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Are the closed landfills recovered habitats for small rodents? A case study in a riparian site, Buenos Aires, Argentina

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Abstract The establishment of landfills in urban areas leads to extensive disturbances. Their development after landfill closure depends on the characteristics of the soil cover, the surrounding communities and the dispersal of plants and animals. This study was carried out in a landfill closed in 2004, surrounded by an urban area, freshwater marshes and a riparian forest. The aim of this study was to determine the role that the closed landfill may play in maintaining rodent communities typical of this zone and its relation to characteristics of the sites. Four rodent and plant samplings were carried out from December 2005 to September 2006 at five sites inside the landfill: three filled cells and two areas of the riparian margin. We recorded a total of 433 individual rodents. The rodent community of the closed landfill included species typical of rural, riparian and rural habitats: *Akodon azarae* (358), *Oligoryzomys flavescens* (32), *Deltamys kempi* (14), *Rattus rattus* (14), *Cavia aperea* (11) and *Scapteromys aquaticus* (4). Rodent species composition varied among sites, but *A. azarae* was usually the dominant species. We found a rich rodent community mostly composed of wild species. The relictual riparian margin may have served as a major refuge for native rodent community while the landfill was in operation, and after closure it possibly acted as a source for some species to colonize the covered cells.

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Introduction

Human population growth and its associated urban expansion result in extensive modification of the natural environment, and lead to irreversible effects on urban surroundings (Foley et al. 2005; Mateucci et al. 1999; Smyth and Royle 2000). One consequence of increasing urbanization is the increase in the amount of wastes, which in most cities are disposed in sanitary landfills (Tchobanoglus et al. 1994, El-Fadel et al. 2001).

Among others, landfill operation may result in the destruction of the original plant communities and in changes in the ground level (Chan et al. 1997, Wong 1988). After operation, the recovery of plant cover at a landfill depends on the characteristics of the soil (content of organic matter, undecomposed materials, gases); on the characteristics of the surrounding communities; on the content of seeds and other propagules in the soil used to cover waste materials; and on the time elapsed after the closure (Kim and Lee 2005, Trotter and Cooke 2005).

As plant succession proceeds, animal communities colonization depends on the local conditions generated by the landfill operation, the composition of the surrounding animal communities and their dispersal ability; all these variables act as a filter that determines the final species composition of the community and their relative abundance (Atkeson and Johnson 1979; Briani et al. 2004; Churchfield et al. 1997; Fox 1982, 1990; Fox et al. 2003; Hirth 1959; MacMahon 1981; Pearson 1959; Schweiger et al. 2000).

The process of colonization described above was observed for rodent species in many riparian sites resulting from filling soils in Buenos Aires City, Argentina. An example is the Costanera Sur Natural Reserve, with a rodent community represented by both commensal and native species (Cavia 2006), which could have colonized the filled area not only from the city but also from surrounding natural areas.

There is an increasing concern about the consequences of man-induced disturbances on biological diversity and about how to manage and conserve the urban and surrounding wildlife (Ferreira and van Aarde 2000; Luniak 2004; Misgav et al. 2001; Savard et al. 2000; van Ommeron and Helmstetter 2004; Young and Jarvis 2001). Landfills, which are an inevitable by-product of urbanization, are commonly included in heterogeneous landscapes with wildlife communities, thereby being used for recreation, forestry production and other commercial plant products (Lanfranco et al. 1999; Marlats et al. 2004, Robinson et al. 1992). In addition, some authors (e.g. Misgav et al. 2001) have proposed landfills to be considered from a conservation perspective. In this regard, studies on the use of modified habitats by animal communities are crucial for any management effort aiming at the recovery of the native flora and fauna (Litvaitis et al. 1994).

The aim of this study is to address the following questions about rodent communities in a closed landfill:

– How is the rodent community composed? Are there native and commensal rodents?
– Is the recover of a native rodent community possible in a restored habitat as this closed landfill?
– What is the relationship between the abundance of the different species and the topography and vegetation characteristics at different sites in the landfill?

