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Food habits of the barn owl *Tyto alba* in the National Reserve Pampa del Tamarugal, Atacama Desert, North Chile

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Abstract
In the present study the diet of the barn owl *Tyto alba* was analysed in the ecosystem of Pampa del Tamarugal, in the Atacama Desert, northern Chile. The area is characterised by extremely dry conditions, and relatively homogeneous and poor vegetation, dominated mainly by tamarugo forests (*Prosopis tamarugo*). The results indicated that small mammals were the greatest proportion (76.2%) in the diet of the barn owl, which predated only four species, of which the rodent *Phyllotis darwini* (approximately 62%) represented the major proportion. Nevertheless, reptiles and arthropods were also relevant prey for the barn owl, with a proportion of 5% and 15.1%, respectively. The general dietary composition of the tamarugos barn owl showed a wide-ranging diet pattern, characterised mainly by a poor diversity of small mammals and a significant consumption of reptiles and arthropods, in contrast to the sites in the central region and south Chile, where the diet included a greater diversity of small mammals, especially rodents. This pattern might reflect the conditions of extreme aridity, and low primary productivity in the ecosystem of Pampa del Tamarugal, restricting the abundance and diversity of the preferential prey (e.g. rodents). Hence, *T. alba* tends to increase its trophic diversity, adding other kinds of alternative prey to compensate for the low proportion of preferential prey available in the field.

Keywords: *Atacama Desert, barn owl, Chile, feeding ecology, Pampa del Tamarugal, small mammals*

Introduction

The nocturnal raptor *Tyto alba* (Gray, 1929) is considered one of the species with the widest distribution in the world (Clark et al. 1978). In Chile, it lives across the entire country, occupying a large proportion of environments, including urban areas (Pávez

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2004). According to the composition of its diet it has been characterised as a raptor which prefers mainly small mammals, especially nocturnal rodents (Jaksic and Yáñez 1979; Cerpa and Yáñez 1981). Although there are many dietary studies of *T. alba* in Chile, most of them have been focused on the Mediterranean (Jaksic et al. 1981; Torres-Mura and Contreras 1989; Zunino and Arcos 1989; Muñoz and Murúa 1990; Ebensperger et al. 1991; González et al. 2003) and temperate forests areas (Rau et al. 1985; Iriarte et al. 1990; Figueroa et al. 1999), whereas studies in arid environments are scarce (Jaksic et al. 1999).

Previous ornithological studies revealed the presence of *T. alba* in the ecosystem of Pampa del Tamarugal, located in the inlands of Iquique, north Chile (Estades 1995). However, its food habits in this area have not been studied. The presence of *T. alba* in this ecosystem offers a unique ecological scenario in Chile for the study of feeding behaviour of a raptor in a highly particular system, since Pampa del Tamarugal is within the Atacama Desert, the driest and oldest desert in the world (Hartley et al. 2005). Climate conditions in the area are extremely arid, the annual rainfall average being only 0.3 mm (Di Castri and Hajek 1976) and with very high temperatures of around 40°C throughout the year (Sudzuki 1975). These unfavourable climate conditions imply a low productivity of the system (Noy-Meir 1973; Estades 1995; Marquet et al. 1998), which would directly influence the amount and variety of available prey for the owl (Noy-Meir 1974, 1985; Marquet 1994; Estades 1995; Kelt et al. 1996; Rau et al. 1998).

Studies in central Chile clearly showed that the abundance of rodents, the main dietary item of *T. alba* in this area, was closely related to the productivity of the system, which at the same time was dependent on rainfall (Jaksic 2001b; Lima et al. 2002). Thus, the diet of the barn owl is expected to show a significant degree of adaptation to the difficult climate conditions of Pampa del Tamarugal.

The aim of this paper is to provide information about the food habits of the barn owl in the arid area of Tamarugal, and to compare it with a group of sites along a geographical and primary productivity gradient in Chile.

Study area and methods

Field studies were conducted in an area named Pintados, which is part of the National Reserve Pampa del Tamarugal in the Tarapacá Region, north Chile (20°51′S, 69°47′W). The reserve is on a plain in the Atacama Desert (1000 m elevation). There is a poor but homogeneous vegetation in the area, dominated mainly by *Prosopis tamarugo* (tamarugo), in spite of the extremely arid conditions. Shrubby and grassland species are very scarce, with only *Tessaria absinthioides*, *Atriplex atacamensis*, *Distichlis spicata*, and *Cressa cretica* occurring (Corporación de Fomento de la Producción 1983).

