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Prey ecology of the burrowing owl *Athene cunicularia cunicularia* (Molina, 1782) on the northern coast of Santa Catarina, Brazil

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ABSTRACT
We analyzed the diet of *Athene cunicularia cunicularia* in order to identify and compare prey items in dune populations in Santa Catarina, Brazil: Interpraias (INT), Praia Brava (BRA), Praia Central (NAV) and Peninsula (BVE). Due to the characteristics of urbanization in these regions, we hypothesized that there would be greater abundance and consumption of urban insect pests in the areas of BRA, NAV, and INT than in BVE. We collect owl pellets monthly in 2017. The non-parametric analysis ANOVA was applied to identify differences in pellet weights and niche amplitude between populations and seasons and PERMANOVA was applied to identify differences between prey items. Were collected 1064 pellets containing 20 prey items, including: invertebrates (Arachnida, Insecta and Crustacea Malacostraca – 83%), vertebrates (Osteichthyes, amphibians, Reptilia, birds and Mammalia – 8.6%), seeds (6.38%) and miscellaneous materials of anthropic origin (0.19%). There was no difference in the pellet weights, but the diets observed in INT and BRA were significantly different, a result that may be a reflection of the microenvironments in which the burrowing owl lives. This shows that, in addition to a generalist diet, this species has the capacity to adapt to urban changes.

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Burrowing owl; dunes; diet; pellets; prey

Introduction

The northern coast of Santa Catarina, a state in southern Brazil, is experiencing increasing urban occupation, induced by tourism in coastal areas (Santos Júnior & Pereira 2011) and port expansion in the port of Itajaí (Mallas 2009), which impact beach and dune ecosystems (Mendes 2008). These environments harbor high diversity of invertebrate animals (Branco et al. 2010; Heusi-Silveira et al. 2012) and small vertebrates (Rocha & Van Sluys 2007; Kunz et al. 2011; Grose & Cremer 2015).

Among the animals that inhabit these ecosystems is the burrowing owl. *Athene cunicularia* (Molina 1782) is an important top predator. It reaches about 25 cm in length (Bonney 2007) and has a body mass between 144 and 205 g (Sick 1997; Baladrón et al. 2015). It has a wide geographical distribution, occurring from Canada to Argentina, and in most of Brazil, except in the northwestern portion of the country (Avibase 2019). *Athene cunicularia* builds its burrows in open environments with natural or modified ground vegetation, such as cerrado (Brazilian tropical savanna eco-region), pastures, wastelands and coastal sand dunes (Sick 1997). Such preference for open environments may favor hunting and protection of the lair (Rebolo-Ifrán et al. 2017), as well as allowing adaptation to niche available among predators (Sick 1997; Odum & Barrett 2007). It is a generalist and opportunistic species with a broad trophic spectrum (Motta-Junior et al. 2004; Santos et al. 2017; Roque-Vásquez et al. 2018). It expels undigested remains of prey, known as pellets, in the perch and areas near the burrows, and these are important in the identification of their diet (Sick 1997), and an important feature for noninvasive studies of their diet.

Studies of trophic ecology, such as of top predators, provide relevant information for the analysis of niche amplitude, foraging behavior, seasonal prey fluctuations and energy demand (Emlen 1966; Krebs 1989; Develey & Peres 2000), as well as changes in the local community, which can help in developing strategies for the management and conservation of degraded areas (Primack & Rodrigues 2001). As predators, owls are essential in the trophic relationships of the environments in which they live (Funess & Greenwood 1983; Ricklefs 2003), showing, when present, variations in the local community and ecological relationships, acting in controlling small rodents and invertebrates as insects (Motta-Junior & Alho 2000).

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Although burrowing owl is commonly found in the dunes of southeastern Brazil, its diet is little known, although some studies were carried out in southeast Brazil by Vieira and Teixeira (2008) and in the south by Soares et al. (1992), Zilio (2006) and Branco et al. (2010). Thus, the present study aims at an inventory and comparison of the diet of *A. cunicularia cunicularia* in four dune regions of the central north coast of Santa Catarina. The chosen areas undergo increasing urban occupation, at different levels, with housing construction increasingly closer to the dune regions, leveraged by the port activity and tourism of the region in high season (Santos Júnior & Pereira 2011).

