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Seasonal variation in rodent consumption by the barn owl (*Tyto furcata*) in a relict of Espinal in southern Santa Fe, Argentina

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Abstract
There are few antecedents on the trophic habits of *Tyto furcata* in the south of Santa Fe province, Argentina. Based from the analysis of pellets, we characterized the diet of this raptor in a relict of Espinal in the south of Santa Fe province, Argentina. A total of 1789 items and 18 prey categories were determined in the 638 pellets collected during the research. According to the Shannon-Wiener index (H'), the dietary diversity was (H'= 1.47). Mammals, represented by 16 taxa, constituted 98% of the total of prey consumed, being Akodon azarae the most consumed prey. No statistically significant differences were found between the seasons and the species consumed, but significant differences were found when analyzing relative abundance. As it happens with other Strigiformes, the seasonal variation in the *Tyto furcata*'s diet in a relict of Espinal in southern Santa Fe, could be explained by the temporal cycles of abundance of rodent prey and its opportunistic hunting behavior according to the fluctuations of its prey, thus incorporating a greater number of alternative taxa in seasons with lower abundance of rodents.

Keywords: argentina, *Tyto furcate*, ecology, micromammal, Santa Fe, argentina, ecology, micromammal, Santa Fe

Introduction

In recent years, biased ferrite material for microstrip antenna structures has attracted noticeable attention. Ferrite is one of the important magnetic materials which are used as in both types single and polycrystalline. Some novel characteristics of polycrystalline ferrite over normal dielectric material make it very useful in microwave antenna applications. Different types of polycrystalline ferrites have their specific advantages as Li substituted ferrites has high dielectric "Pampean grasslands" is one of the most modified natural ecosystems in the world (Bilenca & Miñaro, 2004) [8]. According to its conservation status, the Pampean Region has been categorized by the World Wildlife Foundation (WWF) as a "critically endangered/threatened" area, and is assigned the highest conservation priority due to its high biological diversity, its high degree of alteration, and the scarce presence of protected natural areas (Bó *et al*., 2002) [9]. Around the Pampean Region there are different forest units that form a transition zone between the phytogeographic province La Pampa and the phytogeographic provinces of Chaco to the north and 'Monte', to the west. This transition zone has been called, in particular, the Espinal phytogeographic region (Cabrera, 1976) [11], and its biodiversity has been declining in recent decades as a result of habitat destruction, overexploitation, pollution and the introduction of exotic species (Bucher, 1997) [10]. For this reason, the WWF considers this ecoregion as "critically endangered/threatened", as it does with the Pampas ecoregion. At present, the human activities on the native forests of the province have had drastic consequences, due to deforestation for the advancement of the agricultural frontier, which has left the forest formations very restricted to the banks of the main riverbeds. In this sense, relicts of Espinal can still be observed in the south of Santa Fe province associated with the Carcarañá River, where different edaphic and geomorphologic limitations made it impossible for agriculture to enter. Within the fauna, mammals show different levels of sensitivity to these alterations, depending on their space requirements, feeding needs and behaviors in the face of landscape changes due to anthropization (e.g., Fox & Fox 2000 [17]; Poiani *et al*., 2001) [32]. In this context, while the numbers of several groups of species have been reduced or have become extinct, others, such as certain rodents, have benefited from the appearance of new habitats, the increased availability of food and/or from the breaking down of natural barriers for the spreading of species (Miño, 2003) [18].

In this sense, and in order to expand the existing information in the southern part of the province, the present research aims to continue advancing in mastofaunistic knowledge by analyzing the prey items consumed by the Barn Owl (*Tyto furcata*) in this environment and to introduce the first data on the seasonality of its diet.

Materials and Method

Study area

The sampled area is known as "El Espinillo" and it is located on both banks of the Carcarañá River, near the city of Casilda (32º58' S - 61º15'W), in the Caseros department, Santa Fe province (Fig. 1).

