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Phenotypic changes and small mammal impoverishment on a Brazilian Atlantic Forest Island

Abstract: Faunal impoverishment and distorted species compositions are common phenomena in oceanic islands; however, many land-bridge islands are poorly inventoried, especially in the Neotropics. We sampled a small mammal community on a land-bridge island (Anchieta Island) along the Brazilian coast. We found only one marsupial *Didelphis aurita* (Wied-Neuwied, 1826) and two rodent species *Oligoryzomys nigripes* (Olfers, 1818) and *Trinomys iheringi* (Thomas, 1911) during 12 months of live trapping and 9195 trap-nights. The diversity of rodents and marsupials was not explained by species-area relations, indicating possible past extinctions. The abundance of *D. aurita* and *O. nigripes* was approximately three times higher, while the abundance of *T. iheringi* was approximately four times lower than abundances reported from other Brazilian Atlantic Forest sites. The population of *D. aurita* exhibited many phenotypic changes; males were on average 8% smaller and females produced 30% less litters than those from the mainland and other land-bridge islands. The long history of forest disturbance, habitat loss, reduction in forest productivity, and the recent introduction of mesopredators may be the major drivers that explain the small mammal community composition on this island.

Keywords: defaunation; land-bridge island; mark and recapture method; mesopredator release; predation.

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Introduction

Island biodiversity has long intrigued naturalists (Wallace 1881) and ecologists (MacArthur and Wilson 1967) particularly in tropical ecosystems. Tropical ecosystems hold the highest global diversity of species, and forest cover has been shown to be one of the major factors that affect the composition of small mammals in tropical areas (Malcolm 1994, 1995, Pardini 2004). Another important, but less studied, factor is the impact of mesopredators (i.e., coatis, ocelots, and raccoons) (Johnson et al. 2007, Berger et al. 2008) on the abundance of small mammals (Crooks and Soulé 1999). The extinction of top predators such as jaguars, and pumas from many fragmented forests may trigger a dramatic increase in populations of smaller predators, a phenomenon called "mesopredator release" (Crooks and Soulé 1999, Estes et al. 2011).

Fonseca and Robinson (1990) found that the overabundance of *Didelphis aurita* (Wied-Neuwied, 1826) is also a major determining factor for the abundance of small rodents in Atlantic Forest fragments. In fact, small rodents seem to avoid microhabitats occupied by *D. aurita* (Moura et al. 2009). This marsupial is one of the largest opossums in the Brazilian Atlantic Forest, reaching more than 1.5 kg and is also well known for its generalist diet and predatory behavior (Cáceres and Monteiro 2001, Gentile et al. 2004, Carvalho et al. 2005).

In the Brazilian Atlantic Forest, the biodiversity of land-bridge islands is poorly studied. Most of these islands have suffered intense human occupation and the faunal composition is severely altered (Alvarez and Galetti 2007). One of these islands is Anchieta Island on the coast of São Paulo, Brazil. In 1983, the São Paulo Zoo introduced to this island 100 individuals from 15 mammal species, which originally occurred in the Atlantic Forest mainland or in Brazilian savannas (Cerrado) (Bovendorp and Galetti 2007). After 24 years, some introduced species increased 140 times, many of which were nest and rodent predators (Bovendorp and Galetti 2007, Alvarez et al. 2008, Bovendorp et al. 2008). In this study, we investigated the composition and abundance of small mammals on

this island and compared the results with other Brazilian Atlantic Forest sites.

Materials and methods

Study area

We carried out a series of live-trapping surveys from June 2007 to May 2008 at Parque Estadual Ilha Anchieta (hereafter Anchieta Island; 45°02′ to 45°04′ W, 23°27′ to 23°34′ S) (Figure 1). Anchieta Island is an 828 ha land-bridge island on the northeast coast of São Paulo State, Brazil, and is separated from the continent by 540 m. The island suffered from intense human occupation until 1977 when it was declared a protected area. Today, 70% of its area is covered by secondary rainforest with many exotic species (Fleury 2009). The mammalian fauna of the island is composed mostly of species introduced in 1983, with high densities of agoutis, marmosets, coatis, armadillos, and capybaras (Bovendorp and Galetti 2007, Bovendorp et al. 2008).

