	ZBE	ZIG	ZID
ABE		0	0	0.5	0.5	0	0.33	0	0.5
AIG	0.38		0	0.5	0	0.33	0	0.33	0
AID	0	0		0	0	0	0	0	0
TBE	0.33	0.5	0		0.33	0.25	0.25	0.25	0.33
TIG	0.22	0.67	0	0.5		0	0.25	0	0.33
TID	0.57	0.67	0	0.36	0.43		0.5	0.5	0.25
ZBE	0.57	0.67	0	0.36	0.43	0.43		0.2	0.67
ZIG	0.60	0.5	0	0.54	0.36	0.5	0.5		0.25
ZID	0.44	0.5	0	0.42	0.33	0.33	0.71	0.42	

Table 10. Distribution of small mammals at different sites in the central eastern portion of mid-elevation humid forests. Data from Ambatovy (UADBA specimens), Torotorofotsy (UADBA specimens), Maromiza (Vahatra, unpublished data), Lakato (Vahatra, unpublished data), and Vatoharanana, Vinanitelo, and Andrambovato (Soarimalala *et al*., 2001). Non-endemic taxa are excluded from these comparisons.

	Ambatovy 1025 m	Torotorofotsy 980 m	Maromiza 980 m	Lakato 980 m	Vatoharanana 1025 m	Vinanitelo 1100 m	Andrambovato 1075 m
Site abbreviations	**S1**	**S2**	**S4**	**S2**	**S7**	**S5**	**S6**
Afrosoricida							
Hemicentetes semispinosus	+	+	-	+	-	-	+
Microgale cowani	+	+	-	-	-	+	-
Microgale dobsoni	+	-	+	-	-	-	+
Microgale drouhardi	+	+	+	+	+	+	-
Microgale fotsifotsy	+	+	+	+	+	+	+
Microgale gymnorhyncha	-	-	+	+	+	+	+
Microgale jobihely	+	-	-	-	-	-	-
Microgale longicaudata	+	+	+	-	+	+	+
Microgale majori	+	+	-	-	-	-	-
Microgale parvula	+	-	+	-	+	+	+
Microgale principula	-	+	+	+	+	-	-
Microgale soricoides	-	-	+	-	+	-	+
Microgale taiva	+	-	+	-	+	+	+
Microgale talazaci	+	+	+	+	+	-	-
Microgale thomasi	+	+	-	+	+	-	+
Oryzorictes hova	+	+	+	-	+	-	-
Setifer setosus	+	+	+	-	+	-	+
Tenrec ecaudatus	+	+	+	-	-	+	-
Number of species of Afrosoricida	**15**	**12**	**13**	**7**	**12**	**8**	**10**
Soricomorpha							
Suncus madagascariensis	+	-	-	-	-	-	-
Number of species of Soricomorpha	**1**	**0**	**0**	**0**	**0**	**0**	**0**
Rodentia							
Brachytarsomys albicauda	+	-	-	-	-	-	-
Eliurus grandidieri	-	-	+	-	-	-	-
Eliurus majori	-	-	-	-	-	+	-
Eliurus minor	+	+	+	+	+	+	+
Eliurus tanala	+	+	+	+	+	+	+
Eliurus webbi	+	+	-	+	+	-	+
Gymnuromys roberti	+	+	-	-	+	+	+
Monticolomys koopmani	-	-	-	-	+	-	-
Nesomys audeberti	-	+	-	-	+	-	-
Nesomys rufus	+	-	+	+	+	+	+
Number of species of Rodentia	**6**	**5**	**4**	**4**	**7**	**5**	**5**
Total number of small mammal species	**22**	**17**	**17**	**11**	**19**	**13**	**15**

Artiodactyls

Signs of the bush pig, *Potamochoerus larvatus*, were found in four different habitats (Azonal Benchmark, Transitional Impacted Good Quality, Zonal Benchmark, and Zonal Impacted Degraded; Table 3). These signs include their distinctive scats and diagnostic diggings in the ground. Bush pigs have a broad distribution on the island in a variety of natural and anthropogenic habitats. This animal's status on Madagascar is unclear and it was either introduced to the island, presumably by settlers of Bantu origin, or has naturally colonized the island in the past few millennia (Andrianjakarivelo, 2003; Goodman *et al*., 2008).