In order to describe the diet of *T. alba*, pellets were collected around two nest sites (the same for each time period, see Table I): 18 in September 2003; seven in January 2004, 35 in March, and six in May 2004. The total was 66 pellets, 38% collected during the non-breeding season (September and January), and 62% during the breeding season with chicks (March and May). The relatively low number of pellets collected within each season precluded temporal comparison of the diet of *T. alba*, so further analyses were based on the total pooled data. The pellets were digitally crumbled while humid to determine contents under a stereoscopical magnifying glass. All remains were individualised and identified to the lowest taxonomic level possible. Most vertebrates in the pellets were identified on the basis of skulls, beaks, mandibles or dentary pairs, using the key of Reise (1973) and the reference collection of the Zoology Laboratory of the Universidad Arturo Prat (Iquique,

Table I. Barn owl prey (%) recorded during each collection period in the National Reserve Pampa del Tamarugal.

Category of prey	September 2003	January 2004	March 2004	May 2004	Total
Mammalia					
Order Marsupialia					
Thylamys pallidior (Thomas, 1902)	25.9	7.7	9.5	6.7	12.7
Order Rodentia					
Phyllotis darwini (Waterhouse, 1837)	59.3	76.9	58.7	66.6	61.9
Rattus rattus (Linnaeus, 1758)	–	–	1.6	–	0.9
Order Chiroptera	3.7	–	–	–	0.9
Aves					
Order Passeriformes	–	–	6.3	–	3.4
Reptilia					
Order Squamata					
Phyllodactylus gerrhopygus (Wiegmann, 1835)	3.7	15.4	3.2	–	4.2
Tropidurus sp.	–	–	1.6	–	0.9
Arachnida					
Order Scorpionida					
Brachistosternus sp.	3.7	–	1.6	–	1.7
Insecta					
Order Coleoptera	–	–	1.6	13.3	2.5
Tenebrionidae	3.7	–	7.9	6.7	5.9
Order Himenoptera	–	–	4.8	–	2.5
Insects unidentified	–	–	3.2	6.7	2.5
Total prey	27	13	63	15	118
No. pellets	18	7	35	6	66
Items per pellet $\pm$ SD	1.5 ± 0.71	1.85 ± 1.21	1.8 ± 0.94	2.5 ± 1.47	1.79 ± 0.95

Chile). For reptile prey Donoso-Barros (1966) was used. The number of vertebrates was determined using maximum count of left and right mandibles, skulls or dentary pairs. For insect identification, Peña (1986) was used and these prey quantified by counting head capsules and mandibles. Scorpions were identified with the reference collection mentioned above and easily counted by noting the presence of pincers or stings.

In order to estimate the quality of the collected information, we performed two analyses. First, a species rarefaction curve, based on 100 randomisations (EstimateS 7.5; Colwell 2005), was constructed to determine whether the number of pellets sampled was enough to characterise the dietary diversity of *T. alba*. Second, we estimated the expected total number of taxa in the diet of *T. alba* using the non-parametric Chao1 index (EstimateS 7.5; Colwell 2005). The proportion between the observed and expected number of prey was an indicator of the completeness of our sampling, where values close to unity indicated a complete inventory.

We compared the feeding habits of *T. alba* at Pampa del Tamarugal with other sites in Chile, based on an exhaustive literature search (see Table II). All those studies followed similar sampling protocols, which make them directly comparable to our results. These studies described the diet of the barn owl at nine sites along Chile, covering ca 30° of latitude (22°18′–51°3′S and 68°38′–79°55′W; Figure 1), and a wide range of variation in primary productivity, measured as the mean annual rainfall (Jaksic 2001b; Lima et al. 2002; see Table II).

Table II. Barn owl prey (by classes) at 10 sites in Chile. Prey items (%) and number of small mammal species in parentheses. The mean annual rainfall for each site is also indicated.