Materials and methods

Study area

The study was carried out in a closed landfill located in the locality of Villa Domínico, 10 km to the south of Buenos Aires City, Argentina (34.70 S;58.31 W). The landfill was open in 1979 and definitely closed in 2004. It occupies 500 ha, is surrounded by an urban area and by de la Plata river, and is more than 30 km away from rural areas.

The wastes were disposed in different sites, called cells, inside the landfill. Most of the freshwater marsh, riparian forest and other natural plant communities were lost as a result of this operation. Changes in altitude among cells also occurred because some cells were used twice. In addition, gases and lixiviates generated by waste decomposition reduced plant cover. The riparian margin along the river inside the landfill was not used to dispose waste and remained inhabited by spontaneous plant communities.

Three filled cells (C1, C2 and C3) filled and closed in different years and two sectors of an undisturbed riparian margin (MB1 and MB2) were used as study sites. These sites were selected based on 1) their heterogeneity in altitude, 2) the time since the cell was last used and closed, and 3) its distance from the river (Table 1).

Rodent community

The rodent community inhabiting neighbouring areas is composed by six sigmodontine species: *Akodon azarae* (pampean grassland rodent), *Oligoryzomys flavescens* (argentine rice rat), *O. nigripes* (delta pygmy rice rat), *Deltamys kempi* (kemp's grass mouse), *Scapteromys aquaticus* (water rat) and *Oxymycterus rufus* (red hocicudo); one caviid, *Cavia aperea* (pampa's cavy), and the murine species *Mus musculus* (house mouse), *Rattus rattus* (black rat) and *R. norvegicus* (brown rat). *Akodon* and *Cavia* are characteristic species of linear and less disturbed habitats of rural areas, of the low delta of the Paraná River and of Pampean grasslands (Mills et al. 1991; Busch and Kravetz 1992; Bilenca and Kravetz 1995); *Oligoryzomys* is a good colonizer of disturbed habitats, particularly grasslands and marshes (Sánchez López 1998); *Scapteromys*, *Deltamys* and *Oxymycterus* are characteristic of habitats with an abundant supply of water such as freshwater marshes and riparian forests, while *Mus* and *Rattus* are mostly found in domestic and peridomestic areas, although they are occasionally captured in field crops and along their borders (Kravetz et al. 1987; Miño et al. 2001).

In rural areas, the variation in population density of all species is seasonal, with a minimum in spring and a maximum in late autumn and winter, followed by a drastic drop (Mills et al. 1991; Busch and Kravetz 1992).

Table 1 Characteristics of the study sites. C=cell; RM=riparian margins

Sites	Altitude (m asl)	Area (ha)	Distance from marsh (meters)	Date of site closure
C1	8	30	10	July 1990
C2	11.5	9.8	600	February 2004
C3	6	31	800	November 1987
RM1	1	30	0	–
RM2	1	10	0	–

Rodent and environmental surveys

Rodents were captured with Sherman live traps and cage live traps (15x16x31cm) set 10 and 20 m apart, respectively. Traps were placed on a 50×100-m grid in cells and on 500-m transects along riparian margins. Sherman live traps were baited with a mixture of fat, rolled oats and peanut butter, and cage live traps with pieces of raw meat and carrot. Samplings were performed for 3 consecutive nights on a seasonal basis between December 2005 and September 2006. The species, sex, external reproductive condition, body weight and head-body lengths were recorded for each captured individual (Gómez Villafañe et al. 2005). Each individual was marked and released at the site of capture.

The relative abundance of each species per month and site was estimated with the Trap Success (TS)=no. of individuals/no. of trap nights (Mills et al. 1991). The trap success for big rodents was calculated based on the number of individuals captured in cage live traps, while the trap success for small rodents was based on the number of individuals captured in both types of traps.

We calculated the Shannon-Wiener diversity index (H) (Krebs 1978) for each site as $H=-\sum p_i \times \ln(p_i)$, where p_i=proportion of TS of species i with respect to the total TS.

A cluster analysis was performed (Pielou 1984) to classify sites according to rodent species composition and their relative abundance in the different samplings.

