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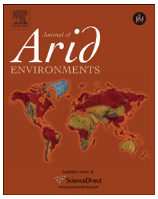

Short communication

Seasonal diet of the burrowing owl *Athene cunicularia* Molina, 1782 (Strigidae) in a hyperarid ecosystem of the Atacama desert in northern Chile

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ABSTRACT

Located in the Atacama desert of northern Chile, Pampa del Tamarugal is a hyperarid ecosystem characterized by extreme arid conditions (<0.7 mm of annual precipitation) and relatively scarce vegetation, dominated by arboreal species of *Prosopis tamarugo*. These unfavorable environmental conditions can affect the quantity and diversity of prey available for carnivores, making Pampa del Tamarugal an interesting environmental scenario for the study of the trophic ecology of raptors. Our analyses of the seasonal diet of the burrowing owl *Athene cunicularia* (Molina, 1782) indicate that insects and scorpions were the most common prey (58.3% and 27.5%, respectively). However, the rodent *Phyllotis darwini* was the most important prey in biomass (49.5%). Significant differences were observed in diverse trophic statisticians between summer and winter seasons. Unlike similar studies carried out in arid areas of South America and North America, we observe that the diet of the burrowing owl in Pampa del Tamarugal shows a higher trophic niche breadth and trophic diversity, but a lower species-prey richness.

1. Introduction

The burrowing owl *Athene cunicularia* (Molina, 1782) is a raptor that shows a wide distribution in the Americas, ranging from Canada to the southern part of Chile and Argentina (Pavez, 2004). In the Atacama desert, northern Chile, the burrowing owl is an annual and common resident (Estades, 1995; Pavez, 2004). This species inhabits mainly open areas with scarce vegetation such as grassland, desert and coastal dunes from sea level to 3000 m.a.s.l. (Martínez and González, 2005; Pavez, 2004). *A. cunicularia* is a crepuscular–nocturnal predator and it is considered a generalist species that consumes a wide range of prey, including small mammals, reptiles, amphibians, insects, and arachnids (Jaksic and Marti, 1981). Although it has been classified as an insectivorous species, different authors have proposed that it should be categorized from the trophic point of view as a carnivorous species, given the great biomass contribution from these types of prey (Andrade et al., 2010; De Tommaso et al., 2009; Silva et al., 1995). In general, the literature about the feeding ecology of *A. cunicularia* in arid ecosystems of South America is scarce. In Brazil, different aspects of the diet of *A. cunicularia* have been studied in sandy coastal environments (Vieira and Teixeira, 2008; Zilio, 2006). In Argentina, the feeding habits of *A. cunicularia* have been studied with some detail in arid-cold ecosystems of northeastern Patagonia (Desierto del Monte) (Nabte, 2004; Nabte et al., 2008) and central Patagonia (Andrade et al., 2004, 2010). In Chile, the dietary studies of *A. cunicularia* are restricted almost exclusively to semi-arid (Pefaur et al., 1977; Silva et al., 1995; Torres-Contreras et al., 1994; Zunino and Jofré, 1999), and Mediterranean areas of Central Chile (Jaksic and Marti, 1981; Schlatter et al., 1980, 1982). There is little information on its diet in arid ecosystems of northern Chile (except for Carevic, 2011).

Available information about food habits of *A. cunicularia* in arid lands of North America is also scarce and limited to only a few studies describing the regional and seasonal diet of the burrowing owl in the deserts of Sonora (California) and Mojave (Nevada) in USA (see York et al., 2002; Hall et al., 2009, respectively).

The ecosystem of Pampa del Tamarugal offers a particular ecological scenario to study the trophic ecology of *A. cunicularia*, as it is inserted in the Atacama desert, the driest and oldest in the world (Hartley et al., 2005). Climate conditions in this desert are

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extreme and vegetation cover is scarce and homogeneous, limiting the amount and variety of available prey for raptors (Carevic, 2011; Carmona and Rivadeneira, 2006).

In addition, native vegetation, especially *Prosopis* spp. forests, are in a vulnerable condition, aggravated by deforestation for coal production and the decline of groundwater for water supply of non-metallic mining in the area (Carvallo and Sudzuki, 1983; Gajardo, 1994). The aim of this study was to increase our knowledge on the seasonal diet of *A. cunicularia* and discuss its feeding ecology in the hyperarid ecosystem of Pampa del Tamarugal, located in the Atacama desert.

