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Can a habitat specialist survive urbanization? the case of the viscacha (*Lagidium viscacia*, Chinchillidae)

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Abstract Urban growth is a strong driver of habitat degradation and loss. In spite of that, a surprising diversity of native species may survive in urban areas. In the La Paz, Bolivia metropolitan area and surroundings, local populations of "viscachas" (*Lagidium viscacia*) currently survive in small, isolated habitat patches. We assessed 13 study sites in 1999, 2003, and 2007 to document the effects of urban growth on *L. viscacia* habitats. Degree of disturbance at the study sites increased more between 1999 and 2003 than it did between 2003 and 2007 due to patterns of urban expansion. Using satellite imagery we determined that the urban area increased 566 ha (from 1987 to 2001) mostly due to southward urban area expansion down the valley where the best viscacha habitats were located. Occupied patch area decreased 74 % between 1999 and 2007, accompanied by significant increases in patch edge-to-area ratios. Currently *L. viscacia* populations in La Paz are experiencing a habitat attrition process. If a current urban expansion plan for La Paz is approved, about 75 % of the remaining habitat may be lost to urban development in a short time, compromising the future viability of this species in the metropolitan area and surroundings. Environmental regulations to control urban growth of the La Paz metropolitan area are urgently required and constitute the only hope for the survival of *L. viscacia* in the city.

Keywords Bolivia · Conservation · Fragmentation · Habitat disturbance · Urban ecosystem · Urban wildlife

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Introduction

Urban growth is a strong driver of habitat loss and degradation, normally leading to high local extinction rates, homogenization of the biota, and elimination of most native species and their replacement by alien species (McKinney 2002, 2006; Donnelly and Marzluff 2006; Shochat et al. 2006). Rapid human population growth is seen as inevitable, and the proportion of the populace living in cities has increased globally. By 2005, 77 % of the population of Latin America and the Caribbean was urban (Obaid 2007), a level similar to Europe, North America, and Japan in 1999 (Sadik 1999).

The La Paz, Bolivia metropolitan area (including the city of El Alto) with a population of nearly 1.5 million people in 2006 (Hardy 2006), is no exception to the global trend toward urbanization. Like other places, population growth and urban expansion have increased greatly, particularly as a result of immigration from rural areas (Hardy 2006; UNICEF-Bolivia 2001).

A rodent habitat specialist, the southern mountain viscacha (*Lagidium viscacia* Molina 1782), still exists in small populations in metropolitan La Paz and surroundings. This species is colonial and lives in rocky outcrops, talus slopes, and steep canyons (Pearson 1948; Rowlands 1974; Werner et al. 2006). Rocks and cliffs are key factors in *L. viscacia* habitat because they provide appropriate places for sunning and resting, establishing small family groups, and seeking refuge from predators (Pearson 1948; Walker 2001; Walker et al. 2000).

In the La Paz metropolitan area and surroundings, *L. viscacia* inhabit small rocky outcrops and other patches of suitable habitat left by urban growth (Tarifa et al. 2004). Thus, urban growth has generated a mosaic of remaining habitat patches progressively surrounded by a heterogeneous “non-friendly” matrix (Ricketts 2001) of buildings and roads that *L. viscacia* are reluctant to disperse through (Walker et al. 2007).

In this study we continue a monitoring effort begun in 1999 (Tarifa et al. 2004). Herein we revisit the sites and apply a Geographic Information System (GIS) spatial analysis to answer the following questions: (1) Did anthropogenic disturbance at the study sites increase to the same degree between 1999 and 2003 as it did between 2003 and 2007? (2) How are land use changes over time in the La Paz metropolitan area affecting habitat availability and the potential for dispersal for *L. viscacia*? Based on our results, we estimate future viability of remnant populations of *L. viscacia* in the La Paz metropolitan area and surroundings.

Methods

Study area

The study area included the metropolitan area of La Paz, Bolivia and surroundings (16°30’S, 68°15’ W; average elevation 3,700 m; Lorini 1991). The metropolitan area is located in a mountainous Pleistocene glacial valley between 2,600 to 4,100 m of elevation. Topography is rugged with cliffs, steep hillsides, and a complex of valleys (Liberman 1991; Lorini 1991). Development is creative with houses sometimes built on very steep hillsides or even cliffs.