Live trapping

Small mammals have never been inventoried on Anchieta Island. Therefore, we do not know their composition before human impacts and the introduction of alien species (Bovendorp and Galetti 2007). We conducted live trapping along three different trails, each one containing the three main island habitats: dense forest, open forest, and open fields. On each trail, we placed 30 small Sherman traps (23×7.5×8.5 cm), 13 large Sherman traps (37.5×10×12 cm), and 12 Tomahawks (45×16×16 cm) that were spaced at 20-m intervals.

Both dense and open forests, although highly diverse, are dominated by species characteristic of secondary forests (Fleury 2009). The major difference between these forest types is the understory cover, which is denser in the dense forest. Ferns *Gleichenia pectinata* (Willd.) and *Dicranopteris flexuosa* (Schrad.) and a few shrubs *Miconia* (Ruiz & Pav.) and *Rapanea* (Ruiz & Pav.) dominate the composition of the open field habitat (details in Fleury 2009).

We sampled the community of small mammals at five nights per month. Traps were checked in the early morning and baited in the afternoon with peanut butter mixed with mashed banana, bacon, and corn meal. We sampled 9195 trap-nights during the year, consisting of 5310 trap-nights using small Sherman traps, 2301 trap-nights using large Sherman traps, and 1584 trap-nights using Tomahawk traps. Each captured individual was marked with ear tags (National Band and Tag Co., Newport, KY); weighed; measured (length of head and body, and length of tail); sexed; checked for reproductive status, age classes for marsupials using the tooth eruption sequence (Quental et al. 2001), and coat color and body proportions for rodents; and released at the same trap station.

We compared our results with a dataset of small mammal species diversity from other Brazilian coastal islands, and with a dataset of the abundance, mean litter

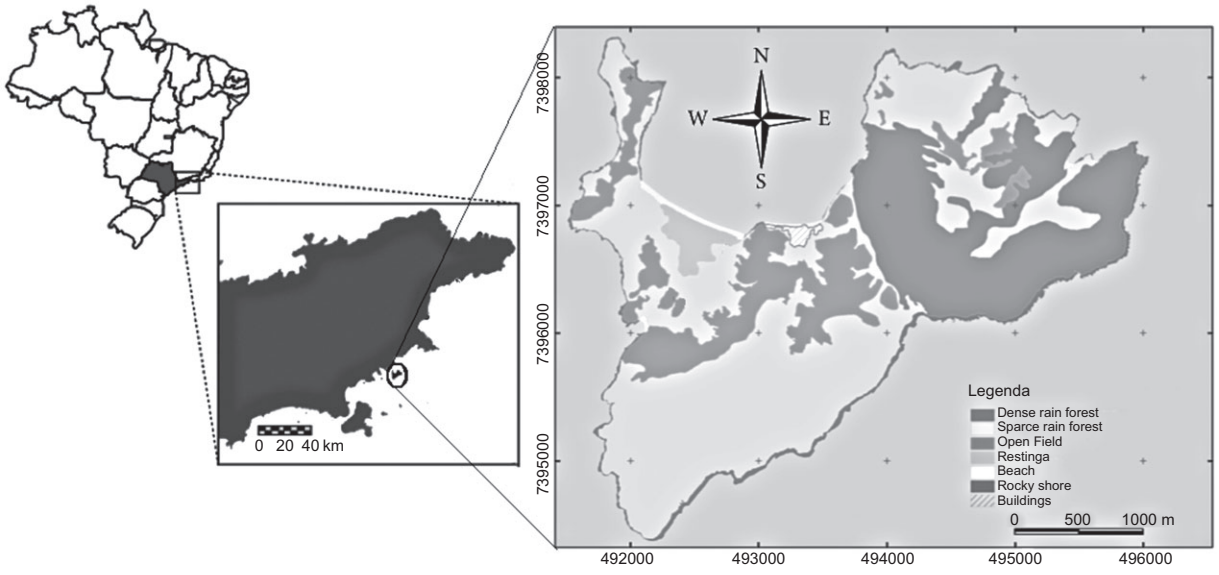

Figure 1 Location and vegetation shape of Anchieta Island in the coast of Brazil.