2. Materials and methods

2.1. Study area

The study was conducted in the National Reserve (NR) Pampa del Tamarugal (20° 28′ S, 69° 40′ W), a wildlife protection area located 70 km from the city of Iquique in northern Chile (Fig. 1). The NR Pampa del Tamarugal is included in the Atacama desert biome (Di Castri and Hajek, 1976), which is characterized by extremely arid climate conditions and low primary productivity (Marquet et al., 1998). The absolute maximum temperature can reach 35 °C during the day, and the absolute minimum −4 °C overnight (Arenas, 2008). Average annual rainfall reaches only 0.6 mm and relative humidity can fluctuate between 10 and 30% on the day and 80–100% at night (Burkart, 1976). The soils of Pampa del Tamarugal are classified as aridisols, and are deep, stratified, sandy, loamy and saline-alkaline, with very low fertility (Luzio and Vera, 1982; Luzio, 1990). They also have a high level of nitrate on the upper layer, making it relatively impermeable against water (Diaz and Wright, 1965). The vegetation in this area is scarce and limited almost exclusively to tamarugos tree species, *Prosopis tamarugo* Phil., and the introduced species *Prosopis chilensis* Mol. Stunz. Shrub and herbaceous species are very rare, with the presence of sorona *Tessaria absinthioides* Hook. et Arn., cachiyuyo *Atriplex atacamensis* Phil., grama salada *Distichlis spicata* L. (Greene), and retama *Cressa cretica* L. (Gajardo, 1994).

2.2. Methodology

The diet of *A. cunicularia* was studied by pellets analysis obtained from two nesting active sites with one couple of burrowing owls each (Pampa Junoy 20° 51′ S, 69° 47′ W, and La Tirana 20° 40′ S, 69° 58′ W). The pellets were collected at both sites during summer (between December 2004 and April 2005, $n = 86$) and austral winter (June–October 2005, $n = 90$). We assume the pellets were collected during non-breeding season, as no chicks were observed in the nesting sites during the sample collection period.

The pellets, previously humid, were disgregated and all remains were individually identified to the highest possible taxonomic level. Most vertebrates (mammals, birds, and reptiles) found in the pellets were identified based on skulls, teeth, and jaws using