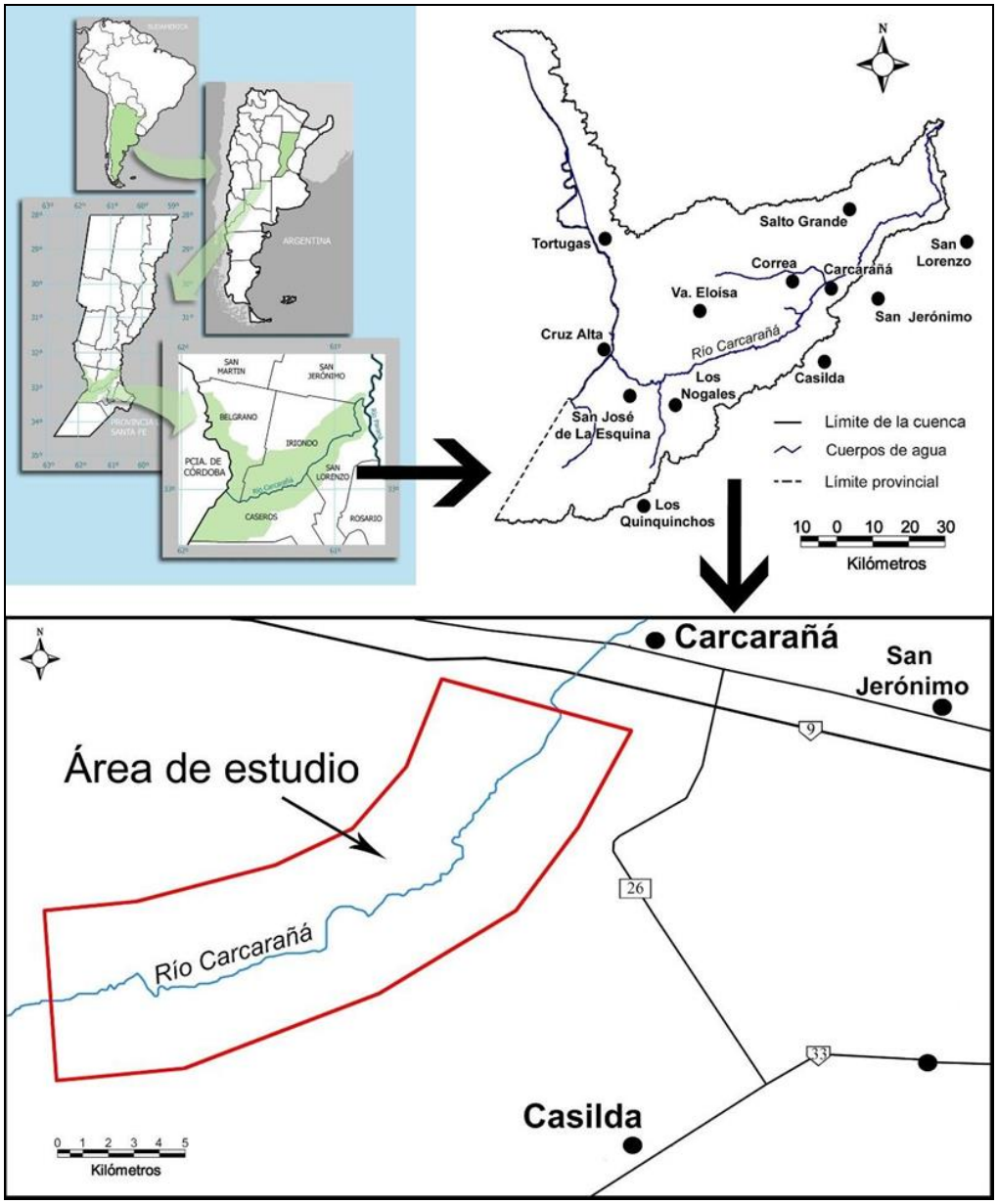


Fig 1: Location of the area under study in the province of Santa Fe, Argentina

The area is a 300-500 meter-wide, 7,500 meter-long strip of land on either side of the river (see Benaglia *et al.*, 1999). The physiognomy of the landscape is characterized, unlike the predominant environment (farmland), by notable variations in relatively small spaces. Having The Carcarañá River as the axis, the area has, a variable ecosystemic and regional landscape value. Its extension depends on the combination of several environmental factors, mainly the topography, which frequently acts as a limiting factor for agricultural activity (irregularities such as undulations in the soil, hollows, hills, etc.) and consequently allows the survival of flora and fauna species in a more or less autonomous way, ensuring the preservation (although with certain limitations) of some structural and functional parameters typical of the native balanced ecosystem. The studied area is characterized by climax communities of Flechillas (*Stipa neesiana, Stipa paposa*) or *Piptochaetium montevidense*, which are frequently accompanied or complemented by other non-grass species (*Chevreulia sarmentosa, Berroa gnaphalioides, Bacharis articulata, Bacharis salicifolia, Bromelia sp.* etc.). The floodable depressions have a particular physiognomy in the landscape because they give rise to very interesting hydrophil *Data collection*