In 1999, we selected 13 study sites with known viscacha populations for long term monitoring effort (Fig. 1). We reassessed nine of them in 2003 (Tarifa et al. 2004). In 2007, we again reassessed the same nine sites to follow further the effects of urban expansion on viscacha habitats. Four of the study sites (Vino Tinto, Khallapa, Mallasa, and Ananta) assessed in 1999, could not be reassessed in 2003 or 2007 due to their inaccessibly during the rainy season when we were able to visit them (detailed study sites information at Supplementary Table S1, available online).

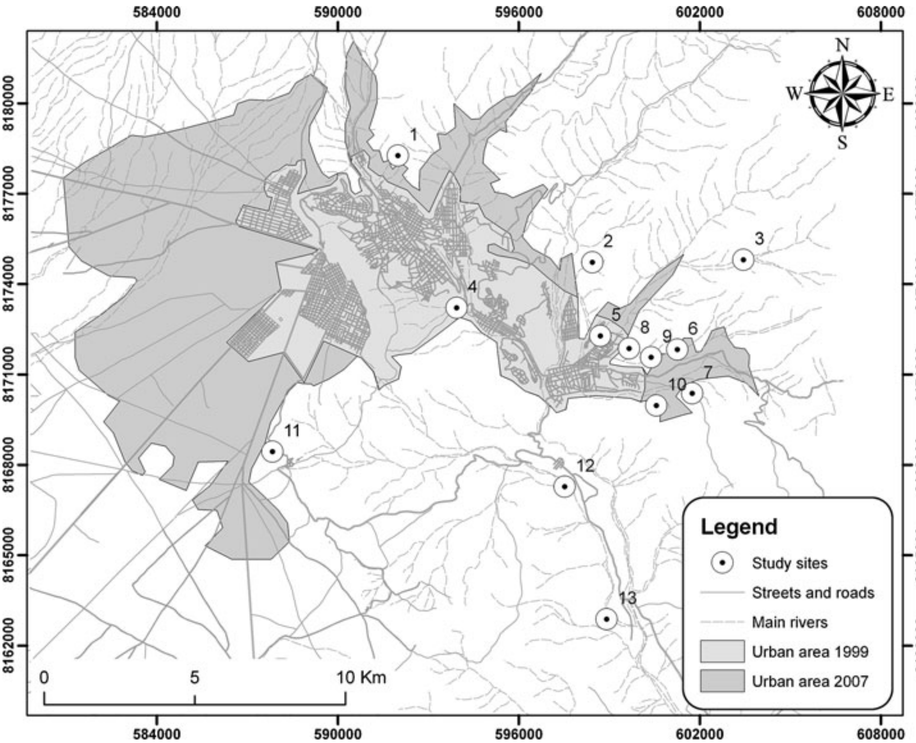

Fig. 1 Map of the study area, metropolitan area of La Paz (Bolivia) and surroundings. Urban areas depicted in the map correspond to 1999 and 2007 data (see Table S1 for coordinates and elevations)

Occupied sites

Sites occupied by *Lagidium viscacia* were found by searching rocky outcrops and other suitable places for the animals or their fecal pellets, which are abundant in sunny places near their shelters (Walker et al. 2003). Their pellets are so distinctive that we could safely use them to confirm the presence of viscachas at a site even if animals were not seen. All sites were discrete and separated from other sites by at least 0.86 km. A study in Patagonia determined that the maximum dispersal distance for *L. viscacia* is 2 km (Walker et al. 2007). The sites selected in 1999 were used as a baseline for subsequent comparisons with 2003 and 2007 data.

Habitat reduction

We used 1999, 2003, and 2007 Landsat 5 TM images to manually digitize vector habitat areas for the 13 study sites. We also used a 1972 Landsat MMS image of the city of La Paz and surroundings to calculate the habitat areas 40 years ago when most of the sites were at a distance from human settlements. We used field data, previously classified images, and hydrologic maps as additional sources to digitize habitat areas. We considered urban areas and large rivers as physical barriers to viscacha dispersal. There are several large and small rivers within the metropolitan area of La Paz, but probably only the largest constitute dispersal barriers during the rainy season (Walker et al. 2007). Areas occupied by viscachas were calculated using the XTools extension for ArcView. Values are expressed as mean ± 1SE. Using this data, we also calculated the perimeter length for each patch in order to estimate the perimeter/area ratio, which is a good proxy for habitat reduction because larger and regular patches have lower perimeter/area ratios than small and irregular patches.