At each site, we recorded the vegetation structure and composition within 1 m^2-quadrats placed at all trap stations where captures occurred and in the same number of randomly selected trap stations where captures did not occurred. The variables recorded at each trap station were as follows: percentage of total plant cover; presence of herbs; shrub and tree cover; percentage of green and dry plant cover; percentage of grass and percentage of forbs cover relative to the total herb cover, and height of the herb layer. The plant species composition in each quadrant was also determined. Ten soil samples were collected and dried at 60°C until constant weight to estimate soil water content (SWC), defined as the difference between the weight of the sample and the weight after drying, divided by the weight after drying.

Data analyses

Rodent abundance was compared among seasons by means of Analyses of Variance and inside each study sites among seasons by means of Difference of Proportion (Zar 1996).

A cluster analysis (Pielou 1984) was performed to group the studied sites on the basis of their topographic characteristics, SWC and the mean of each vegetation variable per site.

We measured the association between both cluster analyses by the Mantel Test (Manly 1997).

Rodent habitat use was analyzed using a Generalised Linear Model for regression with a forward stepwise procedure (Crawley 1993; McCullagh and Nelder 1989; Nicholls 1991), using the GLM procedure of S-Plus 2000 (Insightful 2002). This analysis was performed at two scales according to Litvaitis et al. (1994). At the macrohabitat scale, we explored the relationship between trap success of each rodent species and topography, presence or absence of garbage, abundance of other rodent species and the mean of each vegetation variable per site and month. At the microhabitat scale, the presence or absence of capture of each species at each station was used as the response variable, against the vegetation variables per quadrant. We used a logistic distribution to predict responses of the dependent variable assuming a binomial error distribution. The models were fitted by using a maximum likelihood method (McCullagh and Nelder 1989). Only one variable was chosen in case of correlation, and only those species present in more than one site per month were included.

Results

We recorded a total of 544 captures of 433 individual rodents with a trapping effort of 4406 trap-nights. Five native rodent species were captured: *A. azarae* (358), *O. flavescens* (32), *D. kempi* (14), *C. aperea* (11) and *S. aquaticus* (4) and one commensal rodent: *R. rattus* (Black Rat, 14).

In general, rodent abundance did not vary among seasons ($F_{3,12}=1.77$, $p=0.20$, Fig. 1). However, when the sites were analyzed individually, we observed that in C1 and C3 rodent abundance was lowest in December, increased in March and June and declined in September ($p<0.05$). Significative differences in abundance among seasons were not detected in the other sites (Fig. 1).

A total of more than 70 plant species were recorded. The riparian margins were characterized by the presence of trees, with the dominant species being *Melia azedarach, Tessaria integrifolia* and *Sapium haematospermum*. In cells, grass cover was the dominant layer, with *Cynodon dactilon, Tagetes minuta, Bromus* sp. and *Althernantera* sp. as the most frequent species. Trees and shrubs were also present in C3.

Rodent species composition varied among sites, but *A. azarae* was always the most abundant species (Fig. 2). Rodent diversity was higher in riparian margins ($H_{MB1}=0.77$ and $H_{MB2}=1.52$) than in cells ($H_{C1}=0.59$, $H_{C2}=0.39$ and $H_{C3}=0.5$).

C1 and C3 were more similar to each other than to C2 in relative rodent species abundance (Fig. 3). With regard to vegetation characteristics, C1 and C3 were more similar to each other than to C2 and to the riparian margins (Fig. 4). The vegetation cluster analysis showed that riparian margins were similar to each other while C2 differed from all other sites (Fig. 4). C1 and C3 were similar for some variables of vegetation structure, e.g. percentage of total cover higher than 97% throughout the year, 47–68% of grass cover in March and June. On the other hand, C2 showed the lowest herb layer (18–42 cm), the highest grass cover (over 88%) and the lowest plant species richness throughout the year, possibly due to its recent closure; in addition, it had the highest altitude. The riparian margins were low, dominated by forbs (81–97%), with a high percentage of green plant

