Ecología Austral 33:684-692 Diciembre 2023
Asociación Argentina de Ecología
https://doi.org/10.25260/EA.23.33.3.0.2034

Choosing between human trash and trashed forests: Resilience in nonvolant Atlantic Forest small mammals

FERNANDA GATTO-ALMEIDA[1,✉]; JULIANA QUADROS[2] & LILIANI MARILIA TIEPOLO[2]

[1] Postgraduate Program in Zoology. Department of Zoology, Universidade Federal do Paraná (UFPR). Centro Politécnico, Jardim das Américas. Curitiba, PR, Brazil. [2] Programa de Pós-graduação em Desenvolvimento Territorial Sustentável, Universidade Federal do Paraná (UFPR).

ABSTRACT. Open pit rubbish dumps generate serious environmental problems both in Brazil and elsewhere. The goal of this study was to evaluate the occurrence patterns of an assemblage of small flightless mammals in the area of a landfill deactivated 19 years ago. During nine campaigns, three different sites located in a subtropical protected area near the city of Matinhos, Paraná coast, southern Brazil, were sampled. The selected places were an artificial clearing where urban waste had previously been dumped (Area 1), a site with less anthropic influence with tree species and a poorly developed understorey (Area 2), and a site with well-formed vegetation, with herbaceous, shrubby and tree strata well developed (Area 3). The total capture effort was 5210 trap-nights; 109 captures were made of 82 individuals from five species of Rodentia (all from the subfamily Sigmodontinae) and three species of marsupials (Order Didelphimorphia). The most conserved site (Area 3) had higher abundance than areas 1 and 2 (binomial test; P<0.05). Area 1, considered the most affected, showed less species richness (n=6) than the other two areas (7 and 8 species), although this may be affected by the lower number of captures. The diversity in Area 1, estimated by the Shannon index, was lower than in areas 2 and 3 (Hutcheson's t tests; H'=1.26 for Area 1 vs. 1.76 and 1.68 for Areas 2 and 3, respectively), although the composition of the assemblage did not differ significantly between the areas (PERMANOVA; P=0.085). Our results show that even after 19 years of inactivity, the deposited waste is still having a negative impact on the environment, and highlight the resilience of some native small mammal species in exploiting the resources of degraded areas.

[Keywords: bioindicator, impact, rubbish dump, natural regeneration, rainforest]

RESUMEN. Elegir entre basura humana y bosques impactados: Resiliencia en pequeños mamíferos no voladores del Bosque Atlántico. Los vertederos de residuos sólidos al aire libre (basurales) crean problemas ambientales serios en Brasil y en todo el mundo. El objetivo de este estudio fue evaluar los patrones de ocurrencia de un ensamblaje de pequeños mamíferos no voladores en el área de un vertedero desactivado hace 19 años. A lo largo de nueve campañas se muestrearon tres sitios diferentes, ubicados en un área natural protegida del Bosque Atlántico subtropical, cerca de la ciudad de Matinhos, costa de Paraná, sur de Brasil. Los lugares seleccionados fueron un claro donde se descartaban residuos urbanos (Área 1), un lugar con menor influencia antrópica, con especies arbóreas y un sotobosque poco desarrollado (Área 2), y un lugar con vegetación bien formada, con estratos herbáceo, arbustivo y arbóreo bien desarrollados (Área 3). Con un esfuerzo total de captura de 5210 noches-trampa, se realizaron 109 capturas de 82 individuos de cinco especies de Rodentia (todas de la subfamilia Sigmodontinae) y tres especies de marsupiales (Orden Didelphimorphia). La zona más conservada (Área 3) tuvo mayor abundancia que las áreas 1 y 2 (prueba binomial; P<0.05). El Área 1, considerada más impactada, mostró menos riqueza de especies (n=6) que las otras dos áreas (7 y 8 especies), aunque esto puede estar afectado por el menor número de capturas. La diversidad del Área 1, estimada por el índice de Shannon, fue menor que en las áreas 2 y 3 (prueba de Hutchenson; H'=1.26 para el Área 1 vs. 1.76 y 1.68 para las áreas 2 y 3, respectivamente), aunque la composición de los ensambles no resultó diferente entre áreas (PERMANOVA: P=0.085). Nuestros resultados indican que, incluso después de 19 años de desmantelamiento, los residuos depositados aún influyen negativamente en el medio ambiente, y resaltan la resiliencia de algunas especies nativas de pequeños mamíferos para explotar los recursos en áreas degradadas.

[Palabras clave: bioindicador, impacto, relleno sanitario, regeneración natural, bosque tropical]

Editor asociado: Fernando Milesi

Recibido: 13 de Julio de 2022
Aceptado: 22 de Junio de 2023

✉ fgattoalmeida@ymail.com

Introduction

The generation of solid waste is a global problem. The world's cities generate 2.01 billion tons of solid waste per year, and it is estimated that by 2050 this will increase to 3.4 billion t/year (Kaza et al. 2018). In Latin American and Caribbean countries, 45.3% of the solid waste generated up to 2002 was disposed in open pit garbage dumps (Espinoza et al. 2010). These dumps, also known as rubbish dumps, are sites for the final disposal of solid waste in an open space, usually without any sanitary control or treatment. Such sites often cause negative environmental impacts, including the release of greenhouse gases as a result of waste decomposition, contamination of soil and surface water, and negative impacts on local fauna and flora (Espinoza et al. 2010).

Although many rubbish dumps have been closed in recent years (Espinoza et al. 2010), the materials remain in place, influencing the process of plant recolonization (Trotter and Cooke 2005) and consequently, the ecology of the associated fauna. Studies on the environmental impacts of rubbish dumps have generally focused on assessing soil and/or water contamination (Pastor and Hernández 2012; Regadío et al. 2012) or the emission of polluting gases (Lyons et al. 2010; Penteado et al. 2012). Little is known about the impacts of rubbish dumps on the regional fauna and how long the effects last after the site is decommissioned.

