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Richness and abundance of non-flying terrestrial mammals in an urban environment in the Neotropic

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ABSTRACT

Introduction: Urban green spaces are becoming increasingly important refuges for native fauna. In Costa Rica, most of the human population is concentrated in the Central Valley, producing drastic changes in natural ecosystems as urbanization increases and consequently reducing the natural habitats of multiple species. Urban development generally decreases the native diversity of mammals.
Objective: We described the richness and abundance of medium-sized terrestrial mammals in fragments of second growth and secondary forest vegetation immersed in an urban matrix.
Methods: We conducted a landscape analysis to measure the green spaces and urban land cover, and surveyed terrestrial mammals using night baiting traps, diurnal counts in transects, camera traps, and occasional reports.
Results: We found six native and three introduced species of terrestrial mammals, representing less than 50% of the medium-sized mammal diversity reported for the Central Valley of Costa Rica 40 years ago. The common raccoon (*Procyon lotor*) and the variegated squirrel (*Sciurus variegatoides*) were the most abundant species, both capable of exploiting urban habitats. Introduced species, especially free-ranging and feral cats (*Felis catus*), were the most common species in the study site. Free-ranging introduced species may increase predation and disease transmission. Fragmentation, isolation, and lack of connectivity caused by urbanization are likely affect the populations of sloth species (*Bradypus variegatus* and *Choloepus hoffmanni*) in the study site.
Conclusion: Maintaining natural and seminatural spaces and native vegetation is essential to conserve urban biodiversity.

Keywords: medium-sized mammals, urban green spaces, fragments vegetation, urbanization, mammal diversity, Neotropic.

RESUMEN

Riqueza y abundancia de mamíferos terrestres no voladores en un ambiente urbano del Neotrópico

Introducción: Los espacios verdes urbanos se están convirtiendo en un refugio cada vez más importante para la fauna nativa de Costa Rica. En Costa Rica, la mayor parte de la población humana se concentra en el Valle Central, consecuentemente, la urbanización reduce constantemente la vegetación remanente natural. En mamíferos, el desarrollo urbano generalmente disminuye la diversidad de especies nativas.

Objetivo: Describimos la riqueza y abundancia de los mamíferos medianos terrestres en fragmentos de vegetación en regeneración y bosques secundarios inmersos en una matriz urbana.
Métodos: Realizamos un análisis de paisaje utilizando sistemas de información geográfica para medir los espacios verdes y la cobertura urbana. El estudio de mamíferos terrestres incluyó trampeo nocturno, conteos diurnos en transeptos, cámaras trampa y registros ocasionales.
Resultados: Encontramos seis especies nativas y tres especies introducidas de mamíferos terrestres, lo que representa menos de un 50% de la diversidad de mamíferos terrestre medianos reportada para el Valle Central hace 40 años. El mapache (*Procyon lotor*) y la ardilla (*Sciurus variegatoides*) común fueron las especies más abundantes, ambas con la capacidad de aprovechar hábitats alterados por el desarrollo urbano. Las especies introducidas, especialmente el gato doméstico, representan un problema por ser eficientes depredadores de la fauna nativa y por transmitir enfermedades. Las especies de perezosos (*Bradypus variegatus* y *Choloepus hoffmanni*) en el sitio de estudio se ven afectadas por el aislamiento de los fragmentos de vegetación y la falta de conectividad generada por la urbanización.
Conclusión: Mantener los fragmentos de vegetación natural en las ciudades es primordial para la conservación de la biodiversidad.

Palabras clave: mamíferos medianos, espacios verdes urbanos, fragmentos de vegetación, urbanización, diversidad de mamíferos, Neotrópico.

INTRODUCTION

The urbanscape is rapidly increasing in response to human population growth worldwide, which as significant impact on biodiversity, particularly in hotspot areas (Alberti, 2005; Brooks et al., 2002; Magura et al., 2010; Myers et al., 2000). These changes result in natural habitat loss, species introductions, and the development of artificial environments unsuitable for most native species in most Neotropical countries (Biamonte et al. 2011; Grimm et al., 2008; Joyce 2006; McDonald et al., 2008; McKinney, 2008; Seto et al., 2012).

Within most urbanscapes there are often small fragments of vegetation that vary in shape, area, vegetation structure, and isolation (e.g., forest patches, urban and peripheral parks, corridors) that allow some species to survive and reproduce (Aronson et al., 2017; Biamonte et al. 2011; González-García 2009; Melles et al. 2003), as well as facilitate the colonization of new species (Mayer & Sunde, 2020). Therefore, understanding the abundance, distribution, and behavior of urban species in remaining natural and seminatural habitats is essential to promote conservation efforts and develop sustainable urban planning (Aronson et al., 2014; Luck, 2007; Marselle, et al. 2021; Schneider et al., 2010; Seto et al., 2012).