Degree of anthropogenic disturbance

The degree of anthropogenic disturbance was reassessed after 4 years. That time period may appear short, but the pace of urban growth in the La Paz metropolitan area is exceptionally rapid; the annual growth rate has remained close to 3.5 % for the past 50 years (Arbona and Kohl 2004), thus the potential for impacts on viscacha habitats is high. For example, between 1999 and 2003, we documented the complete destruction of two sites formerly occupied by viscachas (Tarifa et al. 2004).

To reassess disturbance at the nine sites in 2007, we used the same criteria as the baseline study (Tarifa et al. 2004): presence of (1) solid wastes, (2) domestic animal feces, (3) human feces, (4) buildings, (5) domestic animals, (6) hunters or shell casings, (7) landslides (both natural and human-caused), (8) loss of native vegetation, and (9) ease of access for domestic animals and humans. Four grades of intensity were assigned to each criterion, ranging from 0 (no disturbance) to 3 (the worst situation). The degree of disturbance for each site was obtained by summing the scores for each criterion. Based on summed scores, sites were classified as follows: low disturbance from 0 to 9 points, medium disturbance from 10 to 18 points, and high disturbance from 19 to 27 points.

Changes in land use

We assessed changes in land use at the landscape level for the entire metropolitan area of La Paz. We worked with two high-quality satellite images, a 1987 Landsat 5 TM and a 2001 Landsat 7 EMT + (available for free download from the United States Geological Survey website http://glovis.usgs.gov). The images were geometrically corrected and cropped using ERDAS IMAGINE 8.4 (hereafter, ERDAS) software. We conducted a supervised classification in ERDAS, using five landscape classes: “plateau” (high plains), “mountain” (high mountains with elevation>4,000 m), “urban vegetation” (areas with plant coverage, regardless of their type), “urban area”, and “viscacha habitat.” Suitable habitat for *L. viscacia* was defined as areas with rocky outcrops, talus slopes, and steep canyons (Pearson 1948). Only “viscacha habitat” and “urban area” classes were used in land use change analyses.

We used classified images to obtain quantitative landscape data by conducting a fragment analysis using Patch Analysis 3.0 for ArcView GIS 3.2 (Rempel 2006). We considered four kinds of metrics: (1) landscape; (2) edge; (3) shape; and (4) core area (Hargis et al. 1998; Pauchard et al. 2006). We assumed edge effects to penetrate an arbitrary distance of 100 m, which was used to calculate core areas.

Connectivity

To estimate potential dispersal path lengths between study sites, we assumed that *L. viscacia*, like other chinchillids, does not commonly use straight-line dispersal paths (J. Jiménez pers. comm.), because moving across rocky hillsides and along cliffs offers greater protection from predators (Walker et al. 2003, 2007). Distances for each potential dispersal path were estimated using Google Earth software. We considered all cliffs and slopes without anthropogenic intervention to be possible dispersal routes. In some cases where the patch was surrounded by urban areas, a hypothetical dispersal path (i.e., the shortest distance across the urban area or crossing large rivers) was estimated. Landscape connectivity was calculated using the formula:

$$C = \frac{2L}{N * (N - 1)}$$

where C is the landscape connectivity, L is the number of connections (i.e., number of potential dispersal paths with length ≤ 2 km), and N is the number of patches (Knaapen et al. 1992).

Data analysis

We assessed differences in disturbance level and habitat areas among years (1999, 2003, and 2007) using non-parametric Friedman tests for K-related samples. Due to the low sample size, we performed 10,000 Monte Carlo permutations to estimate the probability distribution (Quinn and Keough 2003). Perimeter/area ratios were calculated using the XTools extension, dividing the perimeter by the area for each habitat patch. Friedman tests were used for perimeter/area data as described above.

Results

Habitat reduction

In 1972, we estimated there was a total of 25,553 ha of viscacha habitat associated with our study sites in the La Paz metropolitan area and surroundings. By 1999, only 18,665 ha (74 %) remained. By 2003, this was strikingly reduced to a mere 6,822 ha (27 %), and by 2007, it had been further 6,669 ha (26 %). Based on satellite imagery, in 1972, we identified seven major patches of viscacha habitat associated with our study locations. In 1999, one of those patches (Cementerio Jardín) was lost to city encroachment. Further, the patches containing Pedregal, Muela del Diablo, Cota Cota Calle 29, and Cota Cota Calle 35 were greatly reduced in size (Fig. 2).