Due to the different levels of human occupation in the study areas, with NAV, BRA, and INT more similar to each other in terms of urbanization than BVE, we investigated whether these differences can influence the diet of the burrowing owls present on the coast. First, the content of the pellet was analyzed to determine if the degree of urbanization had an effect on the meristics of the pellets. We hypothesized that weight would be related to the abundance of prey items provided by the environment. Next, analysis of the niche amplitude, i.e. amplitude in the distribution of the species along the sampled environmental gradients, was performed according to location to find out whether or not the owl shows any feeding preference according to changing resource availability throughout the year. We hypothesized that the use of resource may have a cyclical characteristic, with less variety in the winter months. Finally, prey items were categorized by location and season to find out if there were any preferred items. We hypothesize that features may vary, but there would be preferences depending on local availability. We assume that different levels of urbanization influence these resources, e.g. due to the presence of urban pests.

Material and methods

Areas of study

A total of four dune regions located in the central-north coast of Santa Catarina, southern Brazil (Figure 1) were sampled. The climate of the regions is Cfa type according to the Köppen climate classification, i.e. temperate hot and humid, rainfall throughout the year and average temperatures ranging from 20 to 22°C (Alvares et al. 2013). Coastal vegetation in the study areas is composed of remnants of the Atlantic Forest, grass, and typical restinga plants (Klein & Rodriguez 1978; Marenzi 2006).

The Interpraias (INT) region (Balneario Camboriu, 27°1′18.75″S, 48°34′35.10″W) has approximately 19.3 ha, with shrubbery almost all along, with habitations and commercial businesses nearby and artificial night lighting in some places. Brava Beach (BRA) has approximately 9.1 ha (Itajaí, 26°56′49.72″S, 48°37′44.25″W) and has ground vegetation in the dune strip, with habitations and hotels very close to the dune strip, having artificial lighting along almost all its extent. Navegantes Central Beach (NAV) has approximately 28 ha (Navegantes, 26°53′22.33″S, 48°38′31.47″W) and is the longest beach in the current study, with habitations, commercial businesses and artificial night lighting very close to dunes, and it has some areas with shrub and others with undergrowth. Barra Velha Peninsula Beach (BVE) (Barra Velha, 26°35′14.00″S, 48°40′5.64″W) has approximately 17.4 ha, with the presence of shrub and undergrowth, a greater distance among inhabited regions, and some parts without artificial lighting near the dunes. The BRA, NAV and INT areas are more similar to each other in terms of urbanization than BVE, with the former having larger populations, development indexes and tourism (SEBRAE 2013).

Pellet analysis

For material collections, the SISBIO (Authorization and Information System on Biodiversity) authorization number 56557–4 was issued. The pellets were collected at the same time of the month on all beaches from January to December 2017. Twenty sites with active burrows were found throughout the study, which were inspected for pellet collected during the day. Entire pellets were selected and stored in plastic bags labeled with location and collection date, with a minimum of 10 pellets per site.

In the laboratory the pellets were dehumidified in an oven at 50°C for 48 hours, then weighed on a weighing scale (precision 0.01 g). They were then immersed in NaOH (10%) solution for six hours, sieved, rinsed in running water, left in 10% volume hydrogen peroxide solution, rinsed again and placed in the oven for drying at 50°C for four hours (Granzinolli & Motta-Junior 2008) for further screening.