Non-flying terrestrial mammals are one of the groups most affected by urban development and the fragmentation of natural habitats (Haight et al., 2023; Pacifici et al., 2020). Many species, such as large carnivores, require extensive natural habitats to establish territories and maintain viable populations. These carnivores, are rare or extinct in natural areas transformed by urban expansion (Moll et al., 2018; Ordeñana et al., 2010; Presley et al., 2019; Smith et al., 2017). Fossorial mammals are another group whose populations have been drastically reduced or disappeared in urban areas due to soil compaction and loss of food sources (How & Dell, 2000). Introduced non-flying terrestrial mammals (e.g., mice, rats, cats, and dogs) that prey upon native species and compete for the same resources also pose a serious threat to native mammals in urban areas (Van Helden et al., 2020).

Non-flying terrestrial mammals are an important group in controlling populations of other species in natural and some human-modified ecosystems (Moll et al., 2020). However, many species in this group are highly susceptible to human intervention in their habitats, leading to their extinction or their populations being drastically reduced (Dowding & Murphy, 2001). Our objective in this study is to evaluate the richness and relative abundance

of non-flying terrestrial mammals within natural habitats in urban areas that vary in urban development and vegetation cover (e.g., natural habitats or gardens). If the extension of natural habitats, in relation to the area covered by the urbanscape matrix predicts the richness and abundance of non-flying terrestrial mammals, we expect the richness and abundance of these mammals to be higher in larger and more natural fragments.

MATERIALS AND METHOD

Study site: We conducted this study on the campus of the Universidad de Costa Rica from August 2014 to March 2017. This is an urban area in the northeastern section of the Costa Rican Central Valley, San José province, Costa Rica (9°54'N 84°03'W; 1200 m.a.s.l.). Tracts of secondary premontane forest covered part of the study area. These patches are remnants of a much larger, nearly continuous forest that extended to the highlands of the Central Mountain range approximately 60–50 years ago (Di Stéfano et al., 1996; Joyce, 2006; Nishida et al., 2009). Today, the original native vegetation is scarce and restricted to small fragments of remnant riparian vegetation; other vegetation is composed of isolated trees and gardens (Fig. 1 A, B; Sandoval et al., 2019).

The campus includes three separated sectors: (1) Central Campus, occupying a total area of 35 ha, which includes buildings, parking areas, open recreational areas, and two fragments of secondary forest, the Reserva Ecologica Leonelo Oviedo (RELO), bordered by Los Negritos stream and the Jardín Botánico Orozco (JBO); (2) Ciudad de la Investigación, covering 24.9 ha, which includes buildings, parking lots, lawns, riparian vegetation, and