Table 11. Jaccard Similarity indices for Afrosoricida (below the diagonal) and Rodentia (above the diagonal) for the nine inventoried sites in the Ambatovy-Analamay region, Ambatovy, Torotorofotsy and other inventoried mid-elevation localities in the central east. Sources of information for the other sites: S1 = Ambatovy 1100 m (specimens in UADBA), S2 = Torotorofotsy 980 m (specimens in UADBA), S3 = Maromiza 980 m (Vahatra, unpublished data), S4 = Lakato 980 m (Vahatra, unpublished data), S5 = Vatoharanana 1025 m (Soarimalala *et al*., 2001), S6 = Vinanitelo 1100 m (Soarimalala *et al*., 2001), and S7 = Andrambovato 1075 m (Soarimalala *et al*., 2001).

Habitat and sites	ABE	AIG	AID	TBE	TIG	TID	ZBE	ZIG	ZID	S1	S2	S3	S4	S5	S6	S7
ABE		0	0	0.50	0.50	0	0.33	0	0.50	0.17	0	0.25	0.25	0.14	0.20	0.20
AIG	0.38		0	0.50	0	0.33	0	0.33	0	0.17	0.20	0.25	0.25	0.14	0.20	0.20
AID	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0
TBE	0.33	0.50	0		0.33	0.25	0.25	0.25	0.33	0.33	0.17	0.50	0.50	0.29	0.40	0.40
TIG	0.22	0.67	0	0.50		0	0.25	0	0.33	0.33	0.17	0.50	0.50	0.29	0.40	0.40
TID	0.57	0.67	0	0.36	0.43		0.50	0.50	0.25	0.50	0.60	0.17	0.40	0.43	0.33	0.60
ZBE	0.57	0.67	0	0.36	0.43	0.43		0.20	0.67	0.50	0.33	0.17	0.40	0.43	0.33	0.60
ZIG	0.60	0.50	0	0.54	0.36	0.50	0.50		0.25	0.29	0.33	0.40	0.40	0.25	0.14	0.33
ZID	0.44	0.50	0	0.42	0.33	0.33	0.71	0.42		0.33	0.17	0.20	0.50	0.29	0.17	0.40
S1	0.40	0.33	0	0.67	0.33	0.33	0.33	0.67	0.38		0.57	0.43	0.67	0.63	0.57	0.83
S2	0.39	0.42	0	0.83	0.42	0.31	0.36	0.57	0.58	0.69		0.29	0.50	0.71	0.43	0.67
S3	0.27	0.29	0	0.44	0.29	0.29	0.20	0.44	0.33	0.56	0.47		0.60	0.38	0.50	0.50
S4	0	0.09	0	0.42	0.20	0.09	0	0.13	0.17	0.29	0.46	0.33		0.57	0.50	0.80
S5	0.20	0.21	0	0.47	0.31	0.21	0.13	0.38	0.27	0.50	0.50	0.79	0.46		0.50	0.71
S6	0.40	0.08	0	0.29	0.08	0.18	0.18	0.39	0.25	0.44	0.33	0.50	0.25	0.43		0.67
S7	0.23	0.07	0	0.33	0.15	0.15	0.07	0.18	0.13	0.47	0.29	0.53	0.31	0.57	0.39	

Discussion

Small mammals

Species lists

On the basis of the survey conducted in the Ambatovy-Analamay region in early 2009, two species of small mammal, *Eliurus grandidieri* and *Microgale jobihely*, are reported for the first time from the immediate zone. On the other hand, two species of shrew-tenrecs, *M. dobsoni* and *M. gymnorhyncha*, were previously reported from the region but were not captured during the early 2009 inventories (see Table 1).