Prey items were separated under a stereoscopic microscope (Stemi DV4 Stereo Microscope, Carl Zeiss, Germany 32×) into morphospecies categories and identified to the lowest possible taxonomic level, with the help of specialized bibliographies, reference collections and expert consultation (Laboratory of Environmental Sciences, Professor of Invertebrates – University Valley of Itajaí). In order not to overestimate the samples, only identifiable parts or pairs in each item found. Materials such as Styrofoam, plastic,

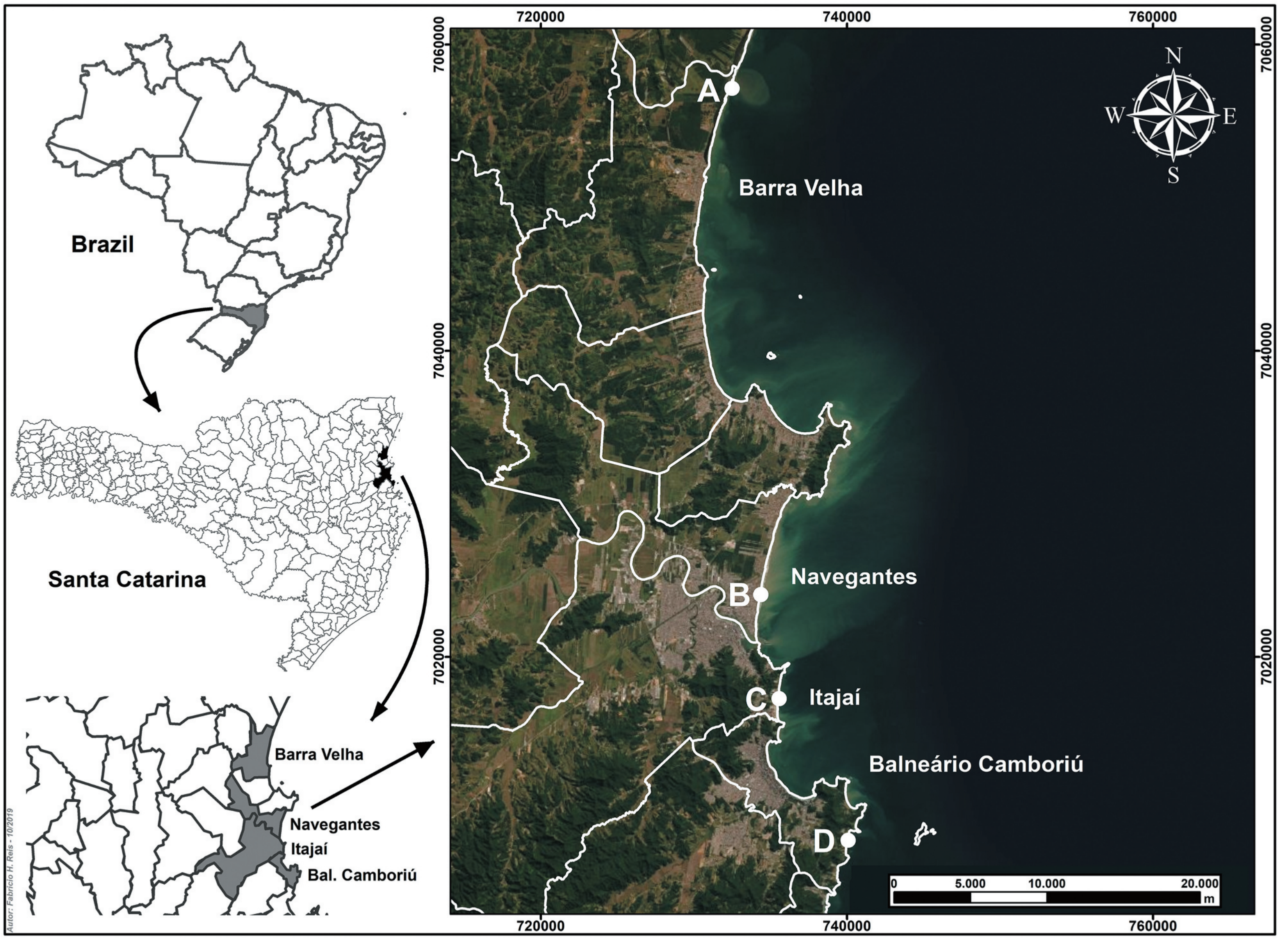

Figure 1. Location of the four regions studied: Interpraias (INT), Navegantes (NAV), Praia Brava (BRA) and Barra Velha (BVE), northern coast of Santa Catarina, Brazil.

nylon, paper and foam were considered material of anthropic origin (M.A).