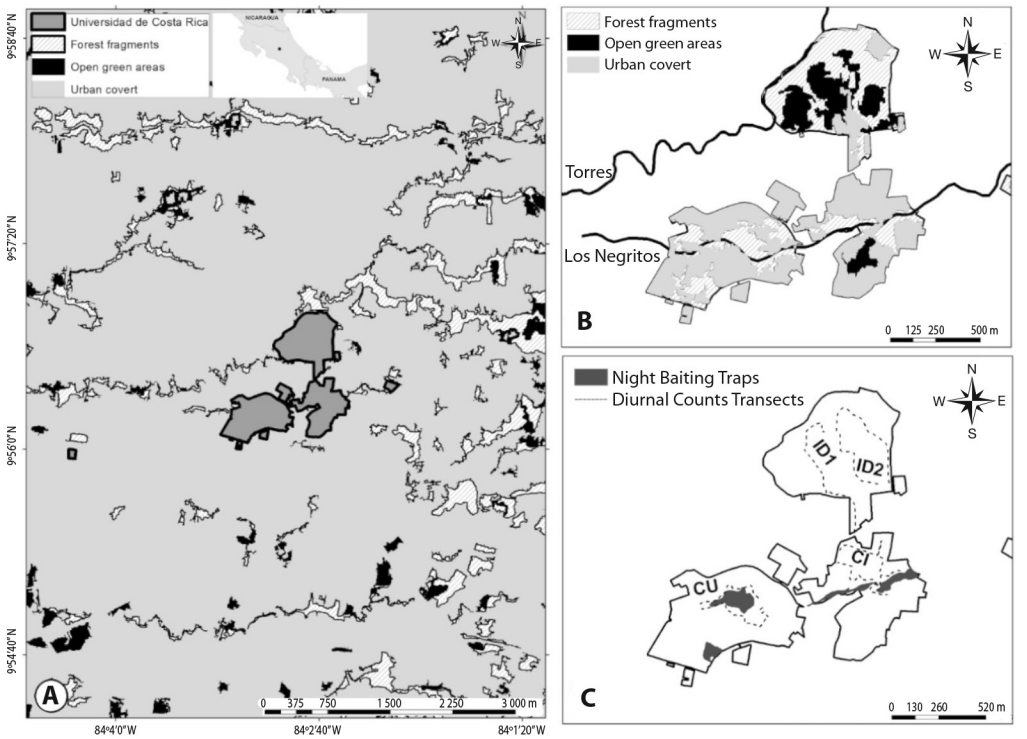

Fig. 1. A) Different cover types in the surroundings of the study site. B) Different cover types in the campus of Universidad de Costa Rica, San José, Costa Rica. C) Diurnal transects and capture night trap sites (Jardín Botánico Orozco, Reserva Ecológica Leonelo Oviedo, and Riparian Vegetation from left to right) in the three major sectors of Universidad de Costa Rica, San José, Costa Rica.

pastures along the Los Negritos stream; and (3) Instalaciones Deportivas, covering 35.2 ha, which includes buildings, lawns used for sports and recreation, riparian vegetation, and spaces covered by trees, bushes, and pastures, with the Torres River at the northern border of this area (Fig. 1B).

Landscape Analysis: We measured the percentage of vegetation and urban cover in the three sectors using satellite photos (resolution 1:5000) from the Information System of the Forest Resources of Costa Rica (2012). We used ArcGIS version 10.5.3 to classify the landscape into three categories: (1) vegetation cover, which includes forest fragments, riparian vegetation, and other spaces covered by trees; (2) open green areas, such as grass, gardens, and pastures; and (3) urban cover, including buildings, roads, sidewalks, and other areas covered by pavement.

Terrestrial mammal survey: We sampled terrestrial mammals from August 2014 to March 2017 using three methods: (1) baited night traps, (2) diurnal counts along transects, and (3) camera traps. We also included occasional reports of sightings of terrestrial mammals collected on campus during the study and information on specimens deposited in the Zoology Museum of the Universidad de Costa Rica.

We placed baiting traps from August 2014 to December 2015 in three forest fragments during nighttime sampling: (1) the Reserva Ecológica Leonelo Oviedo (RELO), (2) the Jardín Botánico Orozco (JBO), and (3) riparian vegetation (RV) along Los Negritos stream (Fig. 1C). We placed 20 box traps (model 108, 25 x 30 x 81 cm; Tomahawk Live Trap Co., Tomahawk, Wisconsin) per trapping night using commercial cat food as bait (Purina® Felix®). The traps were placed 20 m apart. Traps were set from 1600 to 0700 h and checked the next day. We conducted 27 trapping nights (15 RELO, 8 JBO, and 4 RV). The maximum number of days between trapping nights was 91 and the minimum was four (average = 16 days, SD = 24). We placed traps two consecutive nights on three occasions and three consecutive nights on one occasion. We measured the sampling effort as trap nights (number of traps multiplied by the number of trapping nights).

We conducted diurnal counts using binoculars by walking at a steadily pace along four 1-km-long transects from 06:00 to 08:00 am every two weeks. We surveyed each transect 24 times from April 2016 to March 2017. Transects were located in three areas within a matrix composed of forest fragments, open green areas, and buildings (Fig. 1C). We established transects in the three university sectors as follows: two transects at the Instalaciones Deportivas (ID1 and ID2), one at the Ciudad de la Investigación (CI), and one at the Central Campus (CC). During each survey, we counted all mammals observed per transect. The frequency of observations per species was calculated as the number of individuals observed per transect.

We used ten camera traps (Bushnell Trophy Cam HD) in RELO from March to April 2015. The camera-trap method is based on identifying animal species using photographs and videos taken by automatic cameras. Cameras were placed 50 cm above the ground between 20 m and 40 m from each other. We did not consider for the analyses pictures or videos of small mammal species (less than 1kg), because they are difficult to have a correct identification. We repeated this protocol in JBO from June to July 2015. Cameras remained active for 35 consecutive days in RELO and 23 days in JBO. The sampling effort represents the number of trap cameras multiplied by the number of active days (camera days).

We took pictures of the free-ranging and feral cats (*Felis catus*) during night baiting traps, diurnal counts in transects, and occasional observations. We also used the records from camera trap videos to identify and estimate the number of free-ranging and feral cats on campus during the study period.

Data analysis: The frequency of capture was defined as the number of individual per

species by trapping night, diurnal count transects, and camera trapping day. We estimated relative abundance using two methods: (1) the mean of individuals captured per trapping night and (2) the mean of individuals observed per transect for different species. Based on the mean value of relative abundance, occasional reports, and captures in camera traps, we classified the species into three abundance categories: rare (< 1 individual/survey, occasional report of species, or rarely captured in camera traps), uncommon (1–3 individuals/survey, or occasional capture in camera trap), and common (> 3 individuals/survey).