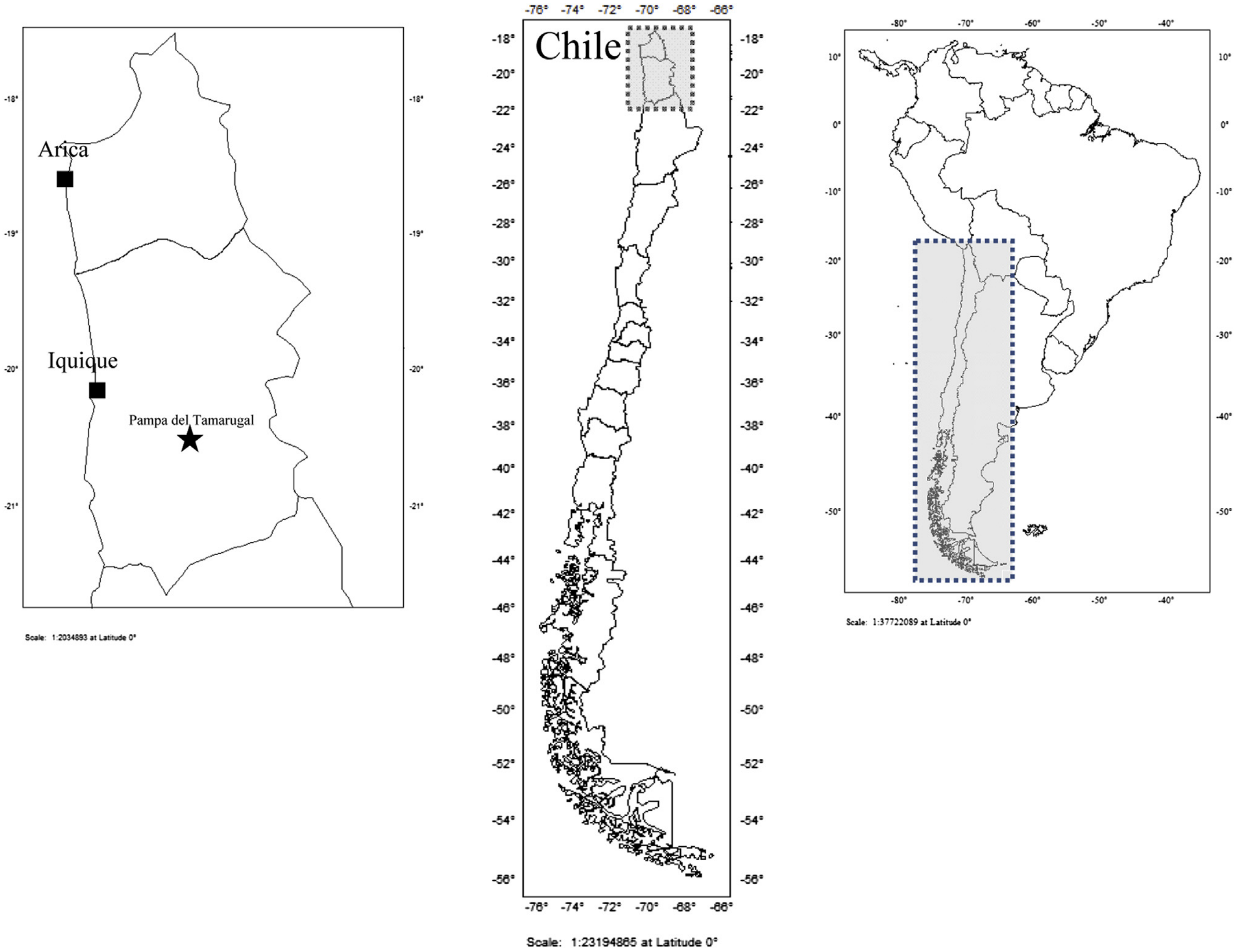

Fig. 1. Map showing South America and study area location in Pampa del Tamarugal (Atacama desert), northern Chile.

technical keys (Donoso-Barros, 1966; Reise, 1973) and the reference collection of the Zoology Laboratory in Universidad Arturo Prat (Iquique, Chile). The individual number of vertebrates in each pellet was determined using either skulls or maximum count of left and right jaws. Insect identification was according to Peña (1992). Similarly, the number of insect prey was established using heads or pairs of elytra. Scorpions were identified according to the above reference collection and numbered by the presence of pincers or stingers.

To analyze the contribution of each prey in biomass consumption we multiplied the number of individuals in each pellet by the average mass (weight in grams) of each species. This mass value was obtained from previous studies carried out by Rau et al. (1998), Cepeda-Pizarro et al. (2005), Braun et al. (2010), Ortiz et al. (2010) and Carevic (2011). To determine seasonal differences in prey consumption in the diet of *A. cunicularia* a χ^2 test was performed. For this analysis, all prey groups found in the diet were employed.

To characterize the diet the following trophic statisticians were used: (a) Geometric mean mass of prey (GMMP) consumed (sensu Marti, 1987); (b) Levins Index according to Simpson (1949). For this index, we worked with all the taxonomic categories of prey (maximum value was 8); (c) Standardized Levins index by Colwell and Futuyma (1971). This index was used to compare the trophic niche breadth in the Tamarugal during summer and winter seasons, where the supply of available prey for *A. cunicularia* can be different; (d) diversity of prey consumed through Shannon and Wiener index (Shannon, 1948), which quantifies the total diversity of a sample, being influenced by two main components: richness and equity. In order to compare Shannon indices between seasons in Pampa del Tamarugal a bootstrap approach with 1000 random samples was used according to Hammer and Harper (2005). Approximate confidence intervals for Shannon–Wiener indices were also calculated with the bootstrapping procedure (1000 random samples were produced). All statistical analyses were performed with the program PAST version 2.12 (Hammer et al., 2001).

3. Results

176 pellets were collected in NR Pampa del Tamarugal. The average size of measurable samples ($n = 111$) was 3.9 ± 1.1 mm length and 2.1 ± 0.5 mm width. 761 preys were identified with an average of items per pellet of 4.3 ± 1.4 individuals (range = 1–6). Table 1 shows the composition of the diet of *A. cunicularia* during the seasons of austral summer and winter. Invertebrates were the most common prey in the diet, among which are, in decreasing order, tenebrionidae insects, scorpion *Brachistosternus* sp., bupestridae, and anobiidae. Among vertebrates, the reptile *Phyllodactylus gerrhopygus* Wiegmann 1834 was the most frequent prey, followed by the rodent *Phyllotis darwini* Waterhouse 1837, the marsupial *Thylamys pallidior* Thomas 1902, and passerine birds. As for the seasonal diet, the summer season showed a lower consumption of insects and scorpions (52.5% and 24.9%, respectively) than the winter season (63.4% and 31%, respectively). In addition, there was a remarkable difference in the consumption of small mammals and reptiles in summer, as their frequencies were higher (13.3% and 9.1%, respectively) than in winter season (2.2% and 3.9%, respectively). The differences in prey consumption between summer and winter were significant ($\chi^2 = 54.57$, df = 7, $p = 0.0001$).