By 2003, we identified nine habitat patches because of fragmentation of Pedregal-Muela del Diablo, Achocalla-Mallasa-Ananta, and Khallapa patches. The remaining patches were smaller in area. By 2007, one more patch (Khallapa) was lost to urbanization (Fig. 2). Overall, mean patch area was significantly reduced among years (3,111±1,527 ha [n=6 patches] in 1999, 758±303 ha [n=9] in 2003, and 741±315 ha [n=8] in 2007; Friedman χ^2=11.56, df=2, p<0.001, n=6), being more drastic between 1999 and 2003 than between 2003 and 2007, following the same trend as anthropogenic disturbance (see below).

In direct relation to habitat reduction, the perimeter/area ratio also increased over time (11 m/ha in 1999, 21 m/ha in 2003, and 22 m/ha in 2007; Friedman χ^2=10.17, df=2, p=0.02, n=6). This shows that habitat patches are getting smaller and more irregular across time, since the same perimeter length in 2007 is associated with half of the area than in 1999. Such figures confirm the trend obtained through satellite imagery: increasing urban encroachment is reducing the number and the size of the occupied habitat patches.

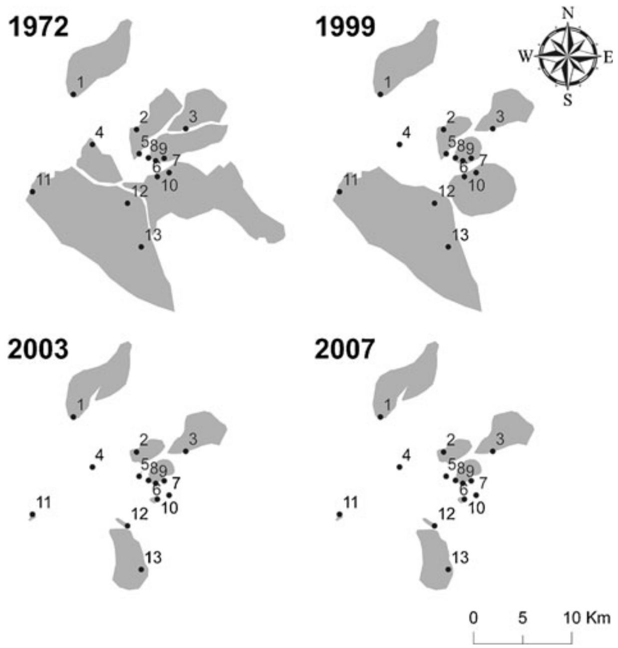

Fig. 2 Habitat areas estimated from satellite imagery of 1972, 1999, 2003 and 2007

Anthropogenic disturbance

Anthropogenic disturbance increased significantly over time (Friedman $\chi^2=17.18$, df=2, $p<0.001$, $n=13$). The increase was greater between 1999 and 2003 than it was between 2003 and 2007 (Table 1). In 2003, two sites, Cementerio Jardín and Pedregal, were destroyed to expand a cemetery and build a new housing development, respectively. By 2007, both sites were well inside the urban area. In 2007, habitat degradation increased at three sites: Cota Cota Calle 29, Achocalla, and Muela del Diablo. Disturbance levels were unchanged at four sites (Kellumani, Ermita de Schoenstatt, Barranco de Achumani, and Cota Cota Calle 35) (Table 1). At the three sites with increased disturbance, new buildings and roads, domestic animals, and solid wastes contributed the most to the increased disturbance levels. Conversely, at these sites hunters, native vegetation, and accessibility for humans remained relatively constant across time. Detailed information on disturbance quantification at each study site and assessment year is available in Table S2, at online Supplementary Material.

Land use changes

The urban core area of La Paz increased by 1,088 ha (ca. 78 ha/year) between 1987 and 2001. During the same time period, it encroached over 566 ha of viscacha habitat. As the city has grown, its shape has become more spherical, changing from a mean shape index (MSI) of 1.26 in 1987 to a MSI of 1.24 in 2001 (where MSI=1 is a perfect circle, MSI between 1 and 2 is an irregular form, and MSI>2 is very irregular). The more spherical shape is consistent with recent southward expansion of the city down the valley. This part of the city has the most accessible areas for new urban development. The city had previously expanded in other directions as far as the rugged topography of the valley would permit.