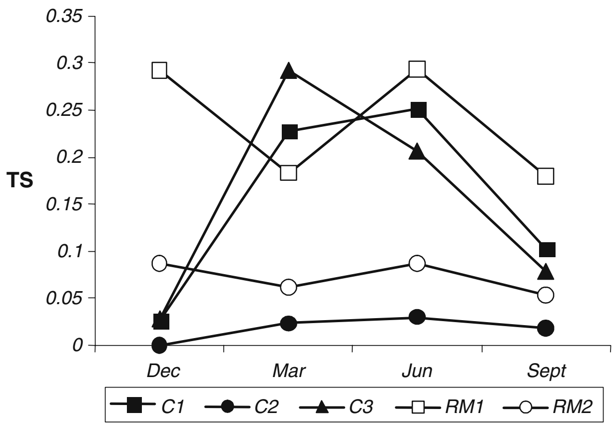


Fig. 1 Trap success (TS) of *A. azarae* (*Aa*) *Oligoryzomys flavescens* (*Of*), *Deltamys kempi* (*Dk*), *Rattus rattus* (*Rr*), *Cavia aperea* (*Ca*) and *Scapteromys aquaticus* (*Sa*) at different sites. C=cell; RM=riparian margin

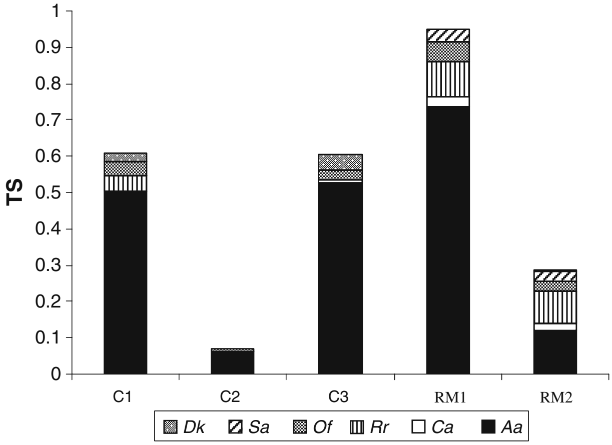


Fig. 2 Trap success (TS) of the rodent species by site. C=cell; RM=riparian margin

cover during the whole year (67–97%), and low soil water content (0.12–0.14 for riparian margins and 0.2–0.24 for cells).

A tendency of habitats with similar vegetation to have a similar rodent community was observed (r=0.82; p=0.09).

The relative rodent abundance was explained by habitat variables that changed according to the month and site. For *A. azarae*, macrohabitat use was mainly explained by the height of the herb layer in summer, with grass cover and total cover explaining 98% of the variance in December and March, respectively (Table 2). In June, the explanatory variables were the presence of the shrub or tree layer and the total cover (as a quadratic term), explaining 94% of the variation (Table 2). For *C. aperea,* the only explanatory variable was the presence of the tree and the shrub layer, explaining 17% of the variation in December (Table 2). For *O. flavescens*, the height of the herbs explained 46% of the variation in March, and the total cover more than 99% in June, the latter being negatively related to density (Table 2). In December, the best explanation of the variation in abundance was the mean of all the variables used in the analysis. For *D. kempi*, the distance from the river explained 53% of the variation in macrohabitat use in March (Table 2).

In June, the best explanation of the variation in abundance was the mean of all the variables used in the analysis. The abundance of *R. rattus* was negatively related to plant cover (mostly herbs) in June (Table 2). In March, the best explanation for the variation in

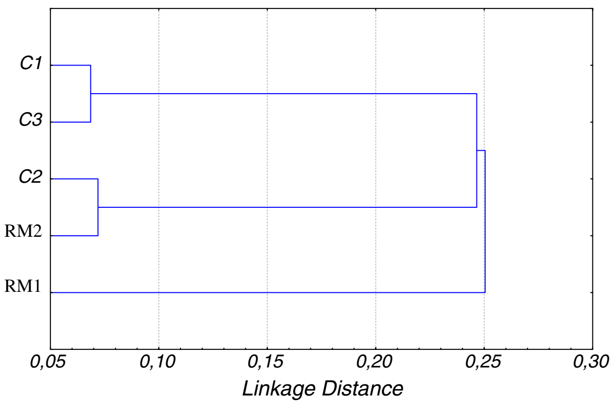
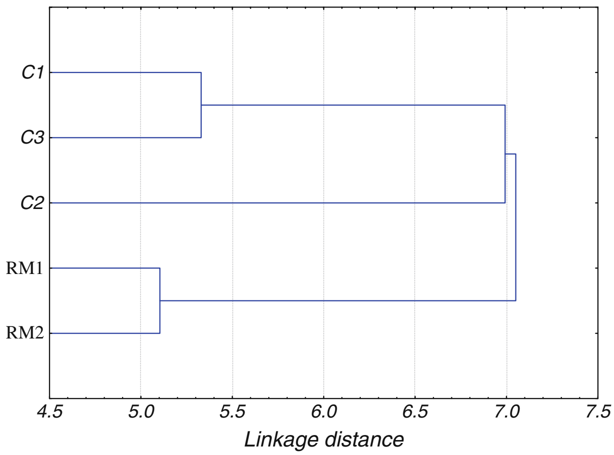