Data analysis

Firstly, the weight data were grouped by location and separated into seasons: spring (October–December), summer (January–March), autumn (April–June) and winter (July–September) and submitted to PERMANOVA analysis (Anderson 2001) to test for differences between seasons and between locations.

Subsequently, the niche amplitude of each location and between seasons was calculated using the Levins index (Krebs 1989) $B = 1/\Sigma pi2$, where B = niche amplitude, and pi = proportion of each prey item consumed. To standardize the measurements, the Hurlbert (1978) formula was applied: $B_{st} = (B - a_{min})/(n - a_{min})$, where B_{st} = Levins index value; B = niche amplitude; n = total number of items consumed and a_{min} = the lowest proportion observed among items consumed. The amplitude was expressed on a scale from 0 to 1; values close to zero indicate smaller amplitude with predominance of consumption of few groups, while those of 1 a large niche amplitude, with a great variety of prey (Krebs 1989). To test the normality of the niche amplitude data, the Shapiro–Wilk test was applied and the seasonal differences between the niche amplitudes were established using the Tukey test (Zar 2010). To calculate the difference between the seasons, the data for all locations were unified.

Finally, to test the significance of differences in prey item composition between seasons and areas, numerical data were transformed into relative abundance and analyzed with multivariate permutational variance analysis (PERMANOVA) with 9999 permutations and significance ≤ 0.05. When significant differences were observed, the data were subjected to similarity percentage analysis (SIMPER; Clarke 1993) to detect which prey items contributed most to the differences between the sampled areas. All tests were performed by the PAST version 3.24 program (Hammer et al. 2001).

Results

A total of 1064 owl pellets were collected from January to December 2017 in the four regions studied. In INT, BRA, NAV, and BVE, 210, 221, 516, and 117 pellets were obtained respectively. The pellets' average weight and standard deviations ranged from 1.39 ± 0.46 to 2.1 ± 0.48 g. PERMANOVA analysis indicated that there were no differences in average weight values ($F = 1.694$, $p > 0.05$) between locations and seasons.

NAV beach has the largest niche amplitude ($B_{st} = 0.343$), followed by BVE ($B_{st} = 0.2649$), BRA ($B_{st} = 0.2615$), and INT ($B_{st} = 0.202$). There were no differences in niche amplitude between regions ($F = 0.515$, $p = 0.678$); however, there were significant differences between the averages of the seasons, with winter differing values from those of autumn ($p = 0.028$) and summer ($p = 0.001$). Summer and autumn had higher niche amplitudes in all locations, dropping by up to approximately 50% in winter (Figure 2, Table 1).

The burrowing owl's diet consisted of 20 prey items, three of which were invertebrates (Arachnida, Insecta and Malacostraca), considered the most abundant and representing 84.8% of the diet. The remaining items were composed by five vertebrates (Osteichthyes, Amphibia, Reptilia, birds, and Mammalia) with 8.6%, in addition to seeds (6.4%) and anthropic materials (0.2%) according to Table 2.

Invertebrates were distributed across 11 orders, with variations of the most abundant groups according to region (Table 1). Orthoptera was the most dominant order in the burrowing owl diet, with frequency higher than 30% on all beaches. Coleoptera was one of the most abundant, ranked second on BRA (15.71%), NAV (16.74%), and BVE (29.16%) beaches and ranked third on INT (9.27%) beach. Araneae was over 5% on BRA, NAV, and BVE beaches. Hymenoptera presented a frequency of more than 5% on INT and NAV; Blattaria on INT and NAV and Dermaptera on BRA were also above 5%. Among the vertebrates, the order Rodentia showed the highest abundance, from 4 to 5% in all beaches, being over 5% on INT. A group that lives in dune environments and that was present in the owl's diet, totaling 4% on BVE, was the Decapoda, with the main representative being the *Ocypode quadrata* crab.