In subsequent fieldwork at Ambatovy (in the latter portion of 2009), two previously locally unrecorded species were captured: *Microgale parvula* and *Suncus madagascariensis*. Amongst rodents, the notably large-bodied *Brachytarsomys albicauda* was found in a hole of a standing tree trunk during the project's salvaging activities conducted during forest clearing. This rodent probably has a broad distribution in the eastern humid forests, but given its size and its arboreal habits, this species is rarely captured and is often unrecorded in most regional small mammal surveys. In the case of our research in the Ambatovy-Analamay forests, it is not clear if the absence of this species in our trapping results is due to low densities of this species or the difficultly in trapping it.

The shrew-tenrec *Microgale jobihely* was described in 2006 based on material collected on the southwestern slope of the Tsaratanana Massif (Goodman *et al*., 2006). This species appears to have a very disjunct distribution, only being known from the original type locality and Ambatovy (Soarimalala *et al.,* in press). Numerous other forested areas between these two sites have been inventoried using identical field techniques and no evidence of *M. jobihely* has been found (Goodman & Jenkins, 1998, 2000; Soarimalala & Goodman, 2003; Rakotomalala *et al*., 2007; Soarimalala *et al*., 2007; Maminirina *et al*., 2008).

The presence of *Eliurus grandidieri* is also noteworthy. This animal was described in 1998 based on material collected on the Anjanaharibe-Sud Massif (Carleton & Goodman, 1998). Subsequently, it has been found at other sites in the north (Soarimalala & Goodman, 2003) and south to the Anjozorobe and Fandriana-Marolambo forests (Soarimalala, 2007; Soarimalala *et al*., 2007).