size, and length of head and body of *Didelphis aurita* from the literature.

Results and discussion

Diversity

We captured two rodent species *Oligoryzomys nigripes* (Olfers, 1818) and *Trinomys iheringi* (Thomas, 1911) and only one marsupial (*Didelphis aurita*) on Anchieta Island. Results from a linear regression model revealed that the species richness of marsupials and rodents on Anchieta Island does not fit the species-area relation for small mammals on the land-bridge islands from the coast of Brazil (log-linear regression for rodents: adjusted r^2=0.76, $p<0.003$; for marsupials: adjusted r^2=0.57, $p=0.01$; Figure 2). Fernandez et al. (1988) found 21 species of mammals, 1 carnivore, 8 rodents, 2 marsupials, and 10 chiropterans, on eight land-bridge islands of Rio de Janeiro State, Brazil. The species-area curve was predicted from three to five rodents and two marsupial species for Anchieta Island. Therefore, it is possible that the missing species have already been extirpated from the island. The long history of forest disturbance (Guillaumon et al. 1989), low forest productivity (Genini et al. 2009), and overabundance of mesopredators (Bovendorp and Galetti 2007) may be the drivers of small mammal impoverishment on this island.

Abundance

We had 172 captures and 532 recaptures of only three species of small mammals, and the overall capture success was 7.66%. The black-eared opossum (*Didelphis aurita*) was the most frequently captured species (105 individuals captured and 503 recaptures; 1.14 individuals-100 trap-nights) followed by *Oligoryzomys nigripes* (55 captures and 27 recaptures; 0.60 individuals-100 trap-nights) and *Trinomys iheringi* (12 captures and two recaptures; 0.13 individuals-100 trap-nights). Voucher specimens of each rodent species were deposited at the "Escola Superior de Agricultura" (ESALQ), University of São Paulo. We also captured one marmoset *Callithrix penicillata* (É. Geoffroy, 1812), three tegu lizards *Tupinambis meriane* (Linnaeus, 1758), one wood-rail *Aramides cajanea* (Statius Muller, 1776), four agoutis *Dasyprocta leporina* (Linnaeus, 1758), and ten coatis *Nasua nasua* (Linnaeus, 1766) during our surveys. The sex ratio of *D. aurita* was 1:1.2 (males/females), which is similar to that found in other studies (Cherem et al. 1996, Macedo et al. 2007).

The abundance we found for *Didelphis aurita* on Anchieta was up to 57 times greater than that reported from other sites in the Atlantic Forest (Table 1). Even when comparing with only the offshore islands, the abundance of *D. aurita* was still up to 14 times greater (Table 1). This high abundance may be due to the lack of predators, as fruit production (Genini et al. 2009) and possibly the invertebrate population (Santori et al. 1996) are extremely low and possible competitors (such as coatis) are also