Table 1 Evidence of presence (based on 1999 data) and degree of human disturbance at the study sites in 1999, 2003, and 2007

No.	Study site	Evidence of presence	Degree of disturbance		
			1999	2003	2007
1	Vino Tinto	Sight (5 individuals)	medium	NA	NA
2	Khallapa	Sight (3 individuals)	medium	NA	NA
3	Kellumani, Achumani	Sight (2 individuals)	low	medium	medium
4	Cementerio Jardín	Feces	high	destroyed	destroyed
5	Ermita de Schoensttat	Sight (4 individuals)	medium	medium	medium
6	Barranco de Achumani	Feces	low	low	low
7	Pedregal	Feces	medium	destroyed	destroyed
8	Cota Cota Calle 29	Feces	medium	medium	high
9	Cota Cota Calle 35	Sight (7 individuals)	high	high	high
10	Muela del Diablo	Sight (Colony[a])	low	low	medium
11	Achocalla	Sight (7 individuals)	low	low	medium
12	Mallasa	Feces	high	NA	NA
13	Ananta	Sight (9 individuals)	low	NA	NA

NA Not assessed

[a] Colony with many individuals

Overall in the La Paz metropolitan area and surroundings, the number of habitat patches increased at a rate of ~97 patches/year (in 1987 there were 12,175 suitable habitat patches; they increased to 13,528 in 2001). However, the increase in patch number was accompanied by a 54 % reduction in the mean core area of the patches (from a mean of 11.63 ha in 1987 to a mean of 6.29 ha in 2001), which represents the area in the interior of each fragment that is unaffected by edge effects. Total habitat area has been reduced from 141,595 ha in 1987 to 85,091 ha in 2001. Moreover, total core area has been reduced from 78,331 ha in 1987 to 63,570 ha in 2001.

Connectivity

Distances calculated for the potential dispersal paths (Table S3) were between 0.86 and 35.65 km with an average distance of 13.85±7.35 km. Considering 2 km as the maximum dispersal distance, only 4 of 78 paths (5.1 %) or 4 of the 62 effective (non–hypothetical) paths (6.5 %) are within maximum dispersal distance and would allow dispersal of individuals among sites. Landscape connectivity decreased from C=0.17 in 1999, to C=0.05 in 2003 and C=0.04 in 2007. This is a loss of 71–77 % in connectivity among occupied patches, effectively leaving all but four sites permanently isolated.

Discussion

The greater habitat loss in the years 1999 to 2003 than 2003 to 2007 is consistent with the real estate boom in the southwestern area of La Paz that started in 2000. More accessible and geologically stable sites, such as Cementerio Jardín (destroyed in 2002), Pedregal (destroyed in 2003), and Cota Cota Calle 29 were the sites most impacted by roads and urban construction. On the other hand, less accessible or remote sites, such as Barranco de Achumani, Muela del Diablo, and Achocalla remained less disturbed due to their former inaccessibility. After 2003, the use of heavy machinery and new access roads permitted building on terrain that had previously been too rugged or unstable. By 2007, anthropogenic disturbances increased due to new urban settlements, the presence of dogs, new roads, and dumping of solid waste, and construction near those sites.

The relatively slower increases in disturbance at the three less accessible sites could change very abruptly after 2012. Recent announcements of the expansion of the city of La Paz from 7,648 ha to 13,911 ha (an increase of about 80 % in urban area) would jeopardize at least eight viscacha sites (i.e., Vino Tinto, Khallapa, Kellumani, Achumani, Cota Cota Calle 29, Cota Cota Calle 35, Muela del Diablo, and Mallasa) (digital edition La Razón [La Paz newspaper], 6 February 2011).

Tarifa et al. (2004) identified the Muela del Diablo and Achocalla sites as potential protected spaces for *L. viscacia*, either as wildlife sanctuaries or as Municipal Protected Areas. As of the present, the Municipal Government of La Paz is the only one in the country that has created a Municipal System of Protected Areas. Thus far, 28 Municipal Protected Areas have been created by municipal order or national law. Among the newly-created protected areas is Área Protegida Municipal Muela del Diablo y Cerro Pachajalla with a total area of 1,299.4 ha (PROMETA 2009) which will protect our Muella del Diablo site. On the other hand, Achocalla is still not listed among the areas being considered for protection. Achocalla's rate of urban development was calculated at 1.54 % per year due to the city "spilling over" into this suburban area (Hardy 2006). If the Municipal Government of La Paz approves the proposed expansion plan, it would be impossible to establish additional protected spaces in southwestern La Paz. However, the system of Municipal Protected Areas has already been beneficial elsewhere. There are other areas near the La Paz metropolitan area that were identified by Tarifa et al. (2004) as having viscachas that are now being protected (i.e., 'Area Protegida Municipal Serranía de Chicani' and 'Área Protegida Municipal Valle de la Luna y Cactario') by the urban refuge system (PROMETA 2009).