The analysis of the content of pellets, non-digestible material regurgitated by raptors in the form of balls, is considered a useful tool to describe the diet in terms of the structure of the communities of small mammals, the availability of prey according to the season of the year, as well as in estimates of the relative abundances of prey populations in a given area and time (González-Calderón, 2017) [20].

In this work we considered samples that could be attributed, without doubt, to *Tyto furcata*, the samples were possibly produced by a single specimen, a couple, or a couple with offspring in each environment under study.

Between January and December 2020, the pellets were collected monthly at previously established points in the sampling site. In all cases, all the pellets were collected leaving the perch clean, which ensured that, for each sampling, the material collected corresponded to the period between the previous and the current sampling. The material from the first collection was discarded. Since these were restricted areas, it was relatively easy to search the entire

exposed surface under the perches, obtaining all the available material.

The pellets were placed in labeled paper bags (the labels containing coordinates, date and quantity) and then in hermetically sealed polyethylene bags, respecting all Biosafety measures (the use of latex gloves and a mask during the collection) even the drying of the material, which was carried out in the laboratory with an oven at 70°C for 48hs (Muñoz-Pedreros and Yañez, 2004). Each pellet was weighed on an analytical scale and the length and width of the pellet were measured with a digital vernier. They were then processed, using surgical instruments to extract the remains of the mandibles and skulls of the animals found. Those pellets that were compacted were soaked in water for 3 hours for their separation.

The jaws and skulls of the captured prey were compared with samples identified in different osteological collections and specialized literature (Reise, 1973 [34]; Bellocq, 1988; Gómez Villafañe *et al*., 2005 [18]; Fernandez *et al*., 2011). Pairs of mandibles of the same species and/or skull were considered as one individual.ic communities that develop in a transitory way accompanying the periods with permanence of water. There it is possible to find important extensions of *Eleocharis sp., Sagitaria sp., Scirpus sp., Cyperus sp.* and even *Typha latifolia*. In spite of what has been described, one of the most important features of the place is the presence of woody species typical of the espinal. There are important specimens of Talas (*Celtis sp*.) that show an age structure typical of an expanding community, a phenomenon which is even more remarkable in the territorial occupation developed by the Chañar (*Geoffroea decorticans*). Both species are distributed preferentially in the highest areas, very rarely associated with flooded depressions. Their forests of different sizes, occupy the hills with a high population density (The Tala outnumbered by the Chañar). Another well distributed species is the Sina-Sina (*Parkinsonia aculeata*) which is accompanied by other species. They appear as more dispersed individuals with a more uniform and less concentrated distribution. The presence of specimens of Algarrobos (*Prosopis sp*.), is an interesting indicator that the formation maintains acceptable conditions even for this type of species which grow more slowly. The fact that there are *Morus alba*, *Melia azedarach*, *Gleditsia triacanthos* and *Ligustrum lucidum* (Fig.2) specimens show us that there is an invasion of woody exotics.

Fig 2: Landscape physiognomy of the "El Espinillo" site.

Data analysis

For each prey item, the minimum number of individuals (MNI) was calculated by counting the cranial homologous element (left-right) represented in greater number (i.e., mandibles and maxillae), the relative frequency (*Ni / Nt*, where *Ni* is the minimum number of individuals of prey *i* and N_t is the total number of prey individuals) and the percentage contributed to the diet in terms of biomass (calculated as *ni wpi* 100 / ∑ (*ni wpi*), where *ni* is the number of individuals of *i* prey and *wpi* is the average weight of prey *i*). The average weights of prey items were taken from specialized literature (Marti 1976 taken from Bellocq 1988 [20]; Gómez Villafañe *et al*., 2005 [18]; SAyDS-SAREM 2019). The diversity of prey items was determined according to Shannon-Wiener indices (H'). The Shannon-Wiener index (H') quantifies the total diversity of a sample, being influenced by two main components: richness and equity. It thus considers the importance value of each species and expresses the uniformity of the importance values through all species in the sample. The formula for this function is:

$H' = -\Sigma\, pi \ln pi$,

Where pi is the ratio of the total number of individuals in the sample that corresponds to the species, whose values go from zero when there is only one species, to the logarithm of S (Moreno, 2001) [28]. Chi-square tests were used to evaluate seasonal variations in prey consumption.