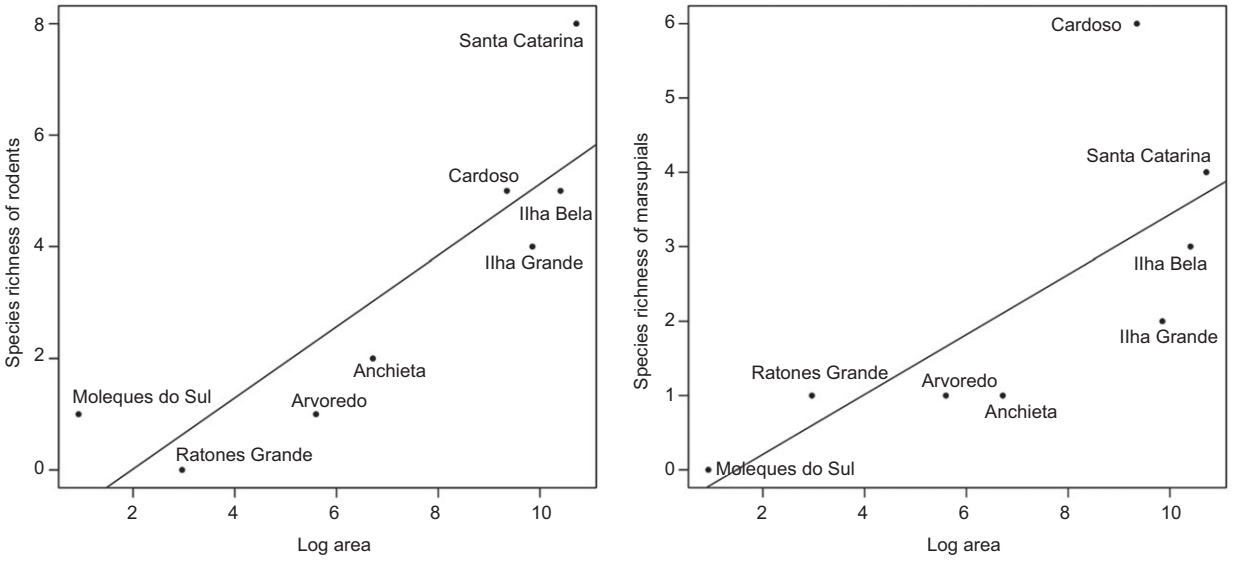

Figure 2 Species-area relation between area (log) and rodent (A) and marsupial (B) species richness in offshore islands in Brazil. Moleques do Sul, Cherem et al. (1999); Ratones Grande, Salvador et al. (2009); Arvoredo, Salvador et al. (2009); Anchieta, this study; Ilha Grande, Pereira et al. (2001), Rocha et al. (2003), Vera y Conde and Rocha (2006), Ilha Bela, Olmos (1996); Cardoso, Bergallo et al. (1998); Santa Catarina, Graipel et al. (2001).

Site (state)	Status	Sampling effort (trap-nights)	Abundance *D. aurita* (Ind.-100 trap-nights)*	Abundance *O. nigripes* (Ind.-100 trap-nights)*	Abundance *T. iheringi* (Ind.-100 trap-nights)*	References
Santa Teresa (ES)	Continuous	6028	0.11		0.10	Passamani (2003)
Intervales (SP)	Continuous	9782	0.11	0.07	0.20	Vieira and Monteiro-Filho (2003)
Santa Virginia (SP)	Continuous	6300	0.14	0.02	0.19	Neves, C.L. (unpublished data)
Santa Teresa I (ES)	Continuous	6028	0.21		0.28	Passamani (2003)
Santa Teresa II (ES)	Continuous	6028	0.21			Passamani (2003)
Juréia (SP)	Continuous	4307	0.53		2.99	Bergallo (1994)
Serra dos Orgãos (RJ)	Continuous	42,015	0.61	0.01		Macedo et al. (2007)
Santa Teresa III (ES)	Fragment	3780	0.15			Passamani (2003)
Santa Teresa IV (ES)	Fragment	3780	0.02			Passamani (2003)
Duas Boca (ES)	Fragment	3352	0.03	0.12	0.03	Paresque et al. (2004)
Santa Lúcia (ES)	Fragment	3300	0.09	0.82	0.15	Paresque et al. (2004)
Poço das Antas (RJ)	Fragment	13,498	0.22	0.31		Pires et al. (2002)
Santa Teresa V (ES)	Fragment	4050	0.07			Passamani (2003)
Santa Teresa VI (ES)	Fragment	4050	0.27		0.11	Passamani (2003)
Santa Teresa VII (ES)	Fragment	4050	0.32		0.15	Passamani (2003)
Sumidouro (RJ)	Fragment	12,250	1.15	0.18		D'Andrea et al. (1999)
Anchieta city (ES)	Fragment	3331	1.77			Passamani et al. (2005)
Cardoso Island (SP)	Island	15,120	0.08		0.58	Bergallo (1994)
Grande Island (RJ)	Island	4480	0.27		0.80	Vera y Conde and Rocha (2006)
Santa Catarina Island (SC)	Island	12,132	0.46	0.31		Graipel et al. (2006)
Anchieta Island	Island	9195	1.14	0.60	0.13	This study