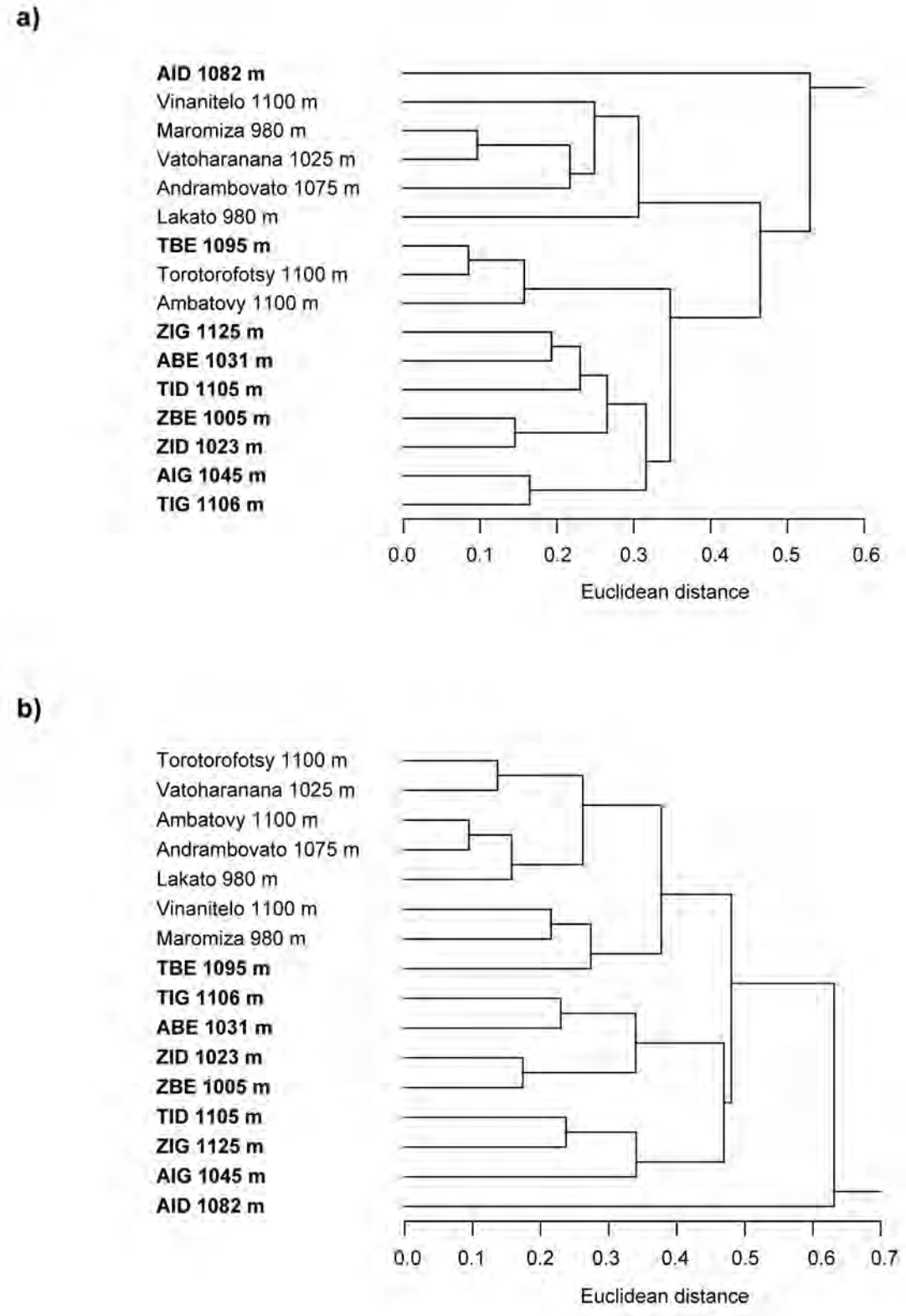

Figure 4. Dendrograms based on the Jaccard's index of faunal similarities of endemic small mammals inventoried at the different sites in the Ambatovy-Analamay region, Ambatovy, Torotorofotsy, and other inventoried mid-elevation localities in the central east, **a)** Afrosoricida and **b)** Rodentia. ABE = Azonal Benchmark, AIG = Azonal Impacted Good Quality, AID = Azonal Impacted Degraded, TBE = Transitional Benchmark, TIG = Transitional Impacted Good Quality, TID = Transitional Impacted Degraded, ZBE = Zonal Benchmark, ZIG = Zonal Impacted Good Quality, and ZID = Zonal Impacted Degraded. Other sites and sources of information: S1 = Ambatovy 1100 m (specimens in UADBA), S2 = Torotorofotsy 980 m (specimens in UADBA), S3 = Maromiza 980 m (Vahatra, unpublished data), S4 = Lakato 980 m (Vahatra, unpublished data), S5 = Vatoharanana 1025 m (Soarimalala *et al*., 2001), S6 = Vinanitelo 1100 m (Soarimalala *et al*., 2001), and S7 = Andrambovato 1075 m (Soarimalala *et al*., 2001).

Species richness

When comparing our measures of small mammal species richness between the nine different surveyed habitats in the Ambatovy-Analamay region there are some notable differences between sites (the number of documented endemic species varies from 0 to 13). These differences may be explained in part by vegetational structure.

In general, the azonal habitat group had low species richness, with the Azonal Impacted Degraded habitat completely lacking any native small mammals. This habitat consists largely of monospecific *Erica* bush, and, hence, this result is not surprising.

The lower species richness of the azonal habitats, as compared to the transitional and zonal habitats may be correlated with substrate variation. The azonal habitats largely occur on very hard packed soils, generally lack ground litter and herbaceous vegetation, and therefore provide few microhabitats that might be occupied by small mammals. Furthermore, these biologically poor zones have fewer food resources, such as soil invertebrates for Afrosoricida or fruits and seeds for Rodentia. In contrast, in the transitional and zonal habitat types, the understory often has an herbaceous vegetation layer and a moderately to well-developed soil litter. There are also distinctions between the three different habitat types inventoried in the transitional and zonal habitats, with more iron dominated soils in the transitional habitats and a more red or yellow clay alluvium soil in the zonal habitats (Goodman & Raselimanana, pp. 40-42). While the species diversity between these habitats did not differ considerably, there were notable differences in the species composition of the local small mammal communities. The absence or presence of certain taxa in a given habitat can be explained by certain life history traits of the species in question. For example, *Oryzorictes hova*, was generally only found in forested habitats with little to moderate levels of degradation, as this taxon is partially fossorial and feeds on soil invertebrates found in rich ground humus.