It was calculated the curves of the accumulation of the observed species and the estimated species for the environment using the program (rarefaction) using the program StimateS 8.2. The calculated estimators were: Chao-2, ICE, Jacknife 2 and Bootstrap. Although the expected values generated by the estimators can be used as diversity measures, in this work they were used to determine how effective the sampling was (Villarreal *et al*., 2006) [38].

Results

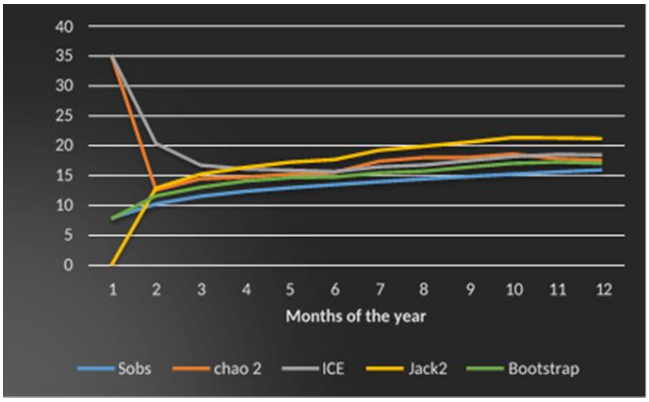
General diet composition

A total of 1789 items and 18 prey categories were determined in the 638 pellets collected throughout the research (Table 1). The average number of prey items per pellet was (average ± *SD*) 2.8 ± 0.72. The number of pellets regurgitated by the raptor had an average of 1.7 with an average weight of 3.27 gr.

Table 1: Diet of the barn owl (*Tyto furcata*) in a relict of Espinal in southern Santa Fe province. For each prey item, values are expressed as the percentage provided by the diet.

Prey items recorded in the diet of *Tyto furcata*	Summer	Fall	Winter	Spring	Total Biomass Percentage
Mammals	94,89		99,31	86,03	97,9
Akodon azarae	21,89	38,4	33,73	37,83	31,4
Oligoryzomys flavescens	32,84	25,74		13,51	
Oligoryzomys nigripes	-	1,13	2,89	0,9	1,75
Calomys cf. C. laucha - C. musculinus	37,59	29,58	24,53	18,91	14,5
Calomys venustus	-	0,85	1,02	0,9	1,13
Cavia aperea	-	0,42	0,08	2,7	11,15
Holochilus chacarius	0,72	0,85	0,15	2,25	8,05
Necromys lasiurus	-	1,42	2,04	0,9	2,04
Oxymycterus rufus	-	0,56	1,19	1,8	2,54
Graomys cf. Chacoensis	1,45	0,99	0,51	2,7	3,18
Lutreolina crassicaudata	-	-	-	0,9	1,32
Monodelphis dimidiata	-	-	-	0,45	0,13
Lepus europaeus	-	-	-	0,9	1,6
Eumops bonariensis	-	-	-	0,45	0,03
Tadarida brasiliensis	-	-	-	0,9	0,05
Molossus molossus	0,36	-	-	-	0,03
Unidentified amphibians and reptiles	3,28	-	0,34	10,81	1,06
Birds	1,82	-	0,34	3,15	0,67

Based on the behavior of the diversity estimators used in this research, it seems unlikely to obtain a greater number of species than those collected, even if we tried to get more samples, since the species accumulation curves stabilized or tended to decrease (Graphic 1).



Graphic 1: Species accumulation curve (S obs) and curves for the non-parametric estimators Bootstrap, Chao 2, ICE, Jack 2.