Table 1 Comparison of relative abundances of *Didelphis aurita*, *Oligoryzomys nigripes*, and *Trinomys iheringi* in the Brazilian Atlantic Forest.
*Ind.-100 trap-nights, individuals-100 trap-nights.

highly abundant on the island (Galetti et al. 2009). In periods of fruit scarcity, it is common to observe hungry *D. aurita* invading human habitations searching for food, and we have also observed three individuals scavenging a carcass of *Cuniculus paca* (Linnaeus, 1766) (L. Calderón, unpublished data).

The abundance of *Oligoryzomys nigripes* was also higher than in other sites in the Atlantic Forest (Table 1), while the *Trinomys hieringi* abundance was below that of other areas (Table 1). It is likely that forest cover and possibly fruit productivity (Genini et al. 2009), competition for resources, and an overabundance of mesopredators such as coatis (Bovendorp and Galetti 2007) may be limiting the population of *T. iheringi*, but not *O. nigripes*. However, *T. iheringi* is usually common in the Atlantic Forest (Bergallo 1994, Bergallo and Magnusson 1999, Prevedello et al. 2008).

Body size and reproduction

The mean body mass of *Didelphis aurita* adults was 766.77±340.29 g (n=102), and the mean body length was 353.73±35.97 mm for males (n=49) and 347.19±54.30 mm (n=53) for females. The average body mass for the rodents was 21.87±4.43 g (n=53) for *Oligoryzomys nigripes* and 244.72±99.13 g (n=9) for *Trinomys iheringi*. We did not find a significant difference in mean body mass for *O. nigripes* on Anchieta Island compared with previous studies (Table 2), but the average body mass of *T. hieringi* was 0.4 times that reported from other areas (Table 3). We believe that *T. iheringi* may be demonstrating an "island effect", as found with *Euryoryzomys russatus* (Wagner, 1848) on Ilhabela Island, where the specimens of *E. russatus* had a greater body size than their continental co-specifics (A. Percequillo, unpublished data).

Reproductive females of *Didelphis aurita* were captured from September to January with only one breeding season, while in rodents, females were reproductive from October to April. The average number of offspring in *D. aurita* pouches was 5.22±2.90 litters per female (n=45), which is less than the mean litter sizes reported from the mainland and other land-bridge islands (Figure 3). We did not find any correlation between female body mass and number of offspring in female poaches (r^2=0.033, F=0.90, p=0.35). A number of researchers have observed that

Site (state)	Status	Species	Individuals	Mean body weight (g)	References
Serra dos Orgãos (RJ)	Continuous	*O. nigripes*	5	22	Macedo et al. (2007)
Santa Virginia (SP)	Continuous	*O. nigripes*	1	19.5	Neves. C.L. (unpublished data)
Intervales-Saibadela (SP)	Continuous	*O. nigripes*	3	20	Vieira and Monteiro-Filho (2003)
Intervales-Barra Grande (SP)	Continuous	*O. nigripes*	3	20	Vieira and Monteiro-Filho (2003)
Reserva Biológica de Duas Bocas (ES)	Fragment	*O. nigripes*	4	22.5	Paresque et al. (2004)
Estação Biológica de Santa Lúcia (ES)	Fragment	*O. nigripes*	27	23	Paresque et al. (2004)
Anchieta (SP)	Island	*O. nigripes*	53	21.87	This study

Table 2 Mean body mass of adults of *Oligoryzomys nigripes* in the Brazilian Atlantic Forest.