Fig. 3 Cluster analysis of the study sites based on topography and vegetation structure variables. C=cell; RM=riparian margin

Fig. 4 Cluster analysis of the study sites based on trap success by species and month. C=cell; RM=riparian margin



abundance was the mean of all the variables used in the analysis. For *S. aquaticus*, the distance from the river explained 99% of the variation in the abundance (Table 2), being negatively related to density in June.

Microhabitat use was poorly explained by the studied variables. The captures of *A. azarae* per trap station were related to total and forb cover in MB1, and to the percentage of green cover and herb layer height in C3 (Table 3).

Discussion

Our results indicate that the closed landfill plays an important role in the recovery of almost all the native rodent species characteristic of the area (four of six native rodent species). They also show the highest total rodent abundance ever recorded in this type of habitat (Bilenca and Kravetz 1998; Bonaventura et al. 1991; Cavia 2006).

The seasonal variation in rodent abundance found in two of the three cells is coincident with the natural cycle observed in natural habitats (Mills et al. 1991; Busch and Kravetz 1992). The atypical pattern of abundance dynamics observed in one of the cells could be explained by the fact that, due to the recent closure of this cell, its rodent community is not yet established.

The high diversity of the rodent community may be a result of the differences in distance from the river, altitude, time since closure, plant structure, floristic composition and cell management found among different cells. These differences may also account for the different species composition found at macrohabitat scale (among sites), while we did not find heterogeneity at microhabitat scale.

The commensal *R. rattus* inhabited the riparian margin which showed antrophic characteristics such as low vegetation cover and presence of garbage which could be used for food and shelter and that was dragged and dropped by the river (Coto 1997).

Akodon azarae, usually living in rural areas, dominated almost all sites. It is worthwhile to mention that this species has also been found in the low delta of Paraná River and Pampean grasslands in Buenos Aires, habitats which share some characteristics with the studied landfill (Bonaventura et al. 1988, 1991, 1992; Bonaventura and Kravetz 1984; Busch et al. 2001). *Oligoryzomys flavescens*, a good colonizer of disturbed habitats, particularly grasslands and marshes (Sánchez López 1998), was infrequent at sites with

Table 2 Multiple regression analysis between trap success (TS) of *A. azarae, O. flavescens*, *R. rattus*, *C. aperea* and *D. kempi* and structure vegetation variables per site and month. df=degrees of freedom