We used the Morisita similarity index to compare the mean species richness and abundance across the four transects. This index ranges from 0 to 1, where values close to 0 indicate no similarity between a pair of transects, and values close to 1 indicate a high similarity between a pair of transects. We built a cluster tree with a single linkage and the Morisita similarity values to represent the transect relationship according to the species richness and abundance. We also conducted a non-metric multidimensional scaling (NMDS) with Bray-Curtis distance to compare the composition of non-flying mammals' communities between transects. Differences in composition among transects were tested with a one-way PERMANOVA with 9999 permutations. We used PAST (version 4.11; Øyvind Hammer, Natural History Museum, University of Oslo, Norway) for Morisita, cluster, NMDS, and PERMANOVA analyses. Values are reported as means ± SD.

RESULTS

Land use: The three sectors varied in the area covered by each land type. The Central Campus and Ciudad de la Investigación had more urban cover than Instalaciones Deportivas, which had more vegetation and open green areas than the other two sites (Table 1). The vegetation covers at Central Campus and Ciudad de la Investigación was restricted mainly to the riparian vegetation along Los Negritos stream (Fig. 1). The Central Campus also presented natural remnants of secondary forest in two reserves RELO and JBO (Fig. 1).

Richness and relative abundances of terrestrial mammals: We registered nine species, including six native species and three introduced species, from nine families of non-flying terrestrial mammals, using the three sampling methods (Fig. 2, Table 2). We captured raccoon (*Procyon lotor*), common opossum (*Didelphis marsupialis*) and feral cats (*Felis catus*) in an effort of 524 trap nights (281 RELO, 165 JBO, and 78 RV). The mean catch per night trap was 5.2 (SD = 2.6). The common raccoon was the species with the highest average catch per night with 3.1 ± 2.7 (mean ± SD) individuals/night, followed by common opossum 1.4 ± 1.5 individuals/night, and feral cats 0.6 ± 0.9 (Table 3).

We recorded six non-flying mammal species during diurnal counts. The mean number of individuals observed per transect per day was 9.1 ± 4.7. Variegated squirrels (*Sciurus variegatodes*) were the most common species in the four transects. We observed the three-toed

Table 1

Size (ha) and percentage occupied by the different habitats in the three major sectors of the Universidad de Costa Rica, San José, Costa Rica.

Land cover	Campus Central	Ciudad de la Investigación	Instalaciones Deportivas	Total
Urban	25.1 (71.5%)	18.6 (75%)	5.6 (16%)	49.3 (51.8%)
Vegetation	10 (28.5)	4.5 (18%)	17.7 (50%)	32.2 (33.8%)
Open green areas	0	1.7 (7%)	12 (34%)	13.7 (14.4%)
Total	35,1	24.8	35.3	95.2