When examined in a broader sense, the small mammal fauna of the Ambatovy-Analamay region is relatively rich. This is associated with the range of different microhabitats found in the eight surveyed forest habitats. On the basis of our 2009 surveys and earlier research, the Ambatovy-Analamay region holds 20 species of endemic small mammals (Table 3). If the fauna of the Ambatovy and Torotorofotsy sites are included, 25 species of endemic small mammals are known from the Ambatovy-Analamay-Torotorofotsy complex (Table 1).

A number of field inventories have been conducted on rodents and tenrecs occurring in the mid-elevation humid forests of Madagascar, in particular, for comparisons presented here, in the central eastern portion of this zone (Soarimalala *et al*., 2001, 2007; Soarimalala & Goodman, 2003; Vahatra, unpublished). In comparison to these other sites, the Ambatovy-Analamay-Torotorofotsy complex holds a small mammal community of moderate species richness (Table 10). In general, across the eastern humid forests of the island, the zone below 1200 m has a distinct reduction in species richness of small mammals as compared to areas at slightly higher elevations (Goodman *et al*., 2008). Hence, all of the sites chosen for comparison are below 1200 m.

Variation in relative abundance

There was considerable variation in capture rates of small mammals between the different habitats surveyed in the Ambatovy-Analamay region. Excluding the azonal habitat type, where very few animals were captured, the Transitional Impacted Good Quality and Zonal Impacted Degraded habitats also had very low trapping success (Tables 4, 5). Given that the season and trapping regimes were similar between these sites, this variation is considered to reflect differences in the density and species composition of the small mammal communities in these habitats.

As mentioned earlier, a number of sites within the general region of Ambatovy-Analamay have been surveyed for small mammals, using similar methodologies as reported herein, including Maromiza and Lakato (just to the south of Route National 2 and to the east of Moramanga), Vinanitelo, Andrambovato, and Vatoharanana between the Parc National de Ranomafana and the Parc National d'Andringitra (Soarimalala *et al*., 2001; Vahatra unpublished data). Faunistic information from these areas provides an important point of reference to evaluate measures of species richness and relative abundance obtained for the Ambatovy-Analamay region.

Capture rates in the pit-fall traps placed in the Ambatovy-Analamay habitats varied from 4.0 to 24.7%, while capture rates at other regional sites are 25.8% at Maromiza, 9.0% at Lakato, 19.0% at Andrambovato, 37.0% at Vinanitelo, and 40.0% at Vatoharanana. It is important to reiterate that within the Zonal Impacted Good Quality habitat, which had the highest capture rates of all the Ambatovy-Analamay habitats (24.7%), *Tenrec ecaudatus* was the dominate species, comprising 54% of the captures. In the case of the standard traps, capture rates for rodents in the

Ambatovy-Analamay region were notably reduced (0.3 to 1.3%) as compared to other regional sites, 2.5% at Lakato, 3.5% at Maromiza, 4.0% at Andrambovato, 7.0% at Vinanitelo, and 11.6% at Vatoharanana. Our results show that the surveyed sites in the Ambatovy-Analamay region have notably reduced small mammal densities as compared to other regional forests where the same trapping methodology was employed. Although certain methodological aspects were not in parallel with the techniques used by our research group, there is some indication that sites within the nearby Mantadia-Zahamena forest corridor and the Réserve Spéciale d'Analamazaotra also have reduced small mammal densities based on capture results (Stephenson, 1993; Rakotondraparany & Medard, 2005).

Several biotic and abiotic factors, acting in a simultaneous fashion, can explain these differences. For example, patterns of microclimate variation associated with elevation and orographic effects, have a direct effect on differences in temperature and humidity, and, hence, vegetational and habitat structure. These aspects, amongst others, have a direct bearing within a given habitat on, for example, 1) soil litter and the associated soil invertebrates which are linked to the diet of insectivorous small mammals and 2) vegetational communities producing seeds and fruits consumed by rodents.

