The small mammals of the highly impacted North-eastern Atlantic Forest of Brazil, Pernambuco Endemism Center

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Abstract: The Atlantic forest of Brazil is nowadays reduced to less than 8% of its total original area and yet many species remain to be described. The Atlantic Forest north to the São Francisco river – The Pernambuco Endemism Center (CEPE) - has less than 2% of its original forest cover and yet the knowledge on small mammals is scarce. Aiming to assess the small mammal community of this region surveys were carried out in 12 forest fragments of different sizes in distinct geographic areas of the CEPE. The capture-mark-recapture technique was used with live-traps set along linear transects. We recorded 15 species, two of which are in the IUCN Red List, but not in the Brazilian List of Threatened Species. The highest richness and abundance indices were recorded in medium-sized fragments and in the rainy season. More marsupial species were recorded compared to rodents. Our results suggest that fragmentation caused the extinction of those most specialized species, currently remaining only those most tolerant to fragmentation and urbanization. It is recommended that urgent measures should be taken to reconnect and restore these fragments to allow recolonization and reestablishment of the gene flow among the populations.
Keywords: *Atlantic forest, forest fragments, Pernambuco Endemism Center, small mammals.*

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Resumo: A Floresta Atlântica do Brasil encontra-se hoje reduzida a menos de 8% da sua área original e contém várias espécies ainda desconhecidas. Sua porção ao norte do Rio São Francisco, o Centro de Endemismo Pernambuco (CEPE), possui atualmente menos de 2% de sua área original e o conhecimento sobre pequenos mamíferos é escasso. Com o objetivo de conhecer melhor a comunidade de pequenos mamíferos desta região foram realizados levantamentos em 12 fragmentos de diferentes tamanhos em áreas geográficas distintas do CEPE. A técnica de captura-marcação-recaptura foi utilizada, com armadilhas de captura viva dispostas em transectos ao longo dos fragmentos. Foram registradas 15 espécies, das quais duas estão inclusas na lista vermelha da IUCN, embora não na lista de espécies ameaçadas do IBAMA. Os maiores índices de riqueza e abundância foram encontrados nos fragmentos de tamanho médio, e durante a estação chuvosa. Foram registradas mais espécies de marsupiais do que de roedores. Os resultados sugerem que a fragmentação causou a extinção daquelas espécies mais especializadas, persistindo atualmente apenas aquelas mais tolerantes à fragmentação e urbanização. Recomendamos que medidas urgentes sejam tomadas para re-conectar e restaurar estes fragmentos, tornando possível sua re-colonização pelas espécies e o aumento do fluxo gênico entre as populações.
Palavras-chave: *pequenos mamíferos, fragmentos florestais, floresta Atlântica, Centro de Endemismo de Pernambuco.*

Introduction

The Atlantic Forest of Brazil, considered one of the most important biodiversity hotspots (Myers et al. 2000), had its original pristine forest reduced to a group of small forest fragments isolated in a matrix of plantations, cattle ranches, and urban areas, which comprises only between 5 and 7% of its original area (Brown & Brown 1992, Viana et al. 1997, Tabarelli et al. 2005). However, it harbors an astonishingly high biodiversity, and new mammal species are still described (Weksler et al. 1999, de Oliveira & Bonvicino 2002, Leite 2003, Mendes Pontes et al., 2006, Costa et al. 2007).

In the North-eastern Atlantic forest of Brazil, north to the São Francisco river, considered an important endemism center in South America – The Pernambuco Endemism Center (hereafter CEPE) (Prance 1982, 1987, Silva & Casteletti 2003), the situation is even more critical, with only 2% of its original forest remaining (Brown & Brown, 1992). In most cases, fragments are not larger than 10 ha (Ranta et al. 1998). In this region, studies on the diversity and abundance of small mammals remain scarce.

In fragmented landscapes, some small mammal species may form isolated populations, others may form metapopulations, with individuals moving between fragments, and yet others may be adapted to highly disturbed environments, or even to urban areas (Adler et al. 1997, Vaughan & Hawkins 1999, Quental et al. 2001, Pires et al. 2002). Umetsu & Pardini (2007) showed also that the destruction of the pristine forest may benefit those generalist or invasive species. This matrix tolerance may determine which species currently occur in the fragments, and is one of the main attributes associated with the vulnerability to fragmentation (Stevens & Husband 1998, Pires et al. 2002, Castro & Fernandez, 2004).