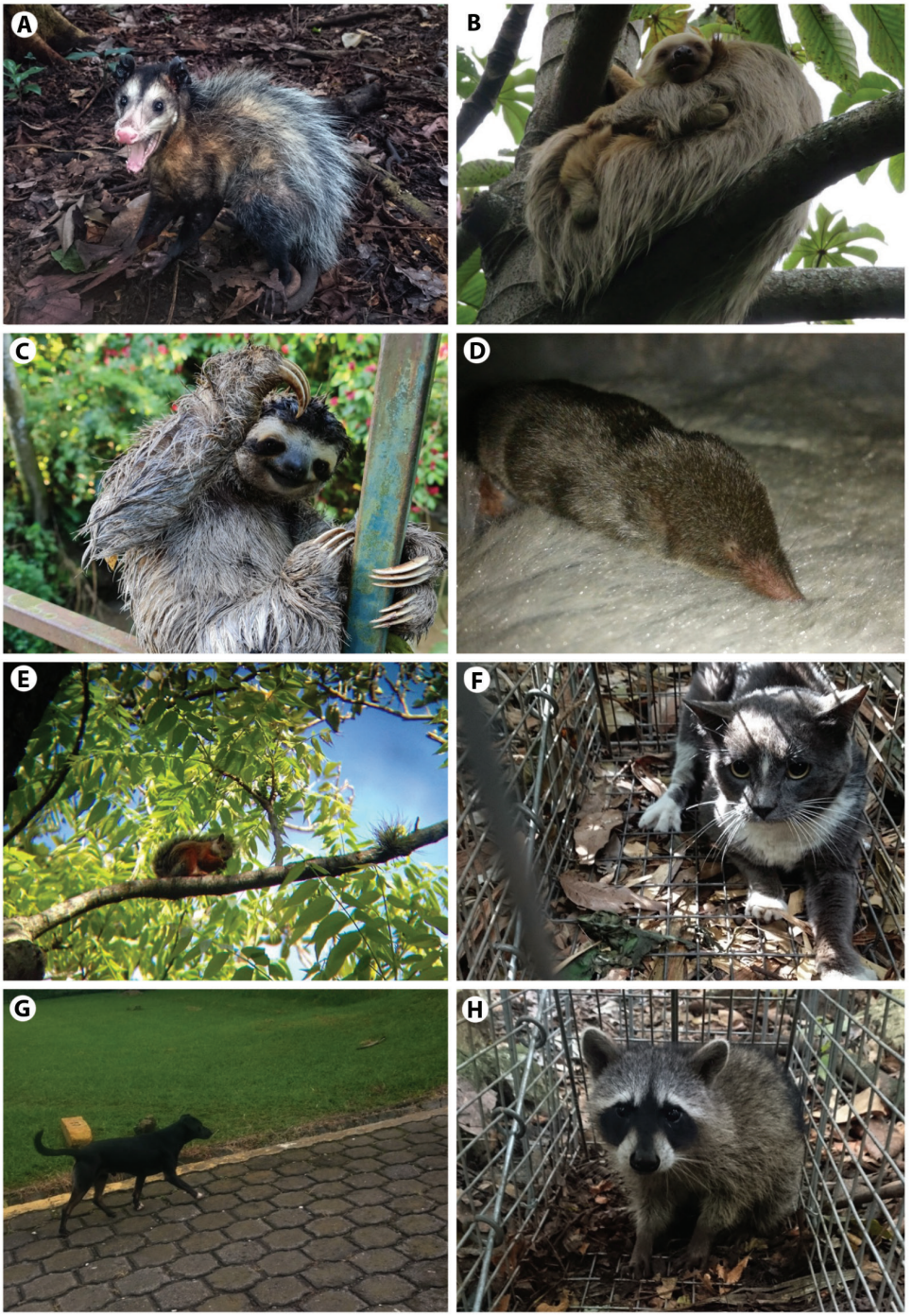

Fig. 2. Terrestrial mammals found in the campus of Universidad de Costa Rica, San José, Costa Rica, August 2014-March 2017. A) Common Opossum *Didelphis marsupialis*. B) Two-toed sloth *Choloepus hoffmanni* (Photograph by Raquel Bone Guzmán). C) Three-toed sloth *Bradypus variegatus* (Photograph by José Gabriel Barquero Jackson). D) Central American least shrew *Cryptotis orophilus*. E) Variegated squirrel *Sciurus variegatoides*. F) Domestic cat *Felis catus* G) Domestic dog *Canis familiaris*. H) Common raccoon *Procyon lotor*.

Table 2

Terrestrial mammals found in the campus of Universidad de Costa Rica, San José, Costa Rica, August 2014-March 2017. Type of record includes: night trap (NT), diurnal counts (DC), camera trap (CT) and occasional report (OR).

Taxa	Common name	Type of record	Abundance category
ORDER DIDELPHIMORPHIA Family Didelphidae *Didelphis marsupialis* Linnaeus, 1758	Common Opossum	NT, CT	Uncommon
ORDER PILOSA Family Megalonychidae *Choloepus hoffmanni* Peters, 1858	Two-toed sloth	DC	Rare
Family Bradypodidae *Bradypus variegatus* Schinz, 1825	Three-toed sloth	DC	Uncommon
ORDER EULIPOTYPHLA Family Soricidae *Cryptotis orophilus* Allen, 1895	Central American least shrew	OR	Rare
ORDER RODENTIA Family Sciuridae *Sciurus variegatoides* Ogilby, 1839	Variegated squirrel	DC, CT	Common
Family Muridae *Rattus norvegicus* Berkenhout, 1769	Norway rat	CT	Rare
ORDER CARNIVORA Family Felidae *Felis catus* Schreber, 1775	Domestic cat	NT, DC, CT, OR	Uncommon
Family Canidae *Canis familiaris* Linnaeus 1758	Domestic dog	DC, CT, OR	Rare
Family Procyonidae *Procyon lotor* Linnaeus, 1758	Common raccoon	NT, DC, CT, OR	Common

Table 3

Terrestrial mammal captures (mean ± SD per capture night) during night trap sessions in the Reserva Ecológica Leonelo Oviedo (RELO), Jardín Botánico Orozco (JBO), and the Riparian vegetation (RP) on the campus of Universidad de Costa Rica.