In general, ecosystems are resilient (i.e., they are able to withstand a certain degree of disturbance without radically altering their functions and services Holling (1973) defined resilience as a measure of the persistence of the system, its ability to absorb change and disturbance, and to maintain the same type of relationship between populations and variable states after disturbance as existed before the disturbance. Studies of nonvolant small mammal assemblages have shown that some species are highly sensitive to anthropogenic change, while others are not. This has been shown for a variety of impacts, including fragmentation (Pardini 2004; Johnstone et al. 2014), fire (Briani et al. 2004; Griffiths et al. 2015), agriculture (Umetsu and Pardini 2007; Fischer et al. 2011; Martin et al. 2012), removal of shrub cover (Kutiel et al. 2000), seasonality (Naxara et al. 2009) and dam construction (Zhang et al. 2014). Given these differential responses, assemblages of small rodents and marsupials can act as bioindicators to help us assess the capacity of the environment to show resilience to the impacts of large-scale trash dumping.

The present study evaluated the composition of small non-flying mammals (rodents and marsupials) in a rubbish dump deactivated 19 years ago in the Rio da Onça State Park, the first protected natural area in the Atlantic Coastal Forest on the coast of Paraná State, southern Brazil. Within this conservation unit, the degraded area was compared with two other areas with lower levels of disturbance. Two scenarios seem possible: 1) the assemblage of nonvolant small mammals associated with the abandoned rubbish dump will be distinct and less diverse than that found in similar adjacent areas which were not directly impacted by such deposits, or 2) after 19 years of natural regeneration in the area both impacted and unimpacted areas will have similar small mammal assemblages and diversity.

Materials and Methods

Study area

The study was carried out in the Rio de Onça State Park (Parque Estadual do Rio da Onça: PERO; 25°45′ S - 48°30′ W), located in the Matinhos municipality, in the coastal area of southern Paraná State, Brazil (Figure 1). By the time we conducted this study, PERO covered an area of 118.5 ha and included habitats typical of the Paraná coastal plain, with altitudes varying between 5 and 8 m a. s. l. and ~400 m from the sea. Forest cover includes Lowland Dense Ombrophylous Forest (49.9%) and Maritime-influence Pioneering Formations (41.5%), as well as areas under human impact (8.6%). The Ombrophylous Dense Forest secondary forestations in advanced stages of regeneration (86.8%) and capoeiras (13.2%) developed from old abandoned agricultural plantations (Roderjan 1988).

Three different areas belonging to the same natural formation and presumably similar except for the anthropic alterations were sampled within the park (Figure 1, Supplementary Material-Figure S1). Area 1, characterized by the presence of an urban rubbish dump deactivated in 1995, was sampled mainly in a clearing colonized by undergrowth and shrubs, and in a forest formation adjacent to the clearing. Outcrops of solid waste, such as glass bottles and plastic packaging, were a common part of the soil

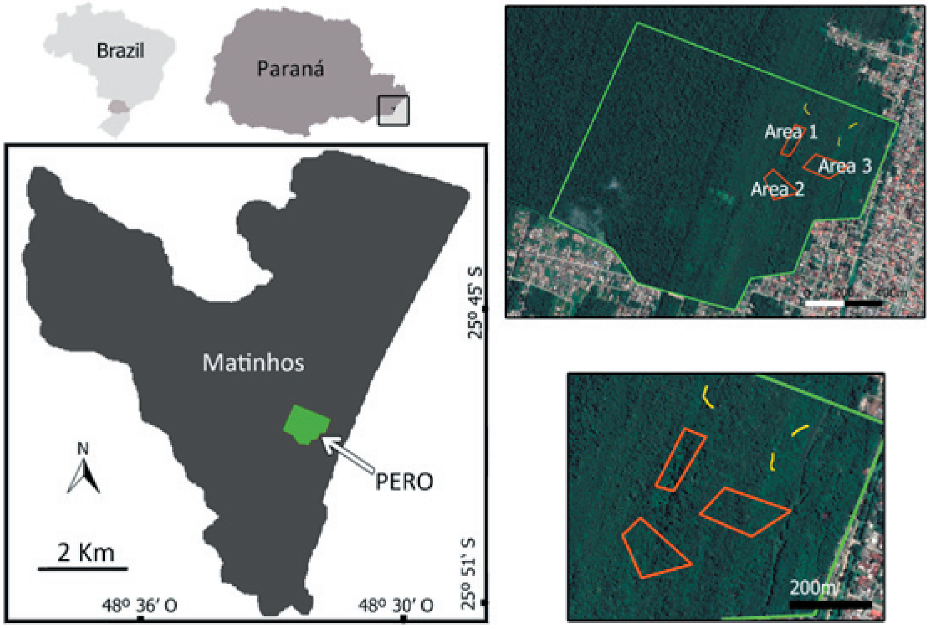

Figure 1. Location of the Rio da Onça State Park (PERO), Matinhos, Paraná State, Brazil. Highlighted areas mark the grids sampled for small nonvolant mammals. Modified by the authors from Google Earth® 2014.

Figura 1. Ubicación del Parque Estatal Rio da Onça (PERO), Matinhos, Estado de Paraná, Brasil. Las áreas resaltadas indican las grillas donde se muestrearon los pequeños mamíferos no-voladores. Modificado por los autores de Google Earth® 2014.

substrate throughout this study site. Area 2 consisted of forest formations less affected than at Area 1, with secondary forest cover and high density of woody tree species, but a poorly developed understorey in most of the area and scarce human litter in the location. A sandy area of restinga vegetation (beach forest) and a small area of marsh were also present. Finally, Area 3 was located in the center of the park's visitor trails, with closed forest, a well-developed understorey and an herbaceous strata, and a small stream. No solid waste was found at this location.