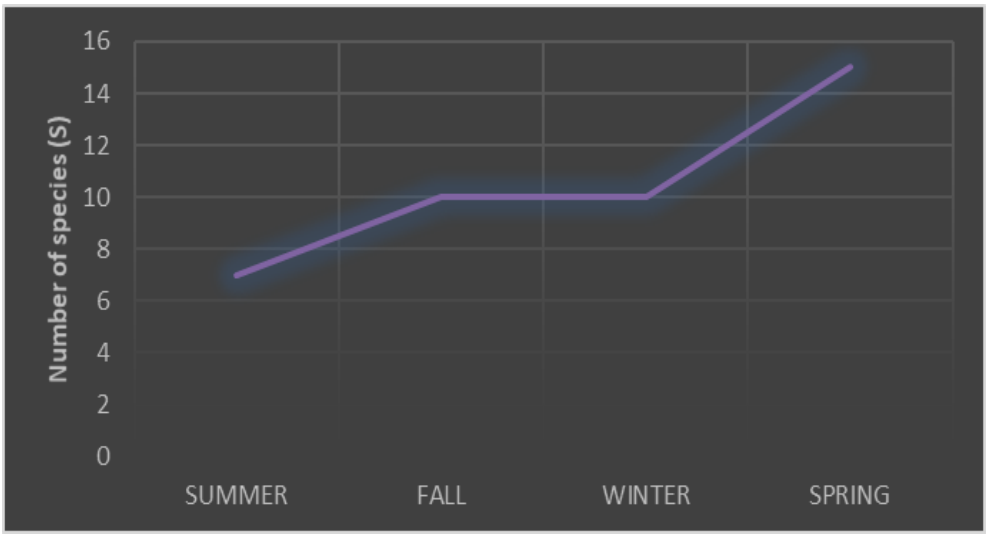
Graphic 1. Species accumulation curve (S obs) and curves for the non-parametric estimators Bootstrap, Chao 2, ICE, Jack 2.

The species recorded were: *Lutreolina crassicaudata* (Desmarest, 1804), *Monodelphis dimidi*ata (Wagner, 1847), *Eumops bonariensis* (Peters, 1874), *Molossus molossus* (Pallas, 1766), *Tadarida brasiliensis* (I. Geoffroy Saint-Hilaire, 1824), *Akodon azarae* (Fischer, 1829), *Oligoryzomys flavescens* (Waterhouse, 1837) *Oligoryzomys nigripes* (Olfers, 1818) *Calomys musculinus* (Thomas, 1913), *Calomys laucha* (Fischer, 1814), *Calomys venustus* (Thomas, 1894), *Holochilus chacarius* (Thomas, 1906), *Necromys lasiurus* (Lund, 1840), *Oxymycterus rufus* (Fischer, 1814), *Graomys chacoensis* (J. A. Allen, 1901), *Cavia aperea* (Erxleben, 1777), *Lepus europaeus* (Pallas, 1778), passerine birds, amphibians and reptiles. For each taxon, the relative abundance modified to percentage is presented in order to visualize the dominant species in each type of environment (see Table 1).

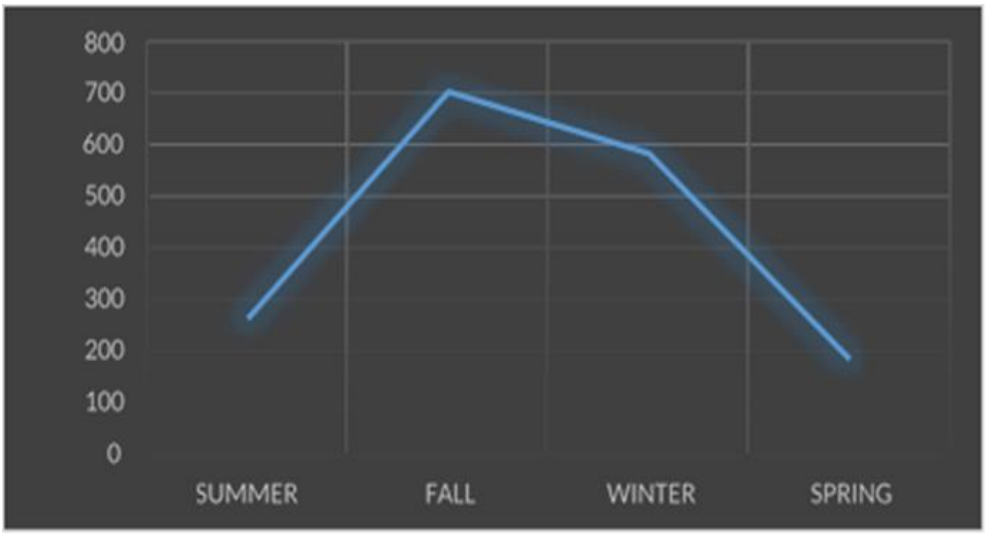
According to the Shannon-Wiener index (H'), the diet diversity was (H'= 1.47). Regarding the percentage of biomass contributed by the different prey items (see Table 1), mammals, represented by 16 taxa, constituted 98% of the total prey consumed. In broad terms, *Tyto furcata*'s diet was mainly composed of sigmodontine rodent species such as *Akodon azarae*, *Oligoryzomys flavescens* and the genus *Calomys* (*Calomys cf. C. laucha - C. musculinus*). No species of the remaining genera of small mammals exceeded 3% representation in the diet during the four seasons. Birds, amphibians and reptiles constituted between 0.68 and 14% of the diet, although the percentage of total biomass contributed did not exceed 2%. Marsupials and chiroptera were minimally represented. Rodents of the family Cricetidae such as *Akodon azarae*, *Oligoryzomys flavescens*, *Calomys cf. C. laucha - C. musculinus* and *Holochilus chacarius* together with the representative of the family Caviidae (*Cavia aperea*) were the largest contributors to the diet in terms of biomass.