No studies were available on the small mammal community of the coastal forests of the Pernambuco Endemism Center. The only previous study available had been carried out at the altitudinal forests (Souza et al. 2004), which comprise a different biogeography unit of the CEPE. Thus, we carried out a series of single rapid surveys to determine the local small mammal community, its diversity and abundance.

Material and Methods

1. Study area

The Pernambuco Endemism Center is the biogeographical area of the Atlantic Forest located to the north of the São Francisco river, which encompasses the States of Alagoas, Pernambuco, Paraíba and Rio Grande do Norte (Figure 1). The CEPE has a long history of fragmentation, which starts in 1500 with the Brazil wood cycle, and was subsequently intensified with the sugar cane exploitation cycle. Although no precise records are available on the age of the sampled fragments, human activities in the Frei Caneca Private Reserve started as early as in 1884, and in the Serra Grande Mill, in 1927.

The study was carried out in 12 fragments of the Atlantic forest of the CEPE, classified into three size classes, which were 1) small (≤100 ha), 2) medium-sized (101-1,000 ha), and 3) large (>1,000 ha). Four of these fragments were located in the Gurjaú Ecological Reserve (1077.10 ha, 8° 15' 00" S and 35° 05' 00" W): Café Forest (118 ha), São Brás Forest (50 ha), Cuxiu Forest (38 ha), and Xangô Forest (6 ha); other four fragments were located in the Frei Caneca Private Reserve of the Natural Patrimony (630.42 ha, 08° 42' 37" S and 35° 50' 01" W): Serra do Quengo Forest (500 ha), Fervedouro Forest (300 ha), Ageró Forest (50 ha), and Espelho Forest (50 ha); the last four fragments studied were located in Serra Grande Mill (35° 52' 12" W and 9° 00' 00" S), a privately owned property that holds the largest areas of the Northeastern Atlantic Forest at CEPE, with 8,000 ha. The fragments in Serra Grande Mill were Coimbra Forest (3,400 ha, the only remnant of more than 1,000 ha), Cachoeira Forest (200 ha), Aquidabã Forest (50 ha), and Bom Jesus Forest (10 ha).

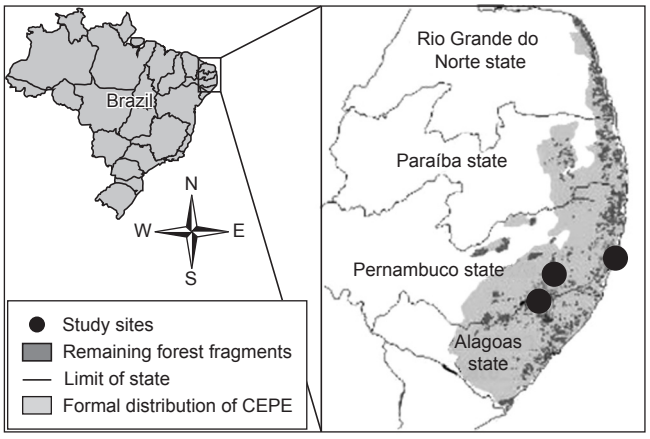

Figure 1. Location of the Pernambuco Endemism Center and of the three main study sites where the 12 fragments are located.

Figura 1. Localização do Centro de Endemismo Pernambuco e das três áreas de estudo onde os 12 fragmentos estão localizados.

Forest types varied from evergreen to semi-decidual tropical rainforest, all subject to some level of human-induced disturbance. The CEPE temperature averages 24 °C, and annual rainfall, 1,300 to 2,400 mm, with a wet season from March to September (Veloso et al. 1991).

The study was carried out between January and September 2003. Each fragment was sampled once during five consecutive nights during this period. Two fragments were sampled during the dry season and the others, during the wet season (Table 1).

2. Surveys

The small mammal community was studied through the capture method adapted from Cerqueira et al. (1993) and Pires & Fernandez (1999). In each fragment, 80 wire live-traps (40 x 17 x 17 cm) baited with pineapple and peanut butter were distributed along single linear transects, which encompassed 40 trapping stations, 20 m from each other. Two live traps, one on the forest floor and another one fixed on tree branches, at an approximate height of 2 m, were set in each station. Due to prohibitive logistics, no traps were set in the canopy.