Sampling collection

Nine 6-day trapping campaigns were made between November 2013 and December 2014, sampling only one area per campaign in a fixed order; so, at the end of the study, the three areas were sampled three times each, once per season (see Supplementary Material-Table S1). We used three sizes of Sherman live traps (9×9×25 cm^3; 9.5×9.5×31 cm^3; 40×21×21 cm^3) and two sizes of Tomahawk live traps (18×14.5×35 cm^3; 18×14.5×45 cm^3) arranged along a 5×10 grid of five 10-station lines spaced 10 m apart per area. The stations along each line were set 20 m apart, each containing one Sherman and one Tomahawk trap, one installed at ground level (terrestrial) and one elevated (arboreal) at 2-4 m height on a tree, alternating model and elevation in consecutive stations (i.e., each grid line had five Shermans on the ground and five on trees, and five Tomahawks on the ground and five on trees). Due to a lack of suitable trees in Area 1, some arboreal traps were placed lower, in the tallest shrub available. All traps were baited with a mixture of bananas, peanut candy, canned fish, and maize flour. The traps were checked once a day in the early morning for six consecutive days.

As some of the local species are cryptic, some individuals were collected for identification through cytogenetic analysis, following the methods and numbers described in Gatto-Almeida et al. (2016). Traps containing animals to be collected were removed from the field for transport to the laboratory and replaced with empty, clean traps. Individuals that were not collected received a uniquely numbered aluminum ear tag and were immediately released into the wild. The capture and collection of small mammals in the area were authorized by the MMA/ICMBIO/SISBIO under License No. 35534-1.

Data analysis

Rarefaction curves and Shannon (H') and Simpson (1-D) diversity indices were calculated for each area using Past 2.17 software (Hammer et al. 2001); Simpson's index calculates the probability that two randomly selected individuals in the sample belong to different species. We tested for equality of Shannon's diversity indices among areas with two-sided Hutcheson's t-tests (Hutcheson 1970) according to the package EcolTest (version 0.0.1) (Salinas and Ramírez-Delgano 2021) in the R statistical environment (version 3.6.1; R Core Team 2021).

To test for different abundance of individuals between areas, pairwise binomial tests were conducted using the BioEstat 5.3 software (Ayres et al. 2007). Recaptures were excluded from the analysis to avoid possible biases caused by individuals who had burrows close to where the traps were set, and also secondary biases caused by the removal of a few collected individuals of cryptic species.

We used non-metric multidimensional scaling analysis (NMDS) using the Bray-Curtis metric to evaluate dissimilarity in the species composition and abundance between areas, considering each line of the trapping grid as a replicate. The residual stress of the NMDS analysis (i.e., the measure of distortion of the data when represented in the reduced two-dimensional space) was 0.173; stress values under 0.2 are commonly accepted as good (see Dexter et al. 2018). The analysis was performed in an R environment (version 3.6.1; R Core Team 2021) using the metaMDS function of the Vegan package for community analyses (version 2.5-6) (Oksanen et al. 2019). We plotted the data for each line and draw ellipses representing 95% confidence intervals around the mean of each area. We performed a PERMANOVA test, using Bray-Curtis index and 999 permutations with the adonis function in the package Vegan (version 2.6-6) (Oksanen et al. 2019) to test if the centroids for all areas were equivalent after checking for the assumption of homogeneity of their dispersions.

Results

A total sampling effort of 5210 trap nights resulted in 109 captures of 82 different individuals. Area 3 had the highest number of captures (n=38) (i.e., number of captures minus number of recaptures), significantly higher than Area 1 (n=23; *Z*=1.86, *p*=0.03) and Area 2 (n=21; *Z*=2.21, *p*=0.01); Area 1 vs. Area 2; *Z*=0.34, *p*=0.37) (Table 1). The species richness observed in the three areas after a very

Table 1. Number of captured individuals (with number of recaptures in parentheses) of species of non-flying small mammals in the three sampled areas (Area 1 is the most impacted; Area 3, the less impacted). Rel. Ab.: relative abundance based on the percentage of captures in the area.

Tabla 1. Número de individuos capturados (con número de recapturas entre paréntesis) de especies de pequeños mamíferos no voladores en las tres áreas muestreadas (el Área 1 es la más impactada; el Área 3, la menos impactada). Rel. Ab.: abundancia relativa basada en el porcentaje de individuos capturados en el área.

Taxon	Area 1		Area 2		Area 3	
	Captures	Rel. Ab. (%)	Captures	Rel. Ab. (%)	Captures	Rel. Ab. (%)
Order Didelphimorphia						
Didelphis aurita Wied-Neuwied, 1826	1(0)	3.8	2(1)	6.2	11(5)	21.6
Metachirus myosuros Temminck, 1824	3(2)	11.5	5(3)	15.6	5(2)	9.8
Marmosa paraguayana Tate, 1931	0	0	3(0)	9.3	4(0)	7.8
Order Rodentia						
Akodon montensis Thomas, 1913	15(1)	57.7	10(2)	31.2	20(3)	39.2
Euryoryzomys russatus Wagner, 1848	5(0)	19.2	5(1)	15.6	2(1)	3.9
Nectomys squamipes Brants, 1827	1(0)	3.8	6(4)	18.8	5(2)	9.8
Oligoryzomys nigripes Olfers, 1818	1(0)	3.8	1(0)	3.1	3(0)	5.9
Thaptomys nigrita Lichtenstein, 1829	0	0	0	0	1(0)	2.0
Total	26 (3)		32 (11)		51 (13)	
Richness	6		7		8	
Trap nights	1720		1740		1750	
Capturability (%)	1.5		1.8		2.9	