Prey	Tamarugal[a] (20°S)	Chiu-Chiu[b] (22°S)	Fray Jorge[c] (30°S)	Puchuncaví[d] (32°S)	Campana[e] (32°S)	Dehesa[f] (33°S)	B. Flaco[g] (34°S)	Burca[h] (36°S)	Lastarria[i] (39°S)	T. Paine[j] (51°S)
Mammals	76.2 (4)	99.3 (7)	99.0 (6)	78.2 (10)	97.0 (8)	84.0 (7)	96.7 (12)	82.0 (6)	98.0 (9)	99.8 (9)
Birds	3.4	0.6	1.0	4.8	3.0	4.0	3.3	10.0	–	0.2
Reptiles	5.0	–	–	0.6	–	–	–	–	–	–
Amphibians	–	0.1	–	–	–	–	–	–	–	–
Insects	13.4	–	–	16.4	–	12.0	–	8.0	2.0	–
Arachnids	1.7	–	–	–	–	–	–	–	–	–
Total	118	692	511	371	76	371	91	169	133	531
No. pellets	66	346	255	95	58	–	76	103	56	302
Mean annual rainfall (mm)[k]	0.3	5.4	85	371	558.6	376.4	792.2	900	1157.4	658.9
Sampling season	Breeding/ non-breeding	Non-breeding	Non-breeding	Non-breeding	Breeding	Non-breeding	Non-breeding	Non-breeding	Non-breeding	Non-breeding

Sources: [a]This study; [b]Jaksic et al. (1999); [c]Schamberger and Fulk (1974); [d]Cerpa and Yáñez (1981); [e]Zunino and Arcos (1989); [f]Reise (1970); [g]Torres-Mura and Contreras (1989); [h]Muñoz and Murúa (1990); [i]Rau et al. (1985); [j]Iriarte et al. (1990); [k]Di Castri and Hajek (1976), Jaksic (2001c), CONAF (2001), www.meteochile.cl.