Didelphis (Linnaeus, 1758) litter size increases with latitude (Fleming 1973, Tyndale-Biscoe and Mackenzie 1976). Therefore, to increase their fitness, they must invest more per reproduction, rearing only one large litter (Rademaker and Cerqueira 2006). At lower latitudes, females split their reproductive investment into three smaller litters during the year, as the environmental conditions are not as extreme as those in higher latitudes (Rademaker and Cerqueira 2006). At low latitudes, variation in the daylight hours is small and resources are available year-round (Cerqueira 1984). Cerqueira and Bergallo (1993) found pouches with 6.8 litters per female and two breeding seasons (late July and February); Gentile et al. (2000) recorded 7.2 litters per female and two breeding seasons (early July and March) at the same latitude. Moreover, the low fruit productivity on Anchieta (Genini et al. 2009) may also affect the reproduction of *D. aurita*.

On Anchieta, the population of *Didelphis aurita* demonstrated many phenotypic changes, with males being on average 8% smaller and females producing 30% less litters than on the mainland and other land-bridge islands at similar latitudes (Rademaker and Cerqueira 2006). A relatively small body size is a common phenomenon for some mammal groups living on islands (Lomolino 1985); however, the average size of *D. aurita* individuals in Anchieta Island is also smaller than in other offshore islands (Figure 4). We hypothesize that the low fruit production and the high intraspecific competition may be the major drivers for explaining the body size reduction and low fecundity of this marsupial on Anchieta Island.

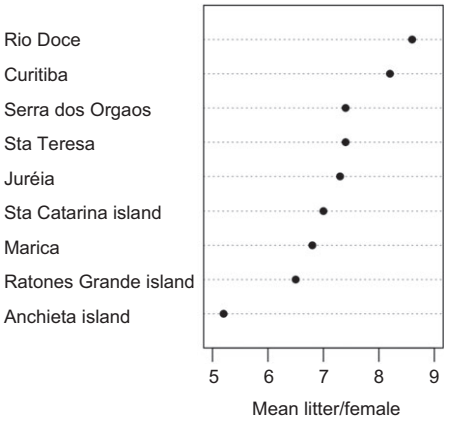

Figure 3 Mean litters per female in *Didelphis aurita* in the Brazilian Atlantic Forest.
Rio Doce, Fonseca and Kierluff (1989); Curitiba, Cáceres and Monteiro-Filho (1997); Serra dos Orgaos, Macedo et al. (2007); Santa Teresa, Passamani (2000); Juréia, Bergallo (1994); Santa Catarina Island, Graipel et al. (2006); Marica, Cerqueira and Bergallo (1993); Ratones Grande Island, Cherem et al. (1996); Anchieta Island, this study.

Site (state)	Status	Species	Individuals	Mean body weight (g)	References
Serra dos Orgãos (RJ)	Continuous	*T. dimidiatus*	19	225	Macedo et al. (2007)
Santa Virginia (SP)	Continuous	*T. iheringi*	12	213	Neves, C.L. (unpublished data)
Intervales-Saibadela (SP)	Continuous	*T. iheringi*	20	212	Vieira and Monteiro-Filho (2003)
Intervales-Barra Grande (SP)	Continuous	*T. iheringi*	0	212	Vieira and Monteiro-Filho (2003)
Reserva Biológica de Duas Bocas (ES)	Fragment	*T. iheringi*	1	110	Paresque et al. (2004)
Estação Biológica de Santa Lúcia (ES)	Fragment	*T. iheringi*	5	110	Paresque et al. (2004)
Anchieta (SP)	Island	*T. iheringi*	9	244	This study

Table 3 Mean body mass of adults of *Trinomys* sp. in the Brazilian Atlantic Forest.