Natural (cyclone) or anthropogenic disturbances can also have a direct effect on forest structure, which in turn, influences the locally occurring small mammal communities. Given the low densities of small mammals in the Ambatovy-Analamay forests, all of which have been degraded to different degrees by human activities, this aspect, combined with soil types, might explain the low densities of these animals. One final aspect to consider is that the opening of forests associated with different types of exploitation is presumed to facilitate the colonization of these zones by introduced rodents, specifically *Rattus rattus*. The entry of these animals into a forest block, particularly in mid-elevation habitats, is correlated with a reduction in the native rodent fauna (Goodman, 1995; Goodman *et al*., 1996, 1997; Carleton & Goodman, 2000; Soarimalala, 2007). Whether this is associated with competition or the introduction of diseases into the Nesomyinae fauna, or both, is unclear.

The Shannon-Weaver Diversity values for the Afrosoricida in the eight forested habitats surveyed in early 2009 (Table 8) indicate that the Transitional Benchmark and Zonal Impacted Good Quality habitats have the highest coefficient, which translates into a relatively rich fauna not dominated by any particular taxon. In contrast, the dominance of *Tenrec ecaudatus* in the Azonal Impacted Good and Transitional Impacted Good habitats indicates a disparity in community structure and hence low diversity coefficients. Given low species diversity, combined with low capture rates, it is difficult to interpret these values for the locally occurring rodent communities.

Inter-habitat differences

With the exception of the azonal habitat type, which has very low small mammal diversity, species richness in the transitional and zonal habitat types indicates more subtle differences. It is clear that these different habitat types share a considerable proportion of small mammal diversity and an important level of homogeneity. The results of the Jaccard faunal analyses between the different habitat types support this observation. However, within these analyses there is no clear grouping for the Afrosoricida or Rodentia with regards to the habitat classification (azonal, zonal, and transitional), which indicates that the distribution of these animals does not necessarily conform to the habitat classification system. More specifically, the habitats considered as being in a relatively good state in relation to anthropogenic pressures, such as the Transitional Impacted Good Quality and Zonal Impacted Good Quality, do not necessarily have similar faunas as compared to those in more degraded states, such as the Transitional Impacted Degraded and Zonal Impacted Degraded. The single notable exception appears to be the Zonal Impacted Good habitat, the only zone where the rodent *Eliurus grandidieri* and the shrew-tenrec *Microgale jobihely* were captured in the Ambatovy-Analamay region. The absence of endemic small mammals in the Azonal Impacted Degraded habitat is not surprising given the locally occurring monospecific stands of *Erica* bush. Furthermore, evidence for the lack of a relationship between habitat classification, habitat quality, and the small mammal composition can be seen in the distribution of the forest-dwelling *M. principula*, which was only captured in the Zonal Impacted Degraded habitat. The relatively elevated species richness in the Zonal Impacted Good Quality habitat might be associated with the presence of numerous microhabitats.

In certain cases, there may be a stochastic element involved in the faunal composition of a local community, particularly during rapid inventories, presumably associated with several variables including dispersal patterns, difficulty in capturing

small mammals, bait types, or rarity tied in part to population demography. This is highlighted with the case of *Eliurus grandidieri*, which was only captured once in a trap placed for small nocturnal lemurs and baited with fruit. Further, the impacts of habitat degradation associated with human activities are elements that are difficult to assess based on current information. The understanding of the importance of these different factors in explaining the distribution of small mammals amongst the eight Ambatovy-Analamay forest habitats can only be deciphered based on long-term ecological monitoring studies.

Biogeographic analysis

The small mammal species composition of the Ambatovy-Analamay forests is typical of montane forest habitats of the Central Domain of Madagascar. In all cases, the mammal species of the Ambatovy-Analamay forests exist in other portions of the Central Domain (Humbert, 1965), which in a phytogeographical sense is the portion of the region occurring above 800 m (Perrier de la Bâthie, 1921).