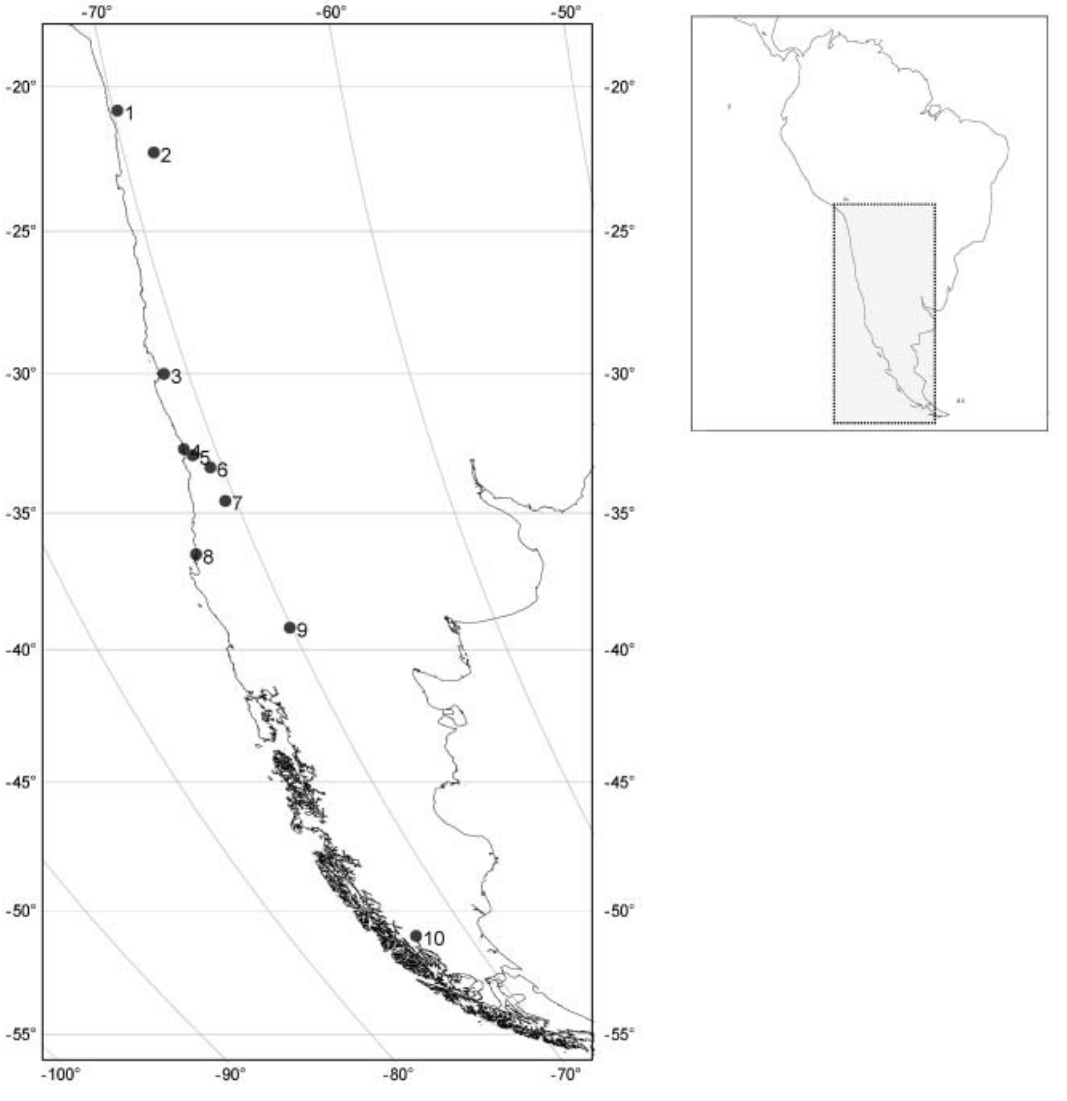

Figure 1. Map of South America, showing the 10 study sites along Chile: 1, Tamarugal; 2, Chiu-Chiu; 3, Fray Jorge; 4, Puchuncaví; 5, La Campana; 6, La Dehesa; 7, Baños del Flaco; 8, Burca; 9, Lastarria; 10, Torres del Paine.

The diet of the barn owl at each site was characterised through the following parameters: (1) total diversity in relation to the number of individuals in higher taxonomic units (i.e. mammals, birds, reptiles, arachnids, and insects), and (2) small mammals diversity (i.e. number of rodents, marsupials, and chiropterans) in the diet of *T. alba*. In both cases, diet breadth was measured with the Shannon–Wiener index, since it has been widely recommended and used to characterise the diet of raptors (Herrera and Jaksic 1980; Jaksic et al. 1982; Muñoz-Pedreros and Rau 2004). We tested whether food habits of *T. alba*, measured as total and small mammal diversity, varied along the latitudinal and primary productivity gradient along Chile. In spite of the relatively low number of sites compared ($n=10$), the dataset did not depart from normality (Shapiro–Wilks, $P>0.05$ in all

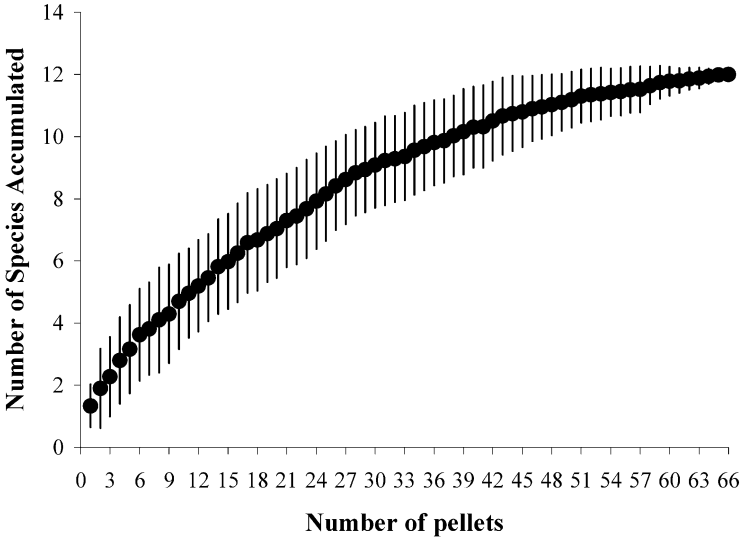

Figure 2. Rarefaction curve for the species richness found in the pellets of the barn owl (mean and standard deviations) based on the number of replicates sampled. The asymptotic curve indicates that total species richness in the Tamarugal was reached after ca 63 samples. Calculation was performed using the EstimateS 7.5 program.

cases), so changes in the diet breadth of the barn owl were evaluated with the Pearson moment-product correlation analysis.

Results

A total of 118 prey were taxonomically identified in the 66 samples (Table I), resulting in an average of 1.79 ± 0.95 SD prey per pellet. The barn owls at Tamarugal only captured four species of small mammals, fewer than at other sites in Chile (Table II). The rodent *Phyllotis darwini* was the most frequent species (61.9%), followed by the marsupial *Thylamys pallidior* (12.7%), while *Rattus rattus* and chiropterans were very scarce in the diet of *T. alba* (<1%). Other vertebrates were rarely present, such as the reptile *Phyllodactylus gerrhopygus* and passeriforme birds, with 4.2% and 3.4%, respectively. In Table II a summary of the main prey (by classes) captured by *T. alba* is shown for 10 sites in Chile, including the ecosystem of Tamarugal. Among the invertebrates, insects appeared in a high proportion (13.4%), especially tenebrionidae (5.9%). It is important to notice the occurrence of arachnids (scorpions) in the diet of the barn owl (1.7%).