	RELO	JBO	RV	Total
Traps nights	281	165	78	524
Nights of capture	15	8	4	27
Didelphis marsupialis	29 (1.9 ± 1.4)	0	11 (2.5 ± 1.3)	40 (1.4 ± 1.5)
Procyon lotor	54 (3.6 ± 2.8)	28 (3.5 ± 2.8)	2 (0.5 ± 0.6)	84 (3.1 ± 2.7)
Felis catus	3 (0.2 ± 0.4)	10 (1.3 ± 1.2)	4 (1 ± 0.8)	17 (0.6 ± 0.9)

sloth (*Bradypus variegatus*) and two-toed sloth (*Choloepus hoffmanni*) only in Central Campus. The maximum number of sloths observed during a diurnal count suggests a minimum of seven individuals of three-toed sloth and three individuals of two-toed sloth on Central Campus during the study period. Feral cats were observed in all three sectors studied. The northern raccoons and feral dogs (*Canis familiaris*) were observed only in Central Campus (Table 4). The two transects in Instalaciones Deportivas showed 100% similarity in species richness and abundance (Fig. 3). Transects in Intalaciones Deportivas were 99% similar to Ciudad de la Investigación (Fig. 3). Central Campus had a 93 % of similarity with transects of the other sites (Fig. 3). The non-flying mammals' community composition varied between transects (PERMANOVA: $F = 7.29$, $P < 0.001$, Fig. 4). Central Campus differed from the

Table 4

Terrestrial mammals observed per diurnal counts (mean ± SD) in four transects (CC: Central Campus, CI: Ciudad de la Investigación, ID1 and ID2: Instalaciones Deportivas 1 and 2 respectively) in the campus of Universidad de Costa Rica, San José, Costa Rica.

Specie	CC	CI	ID1	ID2	Total
Sciurus variegatoides	6.83 ± 3.07	6.46 ± 3.15	8.46 ± 4.88	10.79 ± 5.69	8.14 ± 4.61
Bradypus variegatus	1.79 ± 1.28	0	0	0	0.45 ± 1.00
Choloepus hoffmanni	0.79 ± 0.72	0	0	0	0.20 ± 0.49
Felis catus	0.54 ± 0.59	0.21 ± 0.51	0.08 ± 0.28	0	0.21 ± 0.46
Procyon lotor	0.08 ± 0.41	0	0	0	0.02 ± 0.20
Canis familiaris	0	0.33 ± 1.13	0	0	0.08 ± 0.57

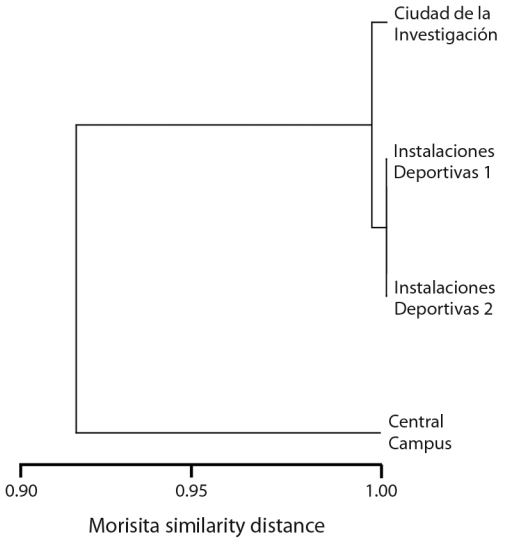

Fig. 3. Similarity of species richness and abundance average between the four studied transects based on the Morisita similarity index and single linkage in the cluster building.

Table 5

Numbers of terrestrial mammals recorded using camera traps in two forest fragments Reserva Ecológica Leonelo Oviedo (RELO) and Jardín Botánico Orozco (JBO) on the campus of Universidad de Costa Rica.

	RELO	JBO	Total
Camera days	350	230	580
Active days	35	23	58
Mammals	391	262	653
Didelphis marsupialis	122	0	122
Procyon lotor	182	252	434
Felis catus	77	9	86
Rattus norvegicus	8	0	8
Sciurus variegatoides	1	1	2
Canis familiaris	1	0	1

other three sites (pairwise comparisons, $P < 0.001$). However, the two transects of instalciones deportivas where 100% similar ($P = 0.31$), forming a separate group, while the Ciudad de la Investigación was different to Instalaciones Deportivas 2 ($P = 0.003$), but similar to Instalaciones Deportivas 1 ($P = 0.14$).

We obtained a total of 653 videos of mammals in 580 camera days and identified a total of six species. The most commonly recorded species was the common raccoon, followed by the common opossum (recorded only in the RELO) and feral cats. Norway rats (*Rattus norvegicus*) variegated squirrels, and dogs were rarely recorded using this method (Table 5).

We identified 24 free-ranging domestic cats on night baiting traps, diurnal counts in transects, camera trap videos and occasional observations. We reported one Central American least shrew *Cryptotis orophilus* captured on April 7, 2016, by a domestic cat near the Los Negritos stream. We deposited the specimen in the Museum of Zoology at the University of Costa Rica (Voucher UCR4694).