Traps were inspected daily at dawn. The animals trapped were preliminarily identified in situ based on literature and had the following information taken: total length, tail length, ear length, rear foot length, weight, sex, and reproductive conditions (pregnant, lactating, testis position). They were also individually marked in the ear following a code of cuts, after which they were released. Voucher specimens of each morphotype were also deposited in the mammal collection of the Federal University of Pernambuco, and used for appropriate identification of individuals. Dr. A. Langguth and MSc F. Oliveira, from UFPB, examined specimens and confirmed identifications. Dr. A. Percequillo, from ESALQ-USP, confirmed identification of specimens of *Rhipidomys mastacalis*.

3. Data analysis

For each fragment, species richness (S) was considered the total number of recorded species, and abundance, the total number of

captured individuals of a given species (n). Species diversity (H') was calculated with the Shannon Index (base 2), and correlations between richness/diversity and area of the fragment were determined with the Spearman's correlation coefficient.

Results

1. Checklist and conservation status of the small mammals of the CEPE

As a result of 4,082 trap-nights, 92 individuals were trapped (trapping success of 2.25%) in the 12 forest fragments. A total of 15 species were recorded, being eight marsupials: *Caluromys philander* Linnaues, 1758, *Didelphis albiventris* Lund, 1840, *Didelphis aurita* Wied-Neuwied, 1826, *Marmosa murina* Linnaeus, 1758, *Metachirus nudicaudatus* É. Geoffroy, 1803, *Micoureus demerarae* Thomas, 1905, *Monodelphis Americana* Muller, 1776, *Monodelphis domestica* Wagner, 1842, and seven rodents: *Akodon cursor* Winge, 1887, *Necromys lasiurus* Lund, 1840, *Nectomys squamipes* Brants, 1827, *Oecomys bahiensis* Hershkovitz, 1960, *Hylaeamys oniscus* Thomas, 1904, *Cerradomys subflavus* Wagner, 1842, and *Rhipidomys mastacalis* Lund, 1840.

Two of the 15 recorded species are in the IUCN Red List of Threatened Species (2007), *Caluromys philander* and *Monodelphis americana*, both considered "Lower Risk/ Near Threatened (LR/nt), due mainly to habitat destruction. None of the species, however, are in the List of the Brazilian Animals Threatened of Extinction, published by IBAMA (2003).

2. Species composition and abundances

Total species richness (S) recorded for CEPE was 15, ranging from zero in Cachoeira and Bom Jesus forest, to nine in Fervedouro. Species diversity (H') varied from zero in the fragments of Serra Grande Mill to 2.77 in Fervedouro (Table 1).

The highest richness and abundance were recorded during the wet season, with two of the surveys conducted at the dry season recording no captures. Species richness was highest in medium-sized fragments (mean richness = 4.75), followed by small fragments (mean richness = 3.29). More specifically, the highest richness was recorded in those fragments that measured between 300 and 500 ha. Fragment size and species richness, however, did not present any statistically significant correlation (rs = 0.11, p = 0.73).

The most abundant species recorded for the CEPE were *Micoureus demerarae* (n = 17, 19%), *Metachirus nudicaudatus* (n = 15, 16%) and *Rhipidomys mastacalis* (n = 9, 11%) whereas the least abundant were *Akodon cursor* (n = 1, 1%), *Necromys lasiurus* (n = 1, 1%), *Nectomys squamipes* (n = 2, 2%), *Caluromys philander* (n = 1, 1%) and *Monodelphis americana* (n = 2, 2%) (Figure 2).

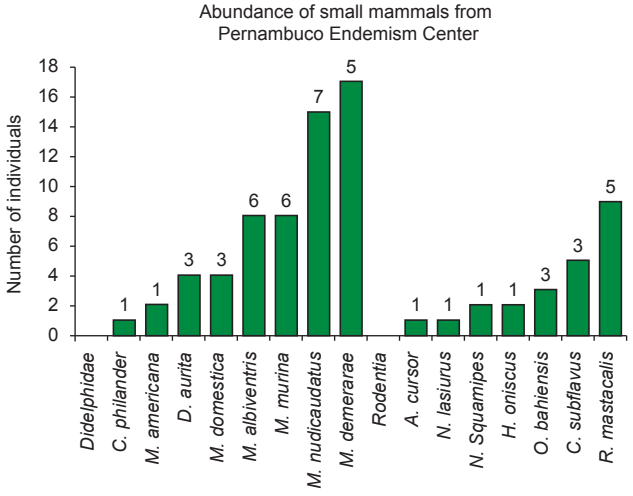

Figure 2. Abundance of small mammal species found at the Pernambuco Endemism Center. The numbers above the bars are the number of fragments where each species occurred.