Prey items did not vary significantly between seasons, but significant differences in the composition of the diet between INT and BVE beaches were observed ($F = 2.693$, $p = 0.028$). The difference in composition was due to the taxa Blattaria and Hymenoptera being the most abundant items in INT and Coleoptera and Decapoda in BVE (Table 3).

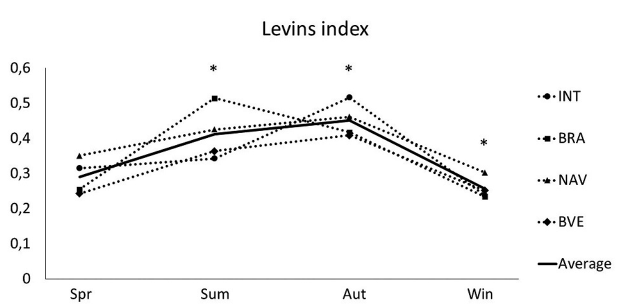

Figure 2. Niche breadth in Interpraias (INT), Brava (BRA), Navegantes (NAV) and Barra Velha (BVE) by seasons: spring (Spr), summer (Sum), autumn (Aut) and winter (Win) and an average of the locations together per season. * Seasons that showed significant differences.

Table 1. ANOVA results showing the different niche amplitudes of the burrowing owl between the seasons.

	Sum of sqrs	df	Mean square	F	p (same)
Between groups:	0.245	3	0.082	6,985	0.001
Within groups:	0.444	38	0.012		
Total:	0.689	41	0.001		
	Tukey's pairwise				
	F	p			
Spring vs. Summer	3.780	0.052			
Spring vs. Autumn	1.726	0.618			
Spring vs. Winter	2.613	0.268			
Summer vs. Autumn	1.921	0.533			
Summer vs. Winter	6.198	0.000			
Autumn vs. Winter	4.145	0.028			

Discussion

The variations observed in the average weight of burrowing owl pellets were probably related to the type of prey consumed, refuting our first differentiation hypothesis, perhaps due to the few differences between the available items in the four regions studied. The weight of pellets recorded on the Santa Catarina (1.39 ± 0.46 to 2.1 ± 0.48) coast were higher than in the coastal region of Venezuela (0.86 ± 0.50) (Roque-Vásquez et al. 2018). They were, however, more similar to those obtained for this species in other South American environments: 1.9 ± 0.82 (Medina et al. 2013) and 1.5 ± 0.82 (Cadena-Ortíz et al. 2016). The observed differences are possibly associated with the variety of prey available at the sampling sites, size of owls, or perhaps the eating habits of burrowing owl subspecies throughout their wide range (Baladrón et al. 2015; Menq 2018).

Analysis of the diet of *A. cunicularia cunicularia* indicated that the species acts as a generalist and opportunistic predator, foraging on a wide range of prey such as insects, arachnids, crustaceans, fish, amphibians, reptiles, birds, and mammals. A general

Table 2. Total number (N) and relative frequency (FR) of all prey items present in pellets, by study area: Interpraias (INT), Brava (BRA), Navegantes (NAV), Barra Velha (BVE). M.A = anthropic material.