Temporal variation: The difference in the number of species present in *Tyto furcata's* diet between seasons was not statistically significant ($\chi 2 = 2.769$, gl=9; $p = 0.973$). Although the number of species remains relatively stable during the different seasons, an increase in (S) can be observed in spring as a result of the incorporation of marsupial didelphids and chiropterans into the diet (see graph 2).

When analyzing the relative abundance of prey items (see graph 3), it did show important seasonal variations, mainly in autumn, which resulted in statistically significant differences ($\chi 2 = 126.341$, gl=9; $p<0.0001$). During the four seasons, the most consumed item by *Tyto furcata* was *Akodon azarae*, with a frequency higher than 30%, with the exception of summer.



Graphic 2: Species richness (S) of prey items consumed during the four seasons of the year.



Graphic 3: Relative abundance of prey items surveyed for the four seasons of the year

Discussion

Because of its abundance and wide distribution in the American continent, the trophic ecology of *Tyto furcata* was characterized in detail (d'Hiriart *et al*., 2017). However, there are still natural environments for which there is little or no information on this topic. Although in Argentina most of these investigations were carried out in the Pampean Region, these were limited to agricultural environments and urban areas being the natural areas poorly studied environments. The owl species of this genus are raptors, with a generalist diet specialized in the consumption of small mammals and with an opportunistic hunting behavior. Thus, the analysis of the contents of their pellets is considered a good approximation to the availability of prey offered by communities of small mammals of a location at a given time (Massa 2015; d'Hiriart *et al*., 2017). Bernard *et al*. (2010) showed that the frequency of a given species in *Tyto furcata*'s diet depends on its actual abundance in the community, so an adequate characterization of the trophic ecology of this owl must be approached from both a spatial and temporal perspective.

The results of this study emphasize this by allowing us to analyze *Tyto furcata's* diet on a seasonal basis in a relict of Espinal located in the south of Santa Fe province, where previous data were practically non-existent.

As regards the samples analyzed, the number of individuals per pellet found in the present work was higher than that observed in central Chile (average of 1.81; Begall, 2005), in Antioquia, Colombia (average of 2.0; Delgado and Cataño, 2004), in Valdivia, Ecuador (average of 2.2.; Moreno, 2010) [29], in Central Oaxaca, Mexico (average of 1.88; Lavariega *et al*., 2016) and similar to the results obtained in agrarian ecosystems in the province of Buenos Aires, Argentina (average of 2.4; Bellocq 1988) [3]. Regarding the amount of pellets regurgitated per day the results were within the expected ones since it is consistent with what was mentioned by Bellocq 1988 [3] (average 1.7), Hercolini 2007 [22] (average 1.4) and Massa 2015 (average 1.4) for the different sites of the Pampas ecoregion. With the weight per pellet occurs the same with what has been mentioned so far: it is within the range of what has been documented in other research related to the trophic habits of this raptor (average weight 2.17gr Bellocq, 1988 [22]; 3.8gr Gonzáles-Calderón, 2017) [20].