similar sampling effort differed: Area 1 had the lowest alpha diversity (n=6 species), Area 2 had 7 species, and Area 3, 8 species. However, rarefaction curves based on total number of captures (Figure 2) showed very similar asymptotical curves of species accumulation for areas 2 and 3, with Area 1 reaching a lower number of species with few individual captures. A comparison among the curves at this lower number of captures suggests that Area 1 still has marginally lower richness than areas 2 and 3, though their standard errors overlap. In terms of diversity, the Shannon index values were similar for areas 2 and 3 (H'=1.76 and 1.68, respectively; 2 vs. 3: t=0.517, df=82.748, *p*=0.607), and areas 3 and 1 (H'=1.26, 3 vs. 1: t=1.946, df=42.329, *p*=0.058), but it was higher for Area 2 when tested against Area 1 (2 vs. 1: t=2.414, df=40.217, *p*=0.020). Likewise, Simpson diversity indices (1-D) were 0.61, 0.80 and 0.76 for areas 1, 2 and 3, respectively. The distribution of the trapping lines of the three sampled areas overlap in the two-dimensional NMDS plot (Figure 3), and although the overlap between Areas 1 and 3 is small, the PERMANOVA test did not show significant differentiation between the three small mammal communities (F=1.752, df=14, *p*=0.085).

Five species were recorded from the Order Rodentia, all Sigmodontinae (i.e., *Akodon montensis*, *Euryoryzomys russatus*, *Nectomys squamipes*, *Oligoryzomys nigripes* and *Thaptomys nigrita*) and three marsupial species from the Order Didelphimorphia (*Didelphis aurita*, *Metachirus myosuros* and *Marmosa paraguayana*). *Marmosa paraguayana* and *Thaptomys nigrita* were absent from Area 1, and the latter not recorded in Area 2. In Area 3, we had six of the seven arboreal captures (*M. paraguayana*, n=3; *D. aurita*, n=2, and *A. montensis*, n=1), with the other in Area 2 (*M. paraguayana*); no arboreal captures were made in Area 1. *Akodon montensis* was the rodent most frequently captured in Area 1 (57.7% of captures) and in general (Table 1). *D. aurita* was the second most frequent species (six individuals, all subadults, and five recaptures) in Area 3, while only a single adult was captured in each of the two other areas (recaptured once in Area 2).

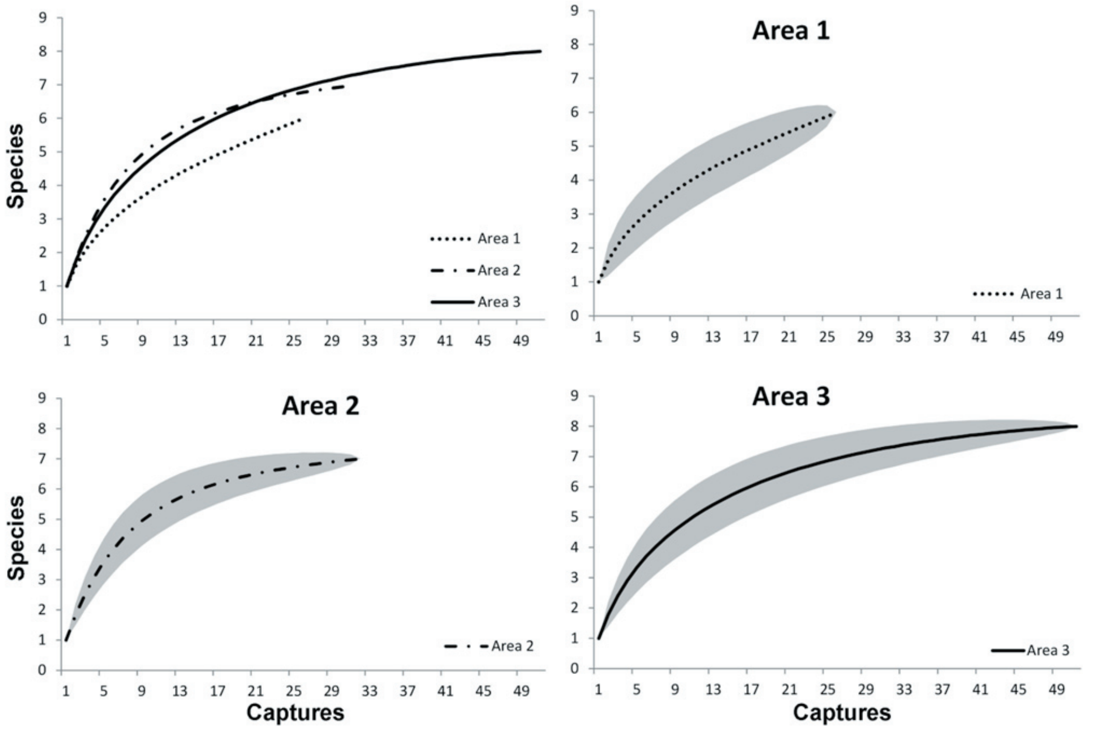

Figure 2. Rarefaction curves for the three areas sampled in PERO Matinhos, in Paraná state, Brazil. Standard error of each curve is showed in gray.

Figure 2. Curvas de rarefacción para cada una de las tres áreas muestreadas en PERO Matinhos, en el estado de Paraná, Brasil. El error estándar de cada curva se muestra en gris.