	INT		BRA		NAV		BVE		TOTAL	
PREY ITEM	N	FR	N	FR	N	FR	N	FR	N	FR
Arthropoda										
Arachnida										
Araneae	166	0.045	79	0.054	350	0.104	137	0.075	732	0.070
Opiliones	3	0.001	0	0	3	0.001	0	0	6	0.001
Ixodida	3	0.001	0	0	0	0	0	0	3	0
Malacostraca										
Decapoda	24	0.006	50	0.034	54	0.016	75	0.041	203	0.020
Insecta										
Orthoptera	1253	0.337	662	0.451	1044	0.309	711	0.388	3670	0.353
Dermaptera	118	0.032	79	0.054	14	0.004	4	0.002	215	0.021
Blattaria	268	0.072	104	0.071	336	0.099	16	0.009	724	0.070
Hemiptera	110	0.03	6	0.004	151	0.045	25	0.014	292	0.028
Coleoptera	346	0.093	267	0.182	560	0.166	534	0.292	1707	0.164
Hymenoptera	828	0.223	88	0.06	294	0.087	58	0.032	1268	0.122
Lepidoptera	0	0	0	0	1	0.001	1	0.001	2	0
Total invertebrates	**3119**	**0.838**	**1335**	**0.909**	**2807**	**0.831**	**1561**	**0.853**	**8822**	**0.848**
Chordata										
Osteichthyes	0	0	0	0	16	0.005	0	0	16	0.002
Amphibia										
Anura	87	0.023	55	0.037	111	0.033	37	0.02	290	0.028
Reptilia	0	0	12	0.008	12	0.004	2	0.001	26	0.003
Birds	19	0.005	2	0.001	13	0.004	12	0.007	46	0.004
Mammalia										
Chiroptera	2	0.001	1	0.001	0	0	0	0	3	0
Marsupialia	0	0	1	0.001	8	0.002	0	0	9	0.001
Rodentia	195	0.052	62	0.042	160	0.047	88	0.048	505	0.049
Total vertebrates	**303**	**0.081**	**133**	**0.091**	**320**	**0.095**	**139**	**0.076**	**895**	**0.086**
Seeds	292	0.078	1	0.001	248	0.073	122	0.067	663	0.064
M.A.	7	0.002	0	0	4	0.001	9	0.005	20	0.002
Total	**3721**		**1469**		**3379**		**1831**		**10400**	

Table 3. SIMPER results listing the Prey items that contributed to dissimilarity between the regions of Interpraias (INT) and Barra Velha (BVE), which obtained significant differences in PERMANOVA.

Taxon	Dissim. mean	Contrib. %	Cumulative %	Mean INT	Mean BVE
Coleoptera	10.250	24.820	24.820	0.090	0.295
Hymenoptera	8.771	21.230	46.050	0.209	0.034
Orthoptera	8.402	20.340	66.380	0.356	0.379
Blattaria	2.934	7.102	73.490	0.065	0.008
Seed	2.399	5.806	79.290	0.079	0.069
Decapoda	1.827	4.423	83.720	0.005	0.042
Dermaptera	1.487	3.599	87.320	0.031	0.002
Araneae	1.452	3.516	90.830	0.045	0.075
Rodentia	1.178	2.850	93.680	0.056	0.051
Amphibian	1.081	2.617	96.300	0.027	0.021
Hemiptera	0.851	2.060	98.360	0.027	0.013
M.A	0.284	0.688	99.050	0.001	0.005
Birds	0.223	0.539	99.590	0.006	0.007
Reptilia	0.058	0.139	99.720	0	0.002
Opiliones	0.044	0.106	99.830	0.001	0
Ixodida	0.030	0.073	99.900	0.001	0
Lepidoptera	0.020	0.048	99.950	0	0.001
Chiroptera	0.020	0.048	100	0.001	0
Fish	0	0	100	0	0
Marsupial	0	0	100	0	0

diet was also recorded for this species in North America by Hall et al. (2009), Trulio and Higgins (2012), Browning (2016), and Mills (2016), in Central America by Ayma et al. (2019), in Brazil by Motta-Junior and Alho (2000), Zilio (2006), Vieira and Teixeira (2008), and Santos et al. (2017), and in other South American countries (Nabte et al. 2008; Andrade et al. 2010; Carevic et al. 2013). This broad trophic spectrum therefore seems to be typical of this species regardless of habitat type or region, and may reflect its foraging habits that include daytime, twilight, and nighttime, thus allowing access to a wide range of prey (Vieira & Teixeira 2008; Santos et al. 2017). The variations presented in the niche amplitude of the burrowing owl between the seasons showed that the niches expanded in summer and autumn due to more significant variability of accessed items, significantly reducing in winter. These could be a consequence of the availability of prey caused by the drop in temperature and rainfall, as reported by other authors (Rodrigues 2004; Siervi 2015), confirming our second hypothesis of the alternation of prey items according to the item's availability in the environment.