In biomass, small mammals, especially the rodent *P. darwini*, were the most important prey in the diet (>55%), followed by insects and scorpions (>38%), while birds and reptiles were scarce (<7%).

Biomass provided by insects and scorpions was lower in summer than winter, while small mammals declined significantly in winter, as opposed to summer. The reptile *P. gerrhopygus* and passerine birds showed no major differences in their contribution to biomass between seasons.

The GMMP consumed was 3.1 g, being higher in summer than winter (Table 1). Trophic niche breadth, according to Levins index, was $B = 4.50$, and according to the standardized Levins index was $B_{sta} = 0.50$. In summer, trophic niche breadth was slightly higher than winter.

The diversity of prey consumed, measured by the Shannon–Wiener index, was higher in summer than winter, with statistically significant differences (Bootstrapped Shannon–Wiener index, $p = 0.003$).

4. Discussion

This is the first study of the seasonal diet of *A. cunicularia* in an arid ecosystem of northern Chile, which in general is not well documented in arid environments of South America. In the Atacama desert this raptor shows a low diet in prey species, having a

Table 1
Description of *A. cunicularia* diet in Pampa del Tamarugal (Atacama desert) during summer and winter seasons. *F%* = percentage by frequency, *B%* = percentage by biomass, GMMP = Geometric mean mass of prey, B = Levins index, B_{sta} = standardized Levins index, H' = Shannon–Wiener Index, 95% CI = Bootstrap 95% confidence intervals.

Prey categories	Mass (g)	Summer		Winter		Total	
		F%	*B%*	*F%*	*B%*	*F%*	*B%*
Mammals		**13.3**	**71.0**	**2.2**	**25.5**	**7.4**	**55.1**
Phyllotis darwini	51.3	10.2	63.7	1.7	23.0	5.7	49.5
Thylamys pallidior	19.3	3.1	7.3	0.5	2.5	1.7	5.6
Birds		**0.3**	**1.4**	**0.7**	**7.7**	**0.5**	**3.6**
Passeriformes	40	0.3	1.4	0.7	7.7	0.5	3.6
Reptiles		**9.1**	**2.8**	**3.9**	**2.6**	**6.3**	**2.7**
Phyllodactylus gerrhopygus	2.5	9.1	2.8	3.9	2.6	6.3	2.7
Invertebrates		**77.4**	**24.8**	**93.1**	**64.2**	**85.8**	**38.6**
Buprestidae	2	17.6	4.3	23.0	12.1	20.5	7.0
Tenebrionidae	2	30.6	7.4	29.9	15.6	30.2	10.3
Anobiidae	2	4.3	1.0	10.5	5.5	7.6	2.6
Brachistosternus sp.	4	24.9	12.1	29.7	31.0	27.5	18.7
Total prey		353		408		761	
Number of pellets		86		90		176	
GMMP		3.66		2.71		3.11	
B		4.81		4.11		4.50	
B_{sta}		0.54		0.44		0.50	
Shannon H' index		1.72 (95% CI = 1.64–1.78)		1.55 (95% CI = 1.45–1.61)		1.67	

biomass contribution based mainly on small mammals, insects, and scorpions, with obvious variations between winter and summer in the consumption of vertebrates and invertebrates. The trophic niche breadth and diversity of prey consumed also show variations during the summer and winter seasons.

This study shows eight taxa in the diet of the burrowing owl in Pampa del Tamarugal, with a prey species richness lower than the documented in different arid and semi-arid environments of Chile, Brazil, and Argentina. For instance, Zunino and Jofré (1999) and Torres-Contreras et al. (1994) have reported a range from 11 to 40 taxa prey for the semi-arid area of Chile. In southern Brazil, a number ranging from 30 to 40 taxa has been reported for regions of coastal dunes (Vieira and Teixeira, 2008; Zilio, 2006). In Argentina, the number of captured taxa reach higher values than those reported in Tamarugal: almost 53 taxa prey in urban environments of Buenos Aires (Sánchez et al., 2008), and between 19 and 38 taxa in cold-arid ecosystems of the Patagonia (Andrade et al., 2010; Nabte et al., 2008).