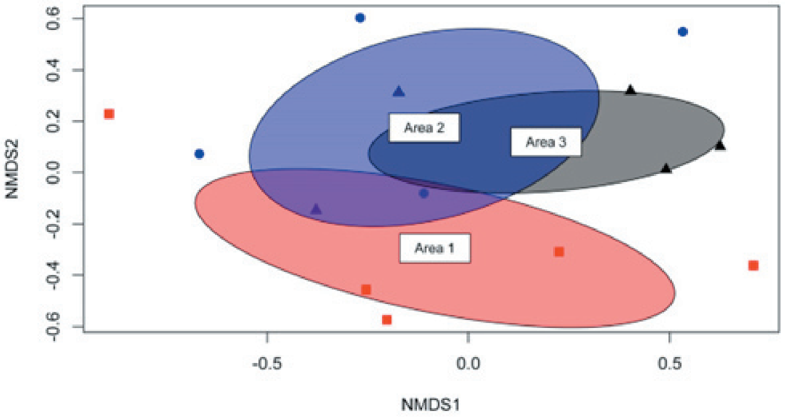

Figure 3. Nonmetric multidimensional scaling ordination of nonvolant small mammals in relation to the three areas sampled in PERO Matinhos, in Paraná state, Brazil. Ellipses represent 95% confidence intervals around the mean of each area. Squares represent Area 1 lines; circles are Area 2 lines; triangles are Area 3 lines.

Figura 3. Ordenamiento multidimensional no métrico de pequeños mamíferos no volátiles en relación con las tres áreas muestreadas en PERO Matinhos, en el estado de Paraná, Brasil. Las elipses representan intervalos de confianza del 95% alrededor de la media de cada área. Los cuadrados representan líneas del Área 1; los círculos son líneas del Área 2; los triángulos son líneas del Área 3.

Discussion

This is the first study to evaluate the long-term effects of an urban household waste on the composition of a nonvolant small mammal assemblage in Brazil. Our results showed that the composition and richness of the species did not differ between the affected and control study areas, although the least affected area (Area 3) had a higher abundance than the other areas, indirectly estimated by the number of captured individuals.

Area 1 had little arborescent vegetation, and consequently, *M. paraguayana*, which has arboreal habit (Vieira and Camargo 2012), was not recorded and *D. aurita*, which is scansorial, appeared with low frequency. The same is true for *T. nigrita*, a semi-fossorial species, which was only recorded in Area 3, the less disturbed one. Some studies indicate that this is a species with very limited ecological flexibility, and is only common in well-preserved areas of mature forests (Pardini et al. 2005; Pardini and Umetsu 2006). While Grazzini et al. (2015) found high densities of *T. nigrita* in Araucaria (*Araucaria angustifolia*) and *Pinus* sp. plantations in a Mixed Ombrophilous Forest, the species occurred at low densities compared to other Akodontini in studies of lowland Atlantic Forest (Gatto-Almeida et al. 2016). Therefore, the absence of some species in the most affected areas suggests an inability of these areas to maintain the full range of ecological functions. However, although the small mammal community was less abundant and diverse in the former rubbish dump area, these differences are quite small considering the large differences in landscape extent between the sampled areas (e.i., the presence of a cleared area colonized by undergrowth and shrubs in Area 1).

In contrast to our results, Pardini et al. (2005) analyzed a variety of forest fragments and reported an increase in small mammal abundance in areas with lower canopy cover and higher understorey leaf density. This was not the case for Area 1, where most of the soil is still covered with plastic and glass litter and herbaceous vegetation with low species richness. However, it must be emphasized that, unlike most studies that sampled fragments, edges or agricultural areas (e.g. Pardini 2004; Pardini et al. 2005; Santos-Filho et al. 2012), Area 1 is an open clearing in the middle of native vegetation in an advanced state of succession, a more complex environment that may serve as a preferred refuge for certain small mammals (Pianka 1994) and act as an ecological sink for other species (Pulliam 1988; Carballido et al. 2011). This may contribute to the resilience of the small mammal assemblage in this disturbed area.

Holling and Gunderson (2002) proposed a concept called adaptative cycle, which was used to describe and understand the long-term dynamics of change in a complex adaptive system. According to their proposal, a system is stable until its limits are exceeded; when this happens, the system switches rapidly into a phase called Ω (omega), where the system collapses and assumes a new condition, different from the original (Holling and Gunderson 2002). If disturbances in Area 1 had led the small mammal fauna in Area 1 to phase Ω, we would have found a very different assemblage than in areas 2 and 3, which would have been evidenced by the PERMANOVA test. This difference would be reflected, for example, in a higher relative abundance of generalist species such as *O. nigripes* (Umetsu and Pardini 2007; Umetsu et al. 2008) or even the presence of opportunistic invasive aliens such as House mouse (*Mus musculus*), Black rat (*Rattus rattus*) or Norway rat (*Rattus norvergicus*), although the latter seems to be negatively affected by forests (Gatto-Almeida et al. 2020). In contrast, *O. nigripes* was similarly abundant in all areas and *E. russatus*, a disturbance-adverse species that is rare in altered areas (Olifiers et al. 2005; Pardini et al. 2005; Umetsu and Pardini 2007) was the second most abundant species in Area 1. As a result, the small mammal assemblage studied had probably already passed through the Ω phase, and was already in the next phase: the phase of renovation and reorganization called α (alpha) (Holling and Gunderson 2002).

The next stage of the adaptative cycle after reorganization (α) would be for the species assemblage to increase its complexity (r phase or exploitation) until it reaches the original state of composition (k phase or conservation), undistinguishable from other similar non-impacted, areas. Moro and Gadal (2007) concluded that the richness and abundance does not vary according to the time available for vegetation to regenerate, but according to the structural diversity of the area. So, it does not matter if the area has been recovering for 19 years if the waste that is still there continues to hamper the increase of complexity of the environment around it. From this point of view, fewer individuals in Area 1 may result from the lack of shelter offered by fallen logs and dense underbrush (Dueser and Shugart-Jr. 1978; Monamy and Fox 2000; Moro and Gadal 2007; Yamada et al. 2016). However, the growth and longevity of trees established on poorly remediated rubbish dumps depend to a great extent on the physical conditions, such as compaction levels and aeration of the soil (Dobson and Moffat 1999). The lack of remediation and the presence of solid residues in Area 1 could have impacted recolonization by woody vegetation that impacts both arboreal small mammals and semifossorial species. The rudimentary situation in which this rubbish dump was operated and its abandonment without any remedial treatment are also likely to have contributed to the still initial stage of recovery of the area, even 19 years after the waste disposal activities in the area ceased.