Despite the wide trophic spectrum, *A. cunicularia cunicularia* presented a diet composed mainly of insects, corresponding to 80% of the consumed items. Similar proportions were reported in other regions of the country (Motta-Junior & Alho 2000; Vieira &

Teixeira 2008; Santos et al. 2017). Orthoptera contributed with values higher than 30% of the sampled items, similar to that recorded in the dunes areas of Rio Grande do Sul (Zilio 2006), cerrado in São Paulo countryside (Motta-Junior & Alho 2000) and prairie regions in the Texas, USA (Browning 2016). This group, besides being abundant, was present in all seasons of the year, being characterized as an important item in the diet of the burrowing owl (Silvas 2006). In the case of beaches, the fact that the nearest vegetation is predominantly small sandbanks, this should favor the occurrence of insects over birds and mammals.

Coleoptera were among the three main items used by *A. cunicularia cunicularia*, as this has been a basic prey of the species in Brazilian regions (Motta-Junior et al. 2004; Bastian et al. 2008; Vieira & Teixeira 2008; Santos et al. 2017) and other countries of the Americas (York et al. 2002; Tommaso et al. 2009; Hall et al. 2009; Trulio & Higgins 2012; Chandler 2015; Mills 2016). Another important group in the diet of owls on beaches was crabs (*Ocypode quadrata*), found in dune environments, especially during the spring and summer seasons (Blankensteyn 2006; Zílio 2006; Branco et al. 2010). It is important to notice that their proportion in biomass is higher than most predated invertebrates (Bernardes et al. 2004).

The predominance of invertebrates emphasizes the ease by which these preys can be accessed by small predators such as the burrowing owl (Sick 1997; Zilio 2006), whereas vertebrates, with frequency less than 5%, become more important when computing their biomass. This is the case for rodents, an item reported as frequent in other studies of this species (Motta-Junior & Alho 2000; York et al. 2002; Williford et al. 2009; Carevic et al. 2013; Mills 2016). Seeds, not commonly consumed by carnivores, were present in the owls' diet in INT, NAV, and BVE, the three regions with the presence of shrubbery. In fact, Menezes and Ludwig (2013) found a range of vegetable items in the owls' diet, including seeds, and came to the conclusion that the seeds may come from the stomachs of beetles or rodents preyed on by owls, a conclusion previously proposed by Sick (1997).

The difference in dietary composition between INT and BVE probably reflects the abundance of prey in the microenvironments exploited by the burrowing owl, since on INT beach the sandbank strip is formed of interconnected building areas with public lighting, whereas on BVE beach the sandbank is far from habitations and artificial lighting. In addition, INT was the region with the lowest niche amplitude. Blattaria and Hymenoptera were frequent and abundant in the INT region, mainly those groups considered pests in urban environments (Vianna et al. 2001; Zorzenon 2002), and thus contributed with high frequency in the *A. cunicularia cunicularia* diet. Coleoptera are a group commonly found in urban environments and are attracted by artificial lighting (Castro et al. 2016); however, they were abundant in BVE, probably associated with abundant vegetation near the burrows. This difference confirms our final hypothesis, because due to human occupation, there is a greater supply of species considered urban pests that are attracted by the remains of human food; consequently, owls take advantage of this availability by feeding frequently on these items.

Adaptation to environmental changes may be a decisive factor for the survival of the species, which has been losing natural habitats in different regions of the Americas (Jones & Bock 2002; Conway et al. 2006; Chipman et al. 2008; Santos et al. 2017). This study indicated that the differences obtained in relation to the prey items consumed, find support understanding the hypothesis raised by the present study. The results we obtained about the prey items may reflect the microenvironments in which the burrowing owl lives, showing that it is a generalist and opportunist feeder, with cyclical feeding behavior and a great capacity to adapt to the urban changes that have expanded exponentially in recent decades.

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