In North America studies in arid habitats similar to the Atacama desert have documented that *A. cunicularia* may consume up to 12 taxa in the deserts of Sonora (California, USA) and Mojave (Nevada, USA) (York et al., 2002; Hall et al., 2009, respectively). This differs markedly with the results reported in the present study, showing clearly that in the Atacama desert there is a low diversity of prey available, directly reflected in the trophic spectrum of *A. cunicularia*.

Insects and scorpions were the most common prey in the diet of the burrowing owl in the Tamarugal. These results are similar to those obtained by Nabte et al. (2008) and Andrade et al. (2010) for cold-arid ecosystems of Argentine Patagonia, and York et al. (2002) and Hall et al. (2009) for the Sonora and Mojave deserts in USA, respectively, where this type of prey appears frequently in pellets of the burrowing owl.

Although arthropods are the most common prey in the diet of the burrowing owl, small mammals could be considered important prey in terms of energy, as they may contribute with a greater proportion of biomass compared to invertebrates. In our study the rodent *P. darwini* showed a greater contribution of biomass: almost 50% of the total biomass of the diet of *A. cunicularia*, compared to that given by insects (20%) and scorpions (18.7%). Thus, different authors have pointed out that the diet of the burrowing owl could be considered carnivorous, given the importance of such prey in the energy contribution for this owl species (Andrade et al., 2010; De Tommaso et al., 2009; Silva et al., 1995). However, it is important to note that arthropods may be alternative prey, as they compensate for an energy deficit during the decline in rodents in winter season (Torres-Contreras et al., 1994). Subsequently, the evidence supports the idea that *A. cunicularia* can have an opportunistic feeding strategy dependent on prey availability between stations (Silva et al., 1995; Sánchez et al., 2008; Torres-Contreras et al., 1994).

In this study, higher consumption of vertebrate prey in summer and their respective decrease during winter season could be explained by a greater abundance and activity of such prey as a result of increased food resources (e.g. seeds and fruits) during the spring and summer periods in *Prosopis* spp. forests in Pampa del Tamarugal (Habit et al., 1981). Thus, *A. cunicularia* could increase consumption of such prey by their higher availability during warmer seasons.

Prey mean consumed by *A. cunicularia* in Pampa del Tamarugal was lower than documented by different authors for sclerophyllous shrubland of central Chile (Jaksic and Marti, 1981; Schlatter et al., 1982), central-southern Argentina (De Tommaso et al., 2009), and the steppe area in Argentine Patagonia (Andrade et al., 2010). This could be explained by prey availability in Tamarugal, which was lower than in the sites described above. In addition, we observed a higher mean of prey consumed in the summer season compared to that of winter. This corresponds to a high proportion and contribution of biomass by the rodent *P. darwini* (51.3 g) in the diet of the burrowing owl in summer, whereas in winter invertebrates appear in greater proportion, but supply a much lower biomass input (only 2 g).

In general, the value of standardized niche breadth obtained in our study was high ($B_{\mathrm{est}} = 0.50$), indicating that the burrowing owl consumed almost all prey categories broadly and equitably. This differs from what is documented in studies conducted in different sites in central (Jaksic and Marti, 1981; Zunino and Jofré, 1999) south-central Chile (De Tommaso et al., 2009), and Argentine Patagonia (Andrade et al., 2010), where the niche breadth showed low values (B_{est} from 0.1 until 0.3), since owl predation was concentrated only on a few species. These differences can be also observed in burrowing owls living in environments similar to Tamarugal, such as the deserts of Sonora and Mojave in the USA, where values of niche breadth were low and uneven, showing a selection for a few taxa (Hall et al., 2009; York et al., 2002). Extreme environmental conditions offered by the Tamarugal ecosystem in the Atacama desert limit the abundance and variety of prey. This could induce *A. cunicularia* to consume a more evenly distributed mix of prey, as a way to compensate for scarcity of prey in this desert ecosystem. Niche breadth also varied between seasons, being higher in summer season. These differences are also corroborated with the analysis of trophic diversity according to Shannon–Wiener index, which leads to the conclusion that the diet of the burrowing owl in Pampa del Tamarugal becomes more diverse and equitable in summer, unlike winter season.

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