Conclusions

Although the area affected by the abandoned rubbish dump had less abundance and diversity than the other two, close areas sampled, the composition of the small mammal community was not as radically affected as expected in an area that is still so obviously impacted by its previous use. Even so, those lower values suggests that even 19 years after deactivation, with native vegetation around the affected area at an advanced state of succession favoring faunal and floral recolonization, the deposited waste still negatively influences the environment.

At landfills, pre-installation and post-decommissioning remediation measures could accelerate regeneration and recolonization by native fauna and flora. They should be adopted, particularly because most decommissioned dumps are not surrounded by valuable forested habitat as in this area, increasing and potentially prolonging their negative impacts.

Finally, because it is a protected conservation unit located within the Atlantic Forest, a severely threatened biome, and a global biodiversity hotspot, remediation measures must be prioritized for management programs that include areas with a history of anthropic use similar to PERO.

Acknowledgements. We thank the National Council for Scientific and Technological Development (CNPq) for its support via Protax Edital (Protax N° 562357/2010- 6, Processo 132719/2012-6), and for providing a scholarship for the first author. We also thank the Federal University of Paraná Graduate Program in Zoology for the financial assistance needed to carry out this work. Adrian Barnett helped with the English. The authors declare that they have no conflict of interest.

REFERENCES

Ayres, M., M. Ayres-Jr., D. L. Ayres, A. de A. S. Dos Santos, and L. L. Ayres. 2007. BioEstat. Aplicações Estatísticas nas äreas das Ciências Bio-Médicas. Sociedade Civil Mamirauá/CNPq, Belém.

Briani, D. C., A. R. T. Palma, E. M. Vieira, and R. P. B. Henriques. 2004. Post-fire succession of small mammals in the Cerrado of central Brazil. Biodiversity and Conservation 13:1023-1037. https://doi.org/10.1023/B:BIOC.0000014467.27138.0b.

Carballido, M. F., P. Arístide, M. Busch, E. A. Cittadino, and I. E. G. Villafañe. 2011. Are the closed landfills recovered habitats for small rodents? A case study in a riparian site, Buenos Aires, Argentina. Urban Ecosystems 14:699-710. https://doi.org/10.1007/s11252-011-0167-6.

Dexter, E., G. Rollwagen-Bollens, and S. M. Bollens. 2018. The trouble with stress: A flexible method for the evaluation of nonmetric multidimensional scaling. Limnology and Oceanography Methods 16(7):434-443. https://doi.org/10.1002/lom3.10257.

Dobson, M. C., and A. J. Moffat. 1999. Examination of tree and root performance on closed landfills in Merseyside. Arboricultural Journal 23:261-272. https://doi.org/10.1080/03071375.1999.9747244.

Dueser, R. D., and H. H. Shugart-Jr. 1978. Microhabitats in a forest-floor small mammal fauna. Ecology 59:89-98. https://doi.org/10.2307/1936634.

Espinoza, P. T., E. Martínez A., D. Daza, M. S. Faure, and H. Terraza. 2010. Regional Evaluation on Urban Solid Waste Management in Latin America and the Caribbean - 2010. Report. Inter-American Development Bank (IADB), Lima, Perú.

Fischer, C., C. Thies, and T. Tscharntke. 2011. Small mammals in agricultural landscapes: Opposing responses to farming practices and landscape complexity. Biological Conservation 144:1130-1136. https://doi.org/10.1016/j.biocon.2010.12.032.

Gatto-Almeida, F., Á. C. Ferreguetti, J. S. Pontes, L. M. Tiepolo, and I. Hass. 2020. The Atlantic Forest as a barrier to invasive rodents: study of a seaport in southern Brazil. Hystrix 31:87-93.

Gatto-Almeida, F., J. S. Pontes, I. J. Sbalqueiro, I. Hass, L. M. Tiepolo, and J. Quadros. 2016. Diversidade, biogeografia, caracterização cariotípica e tricológica dos pequenos mamíferos não voadores do Parque Estadual Rio da Onça, Litoral Sul do Paraná. Papéis Avulsos em Zoologia 56:69-96. https://doi.org/10.11606/0031-1049.2016.56.07.

Grazzini, G., C. M. Mochi-Jr., H. Oliveira, J. S. Pontes, F. Gatto-Almeida, and L. M. Tiepolo. 2015. Identidade, riqueza e abundância de pequenos mamíferos (Rodentia e Didelphimorphia) de área de Floresta com Araucária no Estado do Paraná, Brasil. Papeis Avulsos em Zoologia 55:217-230. https://doi.org/10.1590/0031-1049.2015.55.15.

Griffiths, A. D., S. T. Garnett, and B. W. Brook. 2015. Fire frequency matters more than fire size: Testing the pyrodiversity-biodiversity paradigm for at-risk small mammals in an Australian tropical savanna. Biological Conservation 186: 337-346. https://doi.org/10.1016/j.biocon.2015.03.021.

Hammer, Ø., D. A. T. Harper, and P. D. Ryan. 2001. PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4:1-9.

Holling, C. S. 1973. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4:1-23. https://doi.org/10.1146/annurev.es.04.110173.000245.

Holling, C. S., and L. H. Gunderson. 2002. Resilience and adaptive cycles. Pp. 25-62 *in* L. H. Gunderson and C. S. Holling (eds.). Panarchy: understanding transformations in human and natural systems. 1st ed. Island Press, Washingto, USA.