Figure 2. Abundância das espécies de pequenos mamíferos encontradas no Centro de Endemismo Pernambuco. Os números acima das barras são o número de fragmentos nos quais as espécies ocorreram.

Table 1. Richness (S), diversity (H'), species list and abundance of small mammals for each surveyed fragment at the Pernambuco Endemism Center, and for all fragments combined.

Tabela 1. Riqueza (S), Diversidade (H'), lista de espécies e abundância de pequenos mamíferos de cada fragmento estudado at The Pernambuco Endemism Centre, and for all fragments comnbined.

Fragment (ha)	S	H'	Season	*C. philander*	*M. americana*	*D. aurita*	*M. domestica*	*D. albiventris*	*M. murina*	*M. nudicaudatus*	*M. demerarae*	*A. cursor*	*N. lasiurus*	*N. squamipes*	*O. bahiensis*	*C. subflavus*	*R. mastacalis*	*H. oniscus*
Cachoeira Forest (200)	0	-	Dry	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bom Jesus Forest (10)	0	-	Dry	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coimbra Forest (3400)	3	1.449	Wet	-	-	-	-	-	-	-	3	-	-	-	1	3	-	2
Aquidabã Forest (50)	3	1.371	Wet	-	-	-	-	1	-	-	-	-	-	-	-	-	2	-
Espelho Forest (50)	6	2.503	Wet	-	-	1	2	-	-	2	-	-	-	-	1	1	1	-
Ageró Forest (50)	4	1.549	Wet	-	-	-	-	-	1	1	-	-	-	2	-	-	2	-
Fervedouro Forest (300)	9	2.774	Wet	-	-	1	1	1	1	1	5	1	1	-	1	1	2	-
Serra do Quengo Forest (500)	7	2.471	Wet	-	2	2	-	1	1	6	6	-	-	-	-	-	2	-
Xangô Forest (6)	3	1.5	Wet	-	-	-	-	2	1	-	1	-	-	-	-	-	-	-
São Brás Forest (50)	4	1.842	Wet	-	-	-	1	2	3	1	-	-	-	-	-	-	-	-
Cuxiu Forest (38)	3	1.522	Wet	1	-	-	-	-	-	2	2	-	-	-	-	-	-	-
Café Forest (118)	3	1.5	Wet	-	-	-	-	1	1	2	-	-	-	-	-	-	-	-
Pernambuco Endemism Center	15	3.213	-	1	2	4	4	8	8	15	17	1	1	2	3	5	9	2

None of the species were present in all the 12 fragments. *Metachirus nudicaudatus* was recorded in seven fragments, and *Marmosa murina* and *Didelphis albiventris* were found in six fragments. Most of the species were present in less than half of the studied fragments, and *Caluromys philander*, *Monodelphis americana*, *Akodon cursor* and *Necromys lasiurus* were found in only one fragment (Table 1).

Discussion

The number of small mammal species recorded for all of the CEPE is relatively lower than what was recorded in many single localities, specially from the Southeastern Atlantic Forest of Brazil (Fonseca & Robinson 1990, Leite et al. 1996, Stevens & Husband 1998, Pires et al. 2002, Castro & Fernandez 2004, Pardini et al. 2005; see Pardini and Umetsu, 2006, for a comprehensive review). Moreover, small mammal diversity was distributed among many fragments across the CEPE, which is in agreement with Pardini et al. (2005), which concluded that habitat loss and fragmentation lead to less abundant, less rich and more spatially variable communities.