In the case of the Afrosoricida, the Ambatovy-Analamay-Torotorofotsy complex forms a distinct group, separate from the other central east mid-elevation sites (Figure 4a). This is at least in part due to the absence of the shrew-tenrec *Microgale soricoides* in the complex, which otherwise has a broad distribution across this region. Further, the local absence of this species may be correlated with local ecological changes at different sites within the complex associated with human perturbation. This can result in certain species being rare and not captured during a rapid inventory or their local extirpation. Another explanation is based on combinations of ecological factors, which we simply do not understand, and this taxon never colonized the Ambatovy-Analamay-Torotorofotsy forest block. In trying to understand these factors, we can cite the example of the Azonal Impacted Degraded habitat, a heavily degraded habitat in which no native small mammal species are found. In this case, local extirpation would be the most reasonable explanation.

Another interesting example is that of *M. jobihely*. This species was only found in the Zonal Impacted Good Quality habitat of the Ambatovy-Analamay forests. The only other site across Madagascar where it has been documented is the southwestern slope of the Tsaratanana Massif, 485 km to the northwest. Further, in the Ambatovy-Analamay forests, it is only known from six specimens obtained between 2007-2009 (Soarimalala *et al*., in press). Amongst the Afrosoricida, there is no species recognized that is particular to the Ambatovy-Analamay-Torotorofotsy complex. Although, one species of Soricomorpha, *Suncus madagascariensis*, is broadly distributed in the western dry forests and is notably uncommon in eastern humid forests.

For the Rodentia, the biogeographic analyses are not informative concerning the Ambatovy-Analamay habitats, which separate into two groups with no relationship to the habitat classification, and, in general, are faunistically homogeneous (Figure 4b). One interesting aspect is that the faunal affinity of the Transitional Benchmark habitat shows a closer relationship with the mid-elevation central eastern sites than to the other habitats within the Ambatovy-Analamay forests. Amongst the locally occurring native Rodentia, there is no species recognized that is particular to the Ambatovy-Analamay-Torotorofotsy complex.

Carnivora

Based on the trapping results and observations, our data indicate that the density of Carnivora in the Ambatovy-Analamay forests is notably low. Scats of *Cryptoprocta ferox* were found in the Azonal Impacted Good Quality habitat, but not in any of the other eight habitat types. Given the seemingly uncommon occurrence of *C. ferox* in the Ambatovy-Analamay forests, combined with its large estimated home range (4 to 5 km^2) in the eastern humid forest (Wright *et al*., 1997; Dollar, 1999), it can be surmised that this animal is rare in the study habitats. Based on discussion with local people, *Galidia elegans* is also present within the region but at very low densities. This distinctive diurnal animal was not trapped or observed during our combined six weeks of field research in the region. In other eastern humid forests, such as the Réserve Spéciale d'Ivohibe, Parc National d'Andohahela, and Parc National d'Andringitra, this carnivoran is common and can often be captured in traps set for small mammals (Goodman, 1996; Goodman & Pidgeon, 1999; Rasolonandrasana & Goodman, 1999). Given that the dietary regime of endemic Malagasy Carnivora of the family Eupleridae is composed of mammal prey, it is not surprising that the density of carnivorans in the Ambatovy-Analamay forests is low given the reduced density of the small mammal prey base.

The species of native carnivorans found in the Ambatovy-Analamay forests is largely identical with other eastern humid forest zones found within the same elevation range. One exception is *Eupleres*

goudoti, which has a broad distribution in the region, having been recorded in the Parc National de Mantadia, Réserve Spéciale d'Analamazaotra, and the Maromiza forest (Goodman & Helgen, in press). Given the difficulty in observing this nocturnal species, which has a strong affinity for marsh habitat within forest, it may be locally present in the complex, particularly the Torotorofotsy region.