Hutcheson, K. 1970. A test for comparing diversities based on the Shannon formula. Journal of Theoretical Biology 29: 151-154. https://doi.org/10.1016/0022-5193(70)90124-4.

Johnstone, C. P., A. Lill, and R. D. Reina. 2014. Habitat loss, fragmentation and degradation effects on small mammals: Analysis with conditional inference tree statistical modelling. Biological Conservation 176:80-98. https://doi.org/10.1016/j.biocon.2014.04.025.

Kaza, S., L. Yao, P. Bhada-Tata, and F. Van Woerden. 2018. What a Waste 2.0 - A Global Snapshot of Solid Waste Management to 2050. Urban Development Series, Washington, DC. https://doi.org/10.1596/978-1-4648-1329-0.

Kutiel, P., Y. Peled, and E. Geffen. 2000. The effect of removing shrub cover on annual plants and small mammals in a coastal sand dune ecosystem. Biological Conservation 94:235-242. https://doi.org/10.1016/S0006-3207(99)00172-X.

Lyons, S., L. Murphy, and R. S. J. Tol. 2010. Estimating historical landfill quantities to predict methane emissions. Atmospheric Environment 44:3901-3906. https://doi.org/10.1016/j.atmosenv.2010.07.022.

Martin, P. S., C. Gheler-Costa, P. C. Lopes, L. M. Rosalino, and L. M. Verdade. 2012. Terrestrial nonvolant small mammals in agro-silvicultural landscapes of Southeastern Brazil. Forest Ecology and Management 282:185-195. https://doi.org/10.1016/j.foreco.2012.07.002.

Monamy, V., and B. J. Fox. 2000. Small mammal succession is determined by vegetation density rather than time elapsed since disturbance. Austral Ecology 25:580-587. https://doi.org/10.1111/j.1442-9993.2000.tb00063.x.

Moro, D., and S. Gadal. 2007. Benefits of habitat restoration to small mammal diversity and abundance in a pastoral agricultural landscape in mid-Wales. Biodiversity and Conservation 16:3543-3557. https://doi.org/10.1007/s10531-006-9104-z.

Naxara, L., B. T. Pinotti, and R. Pardini. 2009. Seasonal microhabitat selection by terrestrial rodents in an old-growth Atlantic forest. Journal of Mammalogy 90:404-415. https://doi.org/10.1644/08-MAMM-A-100.1.

Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H., Szoecs, E., and Wagner, H. (2019) vegan: Community Ecology Package. R package version 2.5-6. URL: CRAN.R-project.org/package=vegan.

Olifiers, N., R. Gentile, and J. T. Fiszon. 2005. Relation between small-mammal species composition and anthropic variables in the Brazilian Atlantic Forest. Revista Brasileira de Biologia 65:495-501. https://doi.org/10.1590/S1519-69842005000300015.

Pardini, R. 2004. Effects of forest fragmentation on small mammals in an Atlantic Forest landscape. Biodiversity and Conservation 13:2567-2586. https://doi.org/10.1023/B:BIOC.0000048452.18878.2d.

Pardini, R., S. Marques, D. Souza, R. Braga-Neto, and J. Paul. 2005. The role of forest structure, fragment size and corridors in maintaining small mammal abundance and diversity in an Atlantic forest landscape. Biological Conservation 124: 253-266. https://doi.org/10.1016/j.biocon.2005.01.033.

Pardini, R., and F. Umetsu. 2006. Pequenos mamíferos não-voadores da Reserva Florestal do Morro Grande - distribuição das espécies e da diversidade em uma área de Mata Atlântica. Biota Neotropica 6:1-22. https://doi.org/10.1590/S1676-06032006000200007.

Pastor, J., and A. J. Hernández. 2012. Heavy metals, salts and organic residues in old solid urban waste landfills and surface waters in their discharge areas: Determinants for restoring their impact. Journal of Environmental Management 95:S42-S49. https://doi.org/10.1016/j.jenvman.2011.06.048.

Penteado, R., M. Cavalli, E. Magnano, and F. Chiampo. 2012. Application of the IPCC model to a Brazilian landfill: First results. Energy Policy 42:551-556. https://doi.org/10.1016/j.enpol.2011.12.023.

Pianka, E. R. 1994. Biotic Diversity and Community Stability. *In* E. R. Pianka (ed). Evolutionary Ecology. 5th ed. HCC Publishers, New York, USA.

Pulliam, H. R. 1988. Sources, Sinks, and Population Regulation. The American Naturalist 132:652-661. https://doi.org/10.1086/284880.

R Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: R-project.org.

Regadío, M., A. I. Ruiz, I. S. de Soto, M. Rodríguez Rastrero, N. Sánchez, et al. 2012. Pollution profiles and physicochemical parameters in old uncontrolled landfills. Waste Management 32:482-497. https://doi.org/10.1016/j.wasman.2011.11.008.

Roderjan, C. V. 1988. Caracterização da vegetação do Parque Florestal do Rio da Onça. Instituto Ambiental do Paraná - IAP, Curitiba.

Salinas, H., and D. Ramírez-Delgado. 2021. ecolTest: Community Ecology Tests. R Package Version 0.01. URL: cran.r-project.org/web/packages/ecolTest.

Santos-Filho, M., C. A. Peres, D. J. da Silva, and T. M. Sanaiotti. 2012. Habitat patch and matrix effects on small-mammal persistence in Amazonian forest fragments. Biodiversity and Conservation 21:1127-1147. https://doi.org/10.1007/s10531-012-0248-8.

Trotter, D. H., and J. A. Cooke. 2005. Influence of landfill gas on the microdistribution of grass establishment through natural colonization. Environmental Management 35:303-310. https://doi.org/10.1007/s00267-003-0308-7.