DISCUSSION

Wild mammal populations are subject to extreme pressures from habitat reduction and rapid urban expansion (He et al., 2014). The accelerated expansion of the urbanscape in

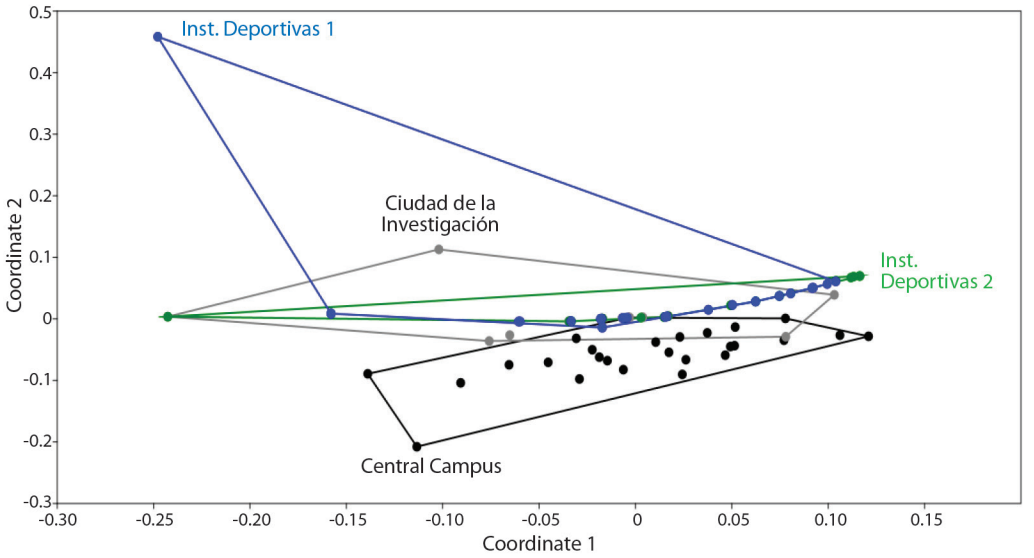

Fig. 4. Non-metric multidimensional scaling comparing the community composition of the four studied transect sampled during diurnal counts using Bray-Curtis distance.

Costa Rica has led to the loss of a significant portion of natural and semi-natural habitats (e.g., coffee plantations and second-growth areas), increasing the isolation of native vegetation. The rapid loss of natural habitats due to urban expansion severely impacts native biodiversity (Grimm et al., 2008; He et al., 2014; McDonald et al., 2013; Sushinsky et al., 2013). A significant percentage of the vegetation in the study area is protected in small, isolated forest fragments. However, over 50% of the area has been occupied by buildings, pavement, and other urban structures. Increasing urbanization negatively impacts animal diversity, as the richness and abundance of most species correlate positively with vegetative complexity and plant species richness (Aronson et al., 2017; McKinney, 2002; Savard et al., 2000). In Costa Rica's Central Valley, urbanization increased by 72% from 1973 to 2006 (Biamonte et al., 2011). Specifically, at the Universidad de Costa Rica, the accelerated construction of multiple buildings and the little interest in preserving the natural and seminatural areas have further threatened urban biodiversity.

The loss of natural habitat is one of the main causes of biodiversity decline (Aronson et al., 2017; Brooks et al., 2002; Fahrig, 2003; He et al., 2014; Pimm & Raven, 2000; Seto et al. 2012). For mammals, species richness decreases significantly in areas with extreme urbanization such as central urban cores (McKinney, 2006). Wilson (1983) reported over 25 species of medium-sized terrestrial mammals in the urban areas of the Central Valley in the 1980s. We registered fewer than ten species. Various medium-sized mammals, such as monkeys, anteaters, rabbits, porcupines, agoutis, weasels, and skunks, reported years ago, were not found in this study. Thus, the isolated and deteriorated fragments sampled in this study support only a small fraction of the original fauna (Aronson et al., 2014; Biamonte et al., 2011).

Variegated squirrels were very common in the three sectors of the study site. Species in the genus *Sciurus* are well-known for their ability to adapt to urban habitats worldwide (Bonnington et al., 2014; Jokimäki et al., 2017; La Morgia et al., 2017; McCleery et al., 2008; McCleery, 2009; Parker et al., 2014; Rézouki et al., 2014).

The squirrels use native and introduced trees for roosting and feeding, and exploit human-provided resources such as food, buildings, poles, and electrical wiring, allowing them to adapt well to urban areas. The high abundance of variegated squirrels may be attributed to the diverse native and nonnative plants in the study site (Di Stefano et al., 1996), and squirrels' capacity to exploit the resources these plants provide. The species was observed feeding on seeds, flowers, fruits, leaves, and branches of native and non-native trees and vines.