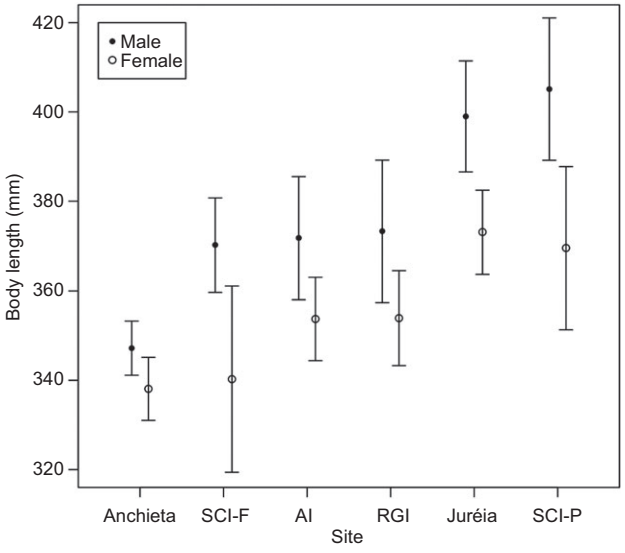

Figure 4 Body length (mm) of *Didelphis aurita* in Anchieta Island and other sites in the Brazilian Atlantic Forest.
SCI-F: Santa Catarina Island – forest site, Salvador et al. (2009); AI, Arvoredo Island, Salvador et al. (2009); RGI, Ratones Grande Island, Salvador et al. (2009); Juréia: Bergallo (1994); Santa Catarina Island, a peri-urban site, Salvador et al. (2009); Anchieta, this study.

Habitat use

All three species were captured in all three habitats on the island, but their abundance was not randomly distributed (χ^2=67.46, p<0.001; Table 4). *Oligoryzomys nigripes* had a higher abundance in the open fields, while *Trinomys iheringi* was more common in the dense forest. Abundances of *Didelphis aurita* were similar in the three habitats. *Didelphis aurita* exhibit more generalist feeding habits among the Didelphidae, and they are very common in environments altered by man and where there are no large predators (D'Andrea et al. 1999). *Oligoryzomys* (Bangs, 1900) species are terrestrial rodents that inhabit forests and open vegetation of the Amazon Forest, Atlantic Forest, Cerrado, Caatinga, and Pantanal biomes. Some species, such as *O. nigripes*, are habitat generalist, occurring in both primary and secondary forest (Bonvicino et al. 2002). *Trinomys* (Thomas, 1921) are terrestrial rodents and most of the species of this genus are restricted to forested habitats (Reis et al. 2006).

Species	Open field	Open forest	Dense forest	p-Value
Didelphis aurita	183	202	222	NS
Oligoryzomys nigripes	59	5	18	<0.01
Trinomys iheringi	3	1	10	NT

Table 4 Number of captures of the three small mammal species in the three main habitats at Anchieta Island, Ubatuba, SP, Brazil.
NS, not significant; NT, not tested.

Conclusions

Anchieta Island presents a low species richness arising from probable past extinctions of small mammals. The high human disturbance, habitat loss, low forest productivity, and the recent introduction of mesopredators are probably the major drivers for the impoverishment of the small mammal community. The only marsupial found on the island, *Didelphis aurita*, was present at a high density, which in turn suggests high intraspecific competition. This may have forced phenotypic changes among males and low fertility in females. The high abundance of *Oligoryzomys nigripes* is probably associated with the generalist habit of this species, which prefers areas of disturbed forests and with low competition with other small rodents. *Trinomys iheringi*, however, had a low abundance probably due to the low fruit production and the lack of suitable habitat on the island.

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