IUCN status

In Table 3, we present the IUCN (2009) conservation status for each of the non-primate mammals found during our inventory work in the Ambatovy-Analamay region. One species of small mammal, *Microgale jobihely*, is considered Endangered and the carnivoran, *Cryptoprocta ferox*, is considered Vulnerable. The majority of species present are considered Least Concern and no Critically Endangered species was found.

Introduced species

During the course of our research in the Ambatovy-Analamay region, the majority of the habitats studied contained an important percentage of introduced rodents and, to lesser extent, bush pigs. This may be indirectly or directly related to human activities within these forest systems. Based on observations, the impact of bush pigs on the different habitats seems to be minimal. Although, at a few localities, the number and extent of holes dug into the ground was extensive which might have a local impact on forest regeneration.

There is evidence from Madagascar and other tropical countries that when non-native *Rattus* colonize natural forest habitats, there is a distinct reduction in the density and diversity of native rodents (Goodman, 1995; Lynam, 1997). Data from the Central Highlands of Madagascar confirm this observation, where at numerous sites, the density of endemic rodents is notably low in comparison to introduced species (Nicoll *et al*., 1988; Stephenson, 1993; Goodman *et al*., 1996, 1997; Carleton & Goodman, 2000; Soarimalala, 2007). Three different factors may explain this observation: 1) demography, including higher reproductive rates and survivorship in *Rattus* than in Nesomyinae rodents, 2) the former out-competes the latter for food resources and/or perhaps nesting sites, and 3) the former is responsible for the introduction of deleterious diseases into endemic populations. It has been shown that amongst Nesomyinae rodents, few if any are able to survive local outbreaks of bubonic plague, which are not uncommon in the Central Highlands of Madagascar, while a significant percentage of introduced *Rattus* survive (Duplantier & Duchemin, 2003).

Recommendations

Given that mineral exploitation is planned in the Ambatovy-Analamay forest, as well as the clearance of forest associated with the installation of infrastructure for these activities, it is crucial to protect a maximum number of local habitats with particular biotas. Long-term ecological monitoring projects need to be implemented for the proper management of species-specific research and conservation programs. These actions are considered the minimum necessary to protect the regional biological diversity. In cases where local habitats are notably reduced in size, it is considered paramount to protect the largest area possible to maintain their long-term viability.

Based on the small mammal data presented here, the most critical habitat to protect in the Ambatovy-Analamay forest is Zonal Impacted Good Quality, as the greatest number of endemic species (13) are found within this habitat including *Microgale jobihely*, which is only known from two disjunct areas and is IUCN listed as endangered. As presented in the above biogeographic analyses, the small mammal community of the Ambatovy-Analamay region forms a subset of that occurring in other areas of the central eastern humid forests. With the exception of *M. jobihely,* all of the small mammal species occurring in the Ambatovy-Analamay block are represented in existing regional protected areas. However, given the heavy human pressure across eastern Madagascar on mid-elevation forests, the current protected area system is inadequate. Thus, it is important to conserve other portions of the larger and relatively intact forest blocks within the Ambatovy-Analamay region as additional refuges for regional taxa.

In relation to the impact of *Rattus rattus* on the native rodents of Madagascar, it is difficult to advance an explicit conservation program. The use of rodenticides is inappropriate, as these would presumably also exterminate the endemic rodent fauna. Within the exploitation area, it will be important to reduce exposed trash and waste, which will attract *Rattus* and provide the nutritional means for population increase and presumed subsequent dispersal to the forested sectors of the region.

The notably reduced density of Carnivora in the Ambatovy-Analamay region maybe associated with low prey density. However, given the high densities

of *Rattus* in certain habitats, this is partially counter-intuitive. In other humid forest areas of Madagascar, there is evidence that diseases have been introduced into the local endemic carnivoran communities, which have greatly reduced populations to the point of near extirpation. This may be associated with the presence of dogs and cats (Vahatra, unpublished data). To avoid further potential introduction of these types of diseases into the Ambatovy-Analamay region, we strongly suggest the elimination of all domestic carnivorans in the region.

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