With respect to the space and constitution of the assemblage, it is well worth mentioning that as this Espinal relict is more complex (vertical variation) and heterogeneous (horizontal variation) than the dominant matrix (croplands), It is observed a greater diversity of prey items than in similar works carried out in agroecosystems of

the Pampean Region (Bellocq, 1988 [34]; Polop and Busch, 2010 [33], Guidobono, 2013; Massa, 2015). The direct relationship between vegetation structure (e.g., complexity) and mammal diversity is well documented (Cruz-Lara *et al*. 2004); thus, the greater diversity of micromammals in the Espinal relict could be explained by the greater spatial heterogeneity and productivity of that habitat, complementary factors whose mode of action is the range of available resources and mean niche breadth (August 1983). In general terms, structurally more complex environments offer a greater variety of different microhabitats than simpler environments (croplands).

The dominance in *Tyto furcata's* diet is represented mainly by the species *Akodon azarae* partially shared by *Oligoryzomys flavescens* demonstrating for both species prefer more stable habitats as mentioned by Bellocq, 1988; Guidobono, 2013 [31]; Massa, 2015 [26] and with high vegetation cover (Polop and Busch, 2010) [33]. The presence of the genus *Calomys* in third place in terms of abundance can be explained by analyzing structurally the study area which is presented as a small area immersed in a matrix of crops. The genus *Calomys* is the dominant taxon in this type of environment (cropland) and in times when there are no standing crops, and taking into account the uniformity of the landscape, these species could exploit their capacity of r strategists by migrating to the study area to satisfy their basic requirements and thus keeping their high assemblage representation in the assemblage during most of the year.

Some authors (Bellocq and Kravetz 1994, Bellocq 1998) agree that *Tyto furcata* would selectively prey on larger rodents (Gonzales Acuña *et al*., 2004). However, previous data on differential predation according to body size are contradictory (Jaksic *et al*. 1982, Torres-Mura and Contreras 1989, Trejo and Guthman 2003 in Gonzales Acuña *et al*., 2004). In this study, larger preys such as *Cavia aperea* (403-530gr), *Lutreolina crassicaudata* (200-540gr), and *Holochilus chacarius* (152-262gr) showed a low representation in the diet. This could indicate that *Tyto furcata* preys on locally available prey sizes. In this case, the high consumption of *Akodon azarae, Oligoryzomys flavescens* and to a lesser extent *Calomys cf. C. laucha - C. musculinus* seems not to be due to their weight but to ease the handling (see Jaksic *et al*. 1977) [23]. The low energetic cost to capture these species (due to factors that can be seen in Gonzales Acuña *et al*., 2004) would thus compensate for the benefit offered by a larger, but more costly to capture prey (Jaksic *et al*. 1977) [23]. Castro and Jaksic (1995) [24] in Gonzales Acuña *et al*., 2004 state that it is difficult to determine whether predators select prey for physical attributes (e.g., size, age) or simply capture those kinds of prey that are more vulnerable.

As it happens with other Strigiformes, seasonal variation in *Tyto furcata*'s diet in an Espinal relict in southern Santa Fe, could be explained by the temporal cycles of abundance of rodent prey and by their opportunistic hunting behavior in the face of prey fluctuation, thus incorporating a greater number of alternative taxa in seasons with lower abundance of rodents. Both *Akodon azarae, Oligormyyzos flavescens* and the genus *Calomys* tend to increase its population during the autumn-winter seasons because the young individuals enter the population, and tend to decline during the spring and summer seasons due to mortality caused by climatic factors, the decrease in trophic resources and predation (Gonzales Acuña *et al*., 2004).

This contribution demonstrates how important the present existence of xerophic forests relics is for the native mastofauna in a purely agricultural area. However, the areas studied in this work could be reduced by the advance of cultivated areas in the future. That is why we recommend the development of actions aimed at increasing research on key, threatened and ecologically relevant species present in the area, in order to incorporate effective strategies in conservation proposals that lead to the sustainable management of resources in the region.

Another point to highlight is the importance of the study of micromammal communities based on diet analysis of *Tyto furcata's*, since it can be considered a tool of high methodological value to determine the distribution of micromammals at low densities, avoiding other procedures (such as intensive trapping) that are potentially risky, in terms of health, and costly, in terms of time and effort.

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