	Coefficient	*t*	*p*-value	Residual deviance	df	Difference of the residual deviance	df	*p*-value
A. azarae								
Dec (98.41%)								
Null model				122.18	4			
Intercept	−14.8846	−6.95	0.002					
% Forbs	0.0680	4.50	0.010	47.30	3	74.880	1	<0.001
Herb layer height	0.1708	6.31	0.003	61.50	2	13.384	1	<0.001
Interaction	−0.0024	−3.45	0.018	11.45	1	1.939	1	0.001
March (97.65%)								
Null model				88.95	4			
Intercept	−12.4438	−6.95	0.002					
Herb layer height	0.0575	4.50	0.011	54.01	3	34.936	1	<0.001
% Total cover	0.0607	6.31	0.003	32.85	2	2.089	1	<0.001
June (93.85%)								
Null model				65.54	4			
Intercept	−2.5559	−5.56	0.005					
Tree/shrub layer	3.0703	5.85	0.004	53.16	3	12.380	1	<0.001
% Total cover^2	8.3490	−2.89	0.045	8.35	2	4.031	1	0.004
O. flavescens								
March (45.76%)								
Null model				12,73	5			
Intercept	−6.7040	−5.27	0.003					
Herb layer height	0.0299	2.15	0.084	5.83	4	6.906	1	0.008
June (99.68%)								
Null model				1262.54	5			
% Total cover	−0.0581	−11.97	0.000	1258.55	4	3.994	1	<0.001
R. rattus								
June (98.20%)								
Null model				280.33	5			
% Total cover	−0.0431	−8.32	0.000	275.29	4	5.038	1	<0.001
C. aperea								
Dec (17.03%)								
Null model				14.75	4			
Intercept	−7.4684	−5.30	0.003					
Tree/shrub layer	5.3186	2.43	0.059	2.51	3	12.237	1	<0.001
D. kempi								
March (52.99%)								
Null model				22.84	4			
Intercept	−6.7737	−6.65	0.001					<0.001
Dist from marsh	5.3186	2.79	0.038	12.10	3	10.737	1	0.001
S. aquaticus								
June (99.99%)								
Null model				483.59	5			
Dist from marsh	−0.0853	6.033	0.002	483.56	4	0.032	1	<0.001

Table 3 Multiple regression analysis between presence-absence of *A. azarae* and structure vegetation variables for each quadrant. df=degrees of freedom

	Coefficient	*t*	*p*-value	Residual deviance	df	Difference of the residual deviance	df	*p*-value
A. azarae								
December MB1 (9.8%)								
Null model				103.638	74			
Intercept	1.5017	2.30						
% Total cover^2	−0.0002	−2.42	0.012	6.262	73	97.38	1	0.012
%Forbs	0.0193	1.80	0.076	3.869	72	93.51	1	0.049
December C3 (48.9%)								
Null model				30.499	22			
% Green cover	−0.0407	−2.47	0.022	14.911	21	15.59	1	<0.001
March C3 (16.1%)								
Null model				59.028	74			
Intercept	−2.4400	−2.75	0.070					
Height of the herb layer	0.0247	2.75	0.070	9.507	73	49.52	1	0.002

high percentage of herb cover, where *A. azarae* was dominant. Finally, *D. kempi* and *S. aquaticus*, typical of riparian areas, used water-related habitats. *Scapteromys aquaticus* used riparian margins, which are relicts of the former native habitat (D'Elia and Pardiñas 2004) and *D. kempi* used the cell with the lowest altitude, which was surrounded by ditches and subjected to temporary floods, in agreement with that reported by Gonzalez and Pardiñas (2000).

Species richness increased with time since the closure of the cells, while the highest diversity was found in the cell at intermediate time since closure and the lowest diversity in the most recently closed cell. These results, which are consistent with the succession model of Clements, have also been reported from sites that were put out of use after causing a disturbance, like lands adjacent to non-operating mines (Rathke and Bröring 2005) and abandoned fields (Hirth 1959; Pearson 1959).

Finally, it is reasonable to speculate that the studied rodent community differs from the original one, based on the absence of species like *Oxymycterus rufus* and *Oligoryzomys nigripes*, which are found in shrubs, freshwater marshes and riparian forests (Bonaventura et al. 2003; Lareschi et al. 2004; Nava et al. 2003). Nevertheless, we found a rich rodent community, mainly composed of wild species rather than commensal species that by the contrary are abundant in landfills that are in operation (Gabrey 1997). It is possible that the relictual riparian margin has been a major refuge for the native rodent community while the landfill was in operation, and after closure it served as a source of some species that colonized rapidly the closed cells. These possible movements from the riparian margin to the cells would not allow to detect rodent abundance variations through the time in these places.

Some commensal species such as *R. norvegicus* have been found in large numbers in the landfill area adjacent to the Buenos Aires city (Busch, personal communication); however, these species were scarcely found in the landfill cells.

Our results indicate that closed sanitary landfill can be used not only for recreational purposes but also for the conservation of native fauna.

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