Urbanization alters ecosystem processes through human activities, which can degrade habitats but also increase the availability of other resources, such as garbage containers and urban structures used as food sources and den sites (Prange & Gerht, 2004). Species that can efficiently exploit these new resources may occur at higher densities in cities compared to rural or natural areas (Fedriani et al., 2001; McKinney, 2002; Prange et al., 2003; Prange & Gerht, 2004). This can lead to the dominance of a few or even a single species in urbanized areas (Prange & Gerht, 2004). Generalist species, with broad dietary and habitat requirements, often respond positively to anthropogenic resources (McKinney, 2002). This included common raccoons, common opossums, and even squirrels, which in the study site used similar habitats, foods, and roosting sites (Ladine, 1997; Kissell & Kennedy, 1992; Prange & Gerht, 2004; Shirer & Fitch, 1970). These species are also tolerant of fragmentation and human presence, which facilitates their survival in urban habitats (Prange & Gerht, 2004).

Similar to other studies, raccoons at the study site appear highly efficient at exploiting anthropogenic resources, leading to their high abundance (Prange et al., 2003; Prange & Gehrt, 2004). The common opossum is widespread in the Neotropics and adapts well to different conditions (Prange & Gehrt, 2004). It thrives in forests and urban environments, with a generalist diet that includes fruits, small animals, and human food residuals (Barros & de Aguiar Azevedo, 2014). However, compared to opossums, raccoons' larger body size and greater dexterity may allow better access to trash cans and dumpsters (Prange & Gehrt, 2004). Common opossums were rarely observed utilizing these resources in the study site. Additionally, differential human responses to specific mammal species (i.e., charismatic species vs repulsive ones) can affect mammal community structure.

Three of the nine species found at the study site were introduced mammals, consistent with patterns observed in other taxonomic groups such as reptiles, amphibians, invertebrates and plants (Duguay et al., 2007; Gibbon et al., 2000; McKinney, 2008; Tait et al., 2005), where the proportion of nonnative species increases toward the urban core. Nonnative species may have detrimental impacts on the native biota through competition, predation, herbivory, habitat alteration, and disease spread (Dowding & Murphy 2001; Manchester & Bullock, 2000; McKinney, 2008). Rats and free-ranging or feral cats are particularly harmful (Longcore et al., 2009; van Heezik et al., 2010). For example, free-ranging and feral cats are major predators of birds, small mammals, reptiles, amphibians, and fish in cities (Jessup, 2004; Loss et al., 2013). Cat abundance is negatively correlated with the densities of some small mammals (Baker et al., 2003; McCleery, 2010). In one study, 69% of the prey items brought home by domestic cats were mammals (Woods et al., 2003). Additionally, rats and feral cats spread diseases to other species and pose published health concerns (Costa et al., 2015; Easterbrook et al., 2007; Robertson, 2008).

Differences in non-flying terrestrial mammal community composition among sectors on the university campus may be a result of the natural habitat patch size and vegetation composition (Markovchick-Nicholls et al., 2008). Contrary to expectations that small and distant patches support fewer species due to limited species movement and fewer resources (Brooks et al., 2002; Faeth et al., 2011; Marzluff, 2005; Watling & Donnelly, 2006), we recorded the highest mammal richness on the Central Campus site. The site has smaller vegetation patches and is more isolated by urbanization.

However, we observed the occurrence of two sloth species, raccoons, and opossum. The lack of connectivity between natural fragments and the presence of large roads and buildings act as physical barriers, isolating sloth populations on the Central Campus and preventing them from reaching other sites. Meanwhile, opossums and raccoons benefit from older buildings, which provide roosting sites such as ceilings and holes. In contrast, the other two study sites (Ciudad de la Investigación and Instalaciones Deportivas) have newer buildings that do not offer such roosting spaces.

Preserving patches of natural habitat within urbanized landscapes is often advocated as a method of conserving natural communities (Aronson et al. 2017; Marzluff & Ewing, 2001; Rivkin et al., 2019; Rudd et al., 2002; Watling & Donnelly, 2006). Better integration of nature in urban environments not only preserves biodiversity but also benefits human well-being. Maintaining high local diversity in urban environments increases contact with elements of the natural world, contributing to the well-being and quality of life because accelerates recovery from stress, enhancing observational skills, and reasoning abilities (Alvey, 2006; Brown & Grant, 2005; Dearborn & Kark, 2010; Horwitz et al., 2001; McPhearson et al., 2016; Tzoulas et al., 2007). This study represents the first description of medium-sized mammals in the metropolitan area of Costa Rica. The findings of this study emphasize the significance of protecting and promoting the establishment of biological corridors and forest patches in urban areas for the conservation of native mammals.

Ethical statement: the authors declare that they all agree with this publication and made significant contributions; that there is no conflict of interest of any kind; and that we followed all pertinent ethical and legal procedures and requirements. All financial sources are fully and clearly stated in the acknowledgments section. A signed document has been filed in the journal archives.

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