Umetsu, F., and R. Pardini. 2007. Small mammals in a mosaic of forest remnants and anthropogenic habitats - evaluating matrix quality in an Atlantic forest landscape. Landscape Ecology 22:517-530. https://doi.org/10.1007/s10980-006-9041-y.

Umetsu, F., J. Paul Metzger, and R. Pardini. 2008. Importance of estimating matrix quality for modeling species distribution in complex tropical landscapes: a test with Atlantic forest small mammals. Ecography 31:359-370. https://doi.org/10.1111/j.0906-7590.2008.05302.x.

Vieira, E. M., and N. F. Camargo. 2012. Uso do espaço vertical por marsupiais brasileiros. Pp. 345-362 *in* N. C. Caceres (ed.). Os marsupiais do Brasil Biologia, Ecologia e Conservação. 2nd edition. Editora UFMS, Campo Grande.

Yamada, T., S. Yoshida, T. Hosaka, and T. Okuda. 2016. Logging residues conserve small mammalian diversity in a Malaysian production forest. Biological Conservation 194:100-104. https://doi.org/10.1016/j.biocon.2015.12.004.

Zhang, M., Y. Wang, B. Li, C. Guo, G. Huang, et al. 2014. Small mammal community succession on the beach of Dongting Lake, China after the Three Gorges Project. Integrative Zoology 9:294-308. https://doi.org/10.1111/1749-4877.12073.

SUPPLEMENTARY MATERIAL

Figure S1. Photos from the sampled areas.

Figura S1. Fotos de las áreas muestreadas.

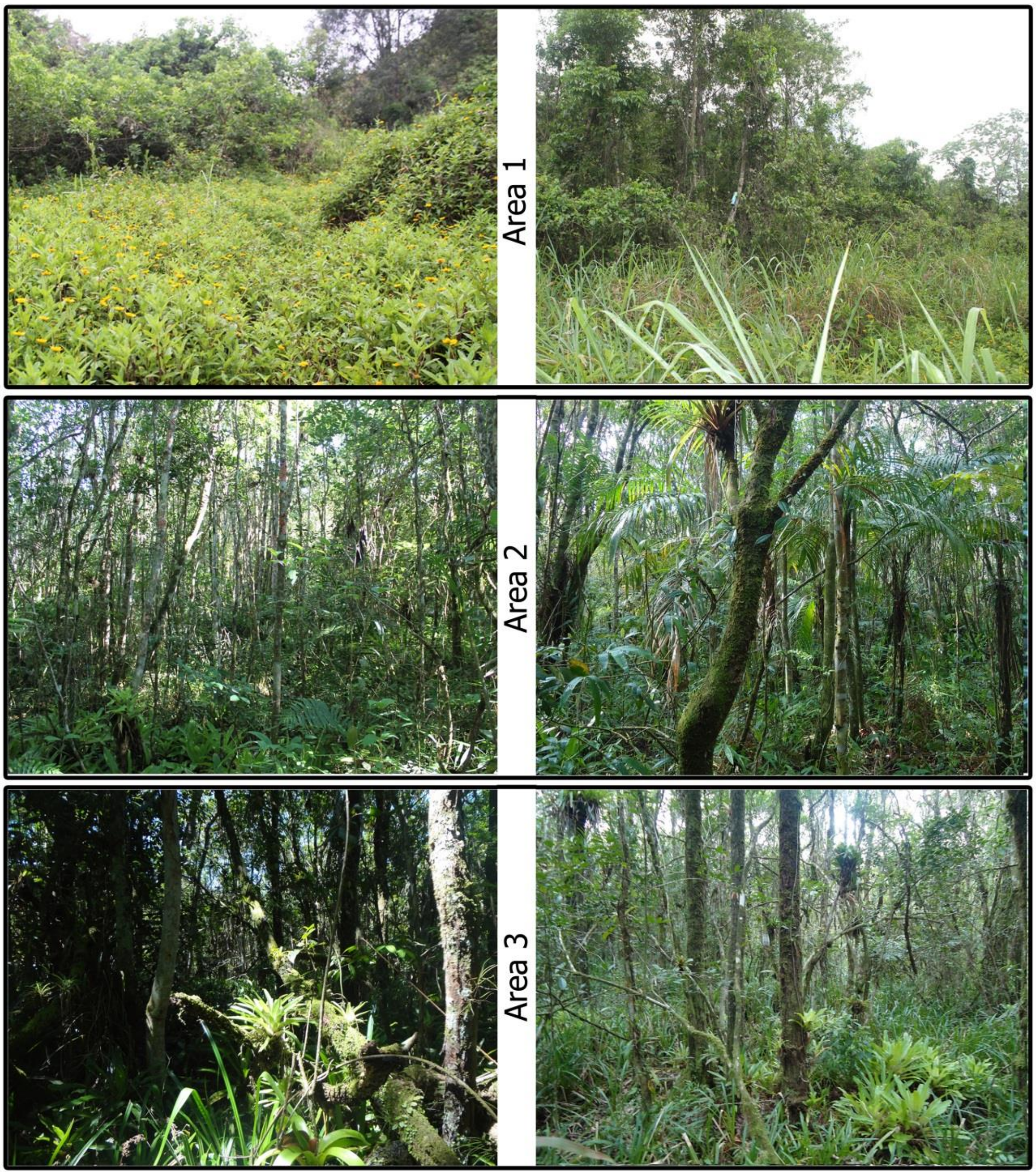

Table S1. Field study visits to PERO, showing the collection periods for each studied area.

Tabla S1. Visitas de estudio de campo a PERO, mostrando los períodos de recolección en cada una de las áreas estudiadas.

Field Visit	Area	Period
1	Area 1	November 2013
2	Area 2	January 2014
3	Area 3	March 2014
4	Area 1	April 2014
5	Area 2	June 2014
6	Area 3	July 2014
7	Area 1	September 2014
8	Area 2	October 2014
9	Area 3	November 2014