The city of La Paz needs more efficient enforcement of urban growth regulations. Despite having an approved land use plan, the urban periphery with favorable habitats for *L. viscacia* is being illegally settled without the builders' complying with environmental regulations or environmental impact assessments. In February 2011, the Municipal Government announced that there were more than 50,000 illegal buildings in the city of La Paz (http://www.cambio.bo/noticia.php?fecha=2011-02-01&idn=37852).

The 566-ha increase in total urban area in the 14-year interval (1987–2001) was concentrated mainly in the southwestern area of La Paz, where we found the largest *L. viscacia* populations in 1999 (Tarifa et al. 2004). Furthermore, urban areas have encroached on viscacha habitats as a result of enclosing rivers in large culverts, flattening hills, and filling ravines. In addition, habitat patches have been converted into garbage dumps, increasing the presence of potential predators such as domestic dogs. Near the Muela del Diablo site, dog feces with viscacha hairs were found (F.E. Fontúrbel, unpublished data). These situations may worsen because of direct and indirect edge effects (Murcia 1995). This increased human disturbance is related to the increase in perimeter/area ratios among the remaining habitat patches, which tend to be fewer and smaller over time.

Not only are viscachas losing habitat, but we note that they are utilizing marginal or atypical habitats. Seven of the 13 sites we studied were typical habitats for viscachas (rocky outcrops, talus slopes, and steep canyons), whereas 6 sites were cliffs or steep slopes formed by clay soil of glacial origin (löss) that is not considered an appropriate habitat for viscachas. Possibly the pressure of urban development is forcing them into habitats they would not otherwise attempt to occupy. Further, on those newly colonized habitats vegetation composition and abundance is markedly different from non- or little-disturbed sites, as we found in a previous research (Tarifa et al. 2004). Viscacha's diet is mainly composed by grasses (specially *Stipa* spp.) and dwarf shrubs (Cortés et al. 2002), which become less diverse and abundant as urban-related disturbance increased. Comparing two contrasting situations (Muela del Diablo vs. Cota Cota Calle 35), Tarifa et al. (2004) found that vegetation cover has been reduced to the half and there was an important turnover in Compositae and Gramineae species. Consequently, viscachas thriving at disturbed habitats are also dealing with a reduced habitat quality in terms of food sources.

Future viability of remnant viscacha populations

Forty years ago, large patches of suitable habitat for *L. viscacia* surrounded the city of La Paz (Tarifa et al. 2004). Following the metapopulation models of Harrison (1991), this pre-urban expansion scenario fits well into a patchy population model (i.e., large patches close enough to function as a single unit). By 1999, habitat patch configurations better fit a classic metapopulation model (i.e., patches of different sizes and degree of connectivity). But when 2003–2007 habitat patches are analyzed, they better fit a non-equilibrium model (i.e., small and mostly unconnected patches). Over time patch number increased via a fragmentation process, while mean patch sizes decreased, suggesting a habitat attrition process (Lindenmayer and Fischer 2006).

This particular case study shows how a naturally patchy population has experienced a non-random sequence of spatial processes (Lindenmayer and Fischer 2006). First of all, the early urban expansion caused the dissection of large patches with little habitat loss. Then, large habitat patches became fragmented and shrank, with larger habitat losses after the urban expansion boom of 2000. Habitat patches that were not destroyed after 2000 continued shrinking in size and losing habitat quality (Tarifa et al. 2004) due to increasing edge effects. If this situation continues at the current pace, viscacha habitat patches will progressively disappear due to a habitat attrition process. However, with the metropolitan expansion plan, 75 % (~5,000 ha) of the remaining habitat would disappear in a very short time (2 or 3 years).

We urge regulation enforcement of urban growth in La Paz, as well as in other cities. Urban development plans should be guided by sound ecological and wildlife management principles. A new environmental policy related to urban expansion could allow conservation of native species that still survive in some parts of the urban matrix. Homogenization of the biota is an irreparable ecological and cultural loss and greatly diminishes the quality of life in urban areas.

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