Rarefaction analysis showed an asymptotic curve, where the total 12 prey were reached after sampling ca 60 pellets (Figure 2). The extrapolated total richness estimated with Chao1 index was 13.9, very close to the observed value. The ratio between observed and expected total was 0.86, suggesting that the sampling has recorded most of the dietary diversity existing in the zone.

When the diet diversity was analysed, total diversity reached a minimum value of 0.02 bits/individual at Torres del Paine (51°03′S) whereas at Pampa del Tamarugal (20°51′S) the value increased to 1.17 bits/individual. However, the total diversity in the diet of the barn owl along the latitudinal and primary productivity gradient studied did not show significant variation tendency ($r=-0.37$, $P=0.284$, $n=10$; $r=-0.22$, $P=0.530$, $n=10$,

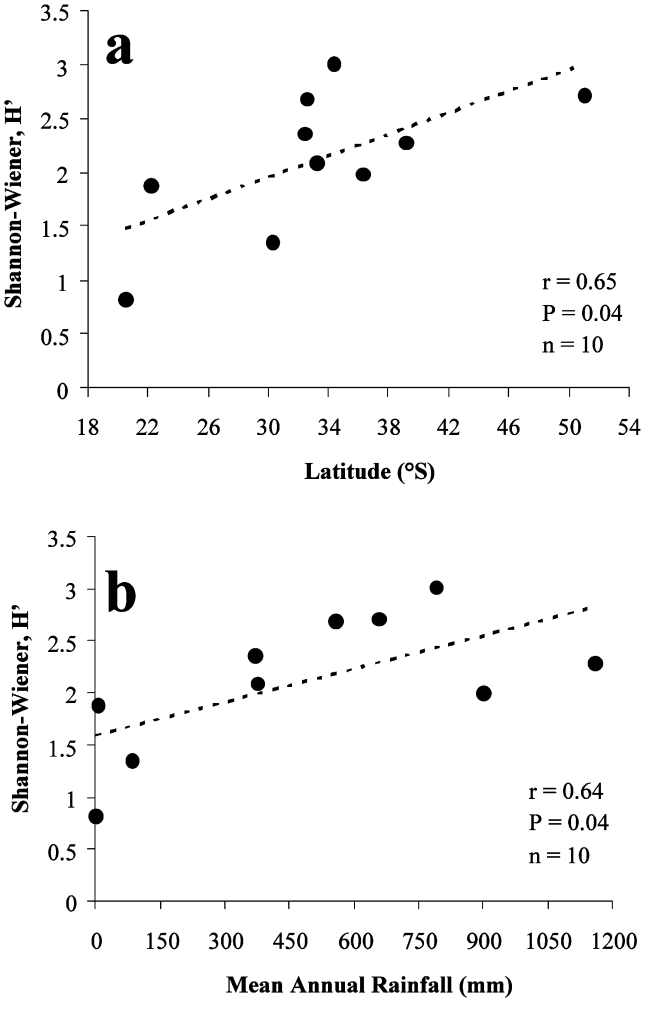

Figure 3. Variation of small mammal diversity in the diet of *Tyto alba* along Chile, measured using the Shannon–Wiener index (*H'*). (a) Variation across the latitudinal gradient; (b) variation across the rainfall gradient.

respectively). On the other hand, when small mammal diversity was analysed, a variation along the latitudinal and primary productivity gradient was observed, together with an increase in the diversity of this kind of prey along a north–south direction, in contrast to the previous case (Figure 3). In both correlations, the tendency was significant (r=0.65, n=10, P=0.041; r=0.64, n=10, P=0.046, respectively). Small mammal diversity reached a minimum value of 0.82 bits/individual at Pampa del Tamarugal and maximum values of 3.01 and 2.71 bits/individual at Baños del Flaco (central Chile) and Torres del Paine (south Chile), respectively.

Discussion

The results of the present study are part of the first evaluation of the diet of *T. alba* in the north of Chile. A wide dietary spectrum was revealed, in spite of the extremely arid

conditions in the study area. The analyses suggested that the diet patterns found at the site of study may be explained by geographical and primary productivity factors that influence the abundance and distribution of prey-species, thus varying the food habits of the barn owl.