We recorded most of the marsupial species referred to the CEPE (Souza et al. 2004, Oliveira and Langguth 2004). The only exception was *Gracilinanus agilis*, a species never collected at the CEPE Atlantic coast, but only in the Altitudinal Forest enclaves in the Caatinga. On the other hand, despite the fact that we had the first record of *Rhipidomys mastacalis* in the CEPE Atlantic coast of Pernambuco, only six of the 11 species of rodents cited by Souza et al. (2004) were recorded in this study. Although Tribe (1996) stated that *Rhipidomys mastacalis* is distributed from the Atlantic Forest of Pernambuco to Rio de Janeiro, he only analyzed material from altitudinal forests at CEPE and Oliveira and Langguth (2004) stated that the genus *Rhipidomys* did not occur in the Pernambuco Atlantic forest.

According to the literature (Fonseca & Robinson 1990, Leite et al. 1996, Stevens & Husband 1998, Pires et al. 2002, Castro & Fernandez 2004, Pardini et al. 2005), the number of individuals trapped seems also to be relatively low in CEPE. Although comparisons are restricted by differences in sampling protocol and sampling effort, which was relatively low in each of the fragments and did not include pitfall traps in the present study, the absence of rodents at Gurjaú Ecological Reserve, the site with the smallest and most disturbed forest fragments, indicates that populations are small in the fragments of CEPE.

Contrary to the expected according to literature (Pardini et al. 2005), we did not find any statistically significant relationship between richness and diversity and fragment size in the CEPE, which suggest that specialized and vulnerable species have gone extinct even from the largest fragments. The highest values of richness and diversity in this study were recorded in medium-sized fragments, which may harbor a higher diversity of microhabitats, including a mosaic of forest edge and interior (Asfora, personal observation), allowing the co-existence of species from both forest interior and open areas. In fact, forests in earlier stages of regeneration or subjected to high levels of disturbance may benefit those species not dependent on specific resources (Pardini et al. 2005).

The higher abundance of marsupials compared to rodents in CEPE, may be related to the fact that marsupials are less vulnerable to fragmentation (Pardini et al. 2005, Castro and Fernandez 2004) and more favored by secondary forests due to their broader diets (Fonseca 1989). According to Pardini et al. (2005) and Castro and Fernandez (2004), terrestrial rodents are the small mammal species most affected by the fragmentation of the Atlantic forest.

In fact, most rodent species recorded in the CEPE are either habitat generalists, occurring in open or disturbed forests, xerophytic vegetation, present broad feeding habits, or are arboreal (Oliveira and Bonvicino, 2006). *Akodon cursor*, *Cerradomys subflavus* and *Necromys lasiurus* are terrestrial species that visit open areas, being common in xerophytic vegetation types, such as Cerrado, Caatinga, and also disturbed areas (Pardini 2004, Figueiredo and Fernandez 2004, Gentille et al. 1997, Weksler et al. 2006, Oliveira et al. 2003). *Rhipidomys mastacalis* is an arboreal rodent that occurs in high abundance in the altitudinal forests in Caatinga (Oliveira et al. 2003) and in secondary forest and cacao plantations in Bahia (Pardini 2004). *Hylaeamys oniscus* is a terrestrial species that is common in gallery forest and Cerrado, and also in isolated patches of humid forests (Weksler et al. 2006). Pardini (2004) showed that in south Bahia rodent species of the genus *Akodon* and marsupials of the genus *Marmosa* and *Micoureus* are found in forest edges, secondary forests, and also in cacao plantations.

Thus, our results are in agreement with the idea that the long-term survival of small mammal populations in small fragments (<15 ha) depends on the recolonization events, which can only take place if the species originally present in the fragments are able to cross or occupy the surrounding matrix (Krohne 1997, Pires & Fernandez 1999, Boyett et al. 2000, Pires et al. 2002, Castro & Fernandez, 2004). The occurrence of *Oecomys bahiensis*, however, which is an arboreal frugivore rodent, and a matrix-avoiding species that has a tendency to disappear from altered areas (Figueiredo and Fernandez 2004), suggests that some habitat specialist species still persist in the CEPE and should receive enough attention before they go regionally extinct.

Considering that 1) the 2% that was left of the forests of the CEPE are mainly distributed in fragments of about 10 ha (Brown & Brown 1992, Ranta et al. 1998) and that 2) these fragments are totally isolated by large distances of agricultural fields, villages, cities and bare land, we hypothesize that re-colonizations are rare, with local and even regional extinctions taking place. Finally, our results suggest that the long history of deforestation of the CEPE has ultimately caused the local extinction of those more specialized species, resulting in a new, less diverse community composed only by those most resilient species.

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