Small mammals were the most important prey for *T. alba* in Tamarugal. The rodent *P. darwini* was the most prominent prey; similar results have been found in the central region and south of Chile, where its bones occur in high proportion in pellets (Herrera and Jaksic 1980; Muñoz and Murúa 1990). It was also frequently found in the pellets of other nocturnal raptors, such as *Athene cunicularia* (Molina, 1782) (Torres-Contreras et al. 1994) and *Bubo magellanicus* (Gmelin, 1788) (Yáñez and Jaksic 1977). The high frequency of *P. darwini* in the pellets of the Tamarugal barn owl can be explained by its strictly nocturnal habits and by it being one of the most abundant species in Chile, thus making it more vulnerable to predation than other rodents (Schamberger and Fulk 1974; Fulk 1976; Mann 1978; Jaksic et al. 1992). On the other hand, the finding of *T. pallidior* in the pellets of the barn owl represented a new mammal record for the National Reserve Pampa del Tamarugal. The Andean mouse opossum had been cited in the lowlands of the Province of Tarapaca, near Arica (Quebrada de Camarones) and in the Andean precordillera in the north of Chile (Palma 1995). Nevertheless, its distribution extends further to the south, up to the limits of Pampa del Tamarugal (approximately between 19 and 22°S) in the interior desert (ca 1000 m) of the Region of Tarapacá. This marsupial would reach the area of Pampa del Tamarugal from the Andean ''pre-cordillera'' via the transverse valleys, which maintain a biogeographical continuity (e.g. vegetation, water courses) with the Atacama Desert (Palma 1995; Meynard et al. 2002). Hence, the complex and peculiar vegetation of the Tamarugal would offer a favourable habitat for the establishment and survival of this small marsupial.

Reptiles are rarely present in the diet of the barn owl in Chile (see Herrera and Jaksic 1980; Cerpa and Yáñez 1981; Jaksic et al. 1981). Thus, the presence of *P. gerrhopygus* in the pellets of the barn owl is of particular interest. However, given its exclusive distribution in the north of Chile (Regions of Tarapacá and Antofagasta) (Vidal 2004), its strictly nocturnal habits, and its high frequency in the Pampa del Tamarugal (Donoso-Barros 1966), the presence of this reptile in the barn owl pellets would not be unexpected. In spite of the low body mass of this species (2.5 g) (Rau et al. 1998) the consumption of this reptile may increase during a scarcity of prey with high energetic value (rodents) as an alternative to compensate this food deficit.

Insects are scarce prey for the barn owl (Pávez 2004). Cerpa and Yáñez (1981), who analysed seasonal changes in the diet of *T. alba* in Chile, suggested that insects can be considered as alternative prey in periods when preferential prey (e.g. rodents) have considerably diminished. However, this feeding behaviour cannot be demonstrated in this study, since it does not include all the seasons of the year. The presence of scorpions in the pellets was remarkable, since this kind of prey has not been cited previously in Chile for the diet of the barn owl.

When comparing the feeding habits of *T. alba* in Tamarugal with other sites along the geographical and primary productivity gradient in Chile, an important variation in small mammal diversity was observed. Trophic diversity of these prey increased southwards, where more productive ecosystems might support larger populations of small mammals. Correspondingly, a study conducted on *Bubo magellanicus* (Jaksic et al. 1986) showed the same overall pattern, suggesting that this trend might be similar among noctural raptors. Even though the correlation between total diversity–latitude and total diversity–rainfall was

not significant, the highest diet breadth was found at Pampa del Tamarugal, as a consequence of the inclusion of several non-mammalian prey, such as insects, reptiles, and arachnids. Therefore, the diet of the Tamarugal barn owl can be characterised as the most wide-ranging diet compared to other areas of Chile (Jaksic et al. 1982; Jaksic 2001a). We hypothesise that the probable low abundance and diversity of small mammals in the Pampa del Tamarugal (e.g. Marquet 1994; Kelt et al. 1996) might be compensated with the inclusion of non-mammalian (i.e. reptiles, invertebrates) prey (Herrera 1974; Herrera and Jaksic 1980; Jaksic et al. 1982).

Difficult environmental conditions in Pampa del Tamarugal forces the barn owl to have a wide flexible opportunist feeding strategy (Noy-Meir 1974), as a response to the food scarcity observed in the area. This ability to capture a wide diversity of prey is a factor that could explain its broad distribution and its ability to colonise areas under severe environmental conditions (Torres-Mura and Contreras 1989). New studies involving long-term scales and effects of climate variation (e.g. ENSO) are necessary in order to clarify the real role of *T. alba* as a top predator at Pampa del Tamarugal.

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