Analysis of the diet and reproductive success of the Boreal Owl (*Aegolius funereus*) population in the Alt Pirineu Natural Park

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My contribution to the different components of this work was the following:

Work components	**Student's contribution**
Project design	B
Field sampling	C
Lab work	A
Data processing	B
Statistical analysis	A
Writing	A

A: Entirely by the student, B: Partially by the student, C: Entirely by other members of the team

The naturalist association La Paniquella, since 2011, has been carrying out a campaign within the Alt Pirineu Natural Park (PNAP) with the aim of improving the productivity of the little owl. Both the monitoring data and the samples of nest pellets used in this work are provided by them. La Paniquella project has 3 distinct study areas: the Lo Calbo forest, the Virós forest and the Puiforniu-Tornafort area. However, this study focuses only on the Lo Calbo Forest area.

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Abstract

Through the analysis of data from the Tengmalm's Owl population that inhabits the forest of the Alt Pirineu Natural Park, its diet is studied through the skulls of its prey. The main objective is to expand the scarce information on the biology of this species, resident in the area. The data set is collected from 2016 to 2021. Using the pellet samples available, it is investigated how the abundance of main prey affects the reproductive success and feeding ecology of the species.

According to the optimal diet model, under conditions of prey abundance the species in question will select the most profitable items. Thus, the diet composition of the boreal owl will depend on the availability of its main prey items. The abundance of micromammals in the study area is then studied using data from the micromammal monitoring campaign in Catalonia (SEMICE).
The main prey of the Tengmalm's Owl in the Alt Pirineu Natural Park are individuals of the family Muridae (*Apodemus sylvaticus*), individuals of the subfamily Arvicolinae (*Microtus agresits, Microtus arvalis, Myodes glareolus* and *Arvicola sapidus*) and individuals of the family Soricidae (*Sorex araneus, Sorex coronatus* and *Crocidura russula*).

Through the analysis of the diet samples, it was found that the most abundant predatory species was wood mouse, followed by field vole and bank vole. The year with the highest abundance of small mammals was 2016 and the year with the lowest abundance was 2017.
Data from the small mammal monitoring campaign (Semice) in the area are also analyzed to try to see if the proportions of small mammals in the field match the proportions in the diet samples. However, only the abundances from two different years coincide, so the results are not conclusive.

Finally, the reproductive success of the species is studied in relation to the abundance of its diet. Linear regression models are plotted with the diet abundances and related to the chicks fledged in each year. The species found to be significant is the greater white-toothed shrew (Crocidura russula. Although if more data were available, the species Sorex coronatus and Myodes glareolus also appear to be significant in relation to this dependent variable.

Introduction

The boreal owl, *Aegolius funereus* (Linnaeus, 1758), is a small, strictly forest-dwelling nocturnal bird that inhabits the boreal forests of Eurasia (Mikkola, 1983) and northern America (Hayward & Hayward, 1993). This species is one of the most unknown raptors of the Iberian Peninsula. The only existing studies in the Pyrenees describe mainly the pattern of habitat selection and distribution (Alamany, 1989), but little is known about the rest of its biology in this specific area. The first citation of this species in the mountain range was in 1892 by Bleach, when it was catalogued as "Òliba calçada" (traducció a l'anglès?). Subsequently, a sighting was made in 1963 on the French side of the Pyrenees, in the spruce forests of Font Romeu, inside a green woodpecker hole (*Picus viridis*) (Van Der Vloet, 1964).

In central and northern Europe, the boreal owl is found in mixed forests of *Pinus sp*., *Betula sp*. and *Populus sp*. (Cramp et al., 1983). In the Iberian Peninsula it mainly inhabits the forests of the subalpine belt of the Pyrenees (between 1700- and 2400-meters altitude). Although there is some asymmetry between east and west, and between north and south, its presence seems to be almost exclusively associated with coniferous forests at high altitudes, with the presence of Black pine (*Pinus uncinata*) and Silver fir (*Abies alba*) (Dejaifve et al., 1990). The species selects mature, open, regenerating forest stands with abundant dead wood and little undergrowth (Dalmau & Mariné, 2004). In addition to forest type, other variables such as temperature also seem to be determinant. Thus, a study performed in the Pyrenees concluded that it does not select areas that exceed an average maximum temperature of 18ºC during the warmest months (Mariné et al., 2003). This suggests that the increase in temperatures due to climate change could have a negative effect on the distribution of this population (López et al., 2010). On the other hand, the availability of prey for feeding and nesting cavities, preferably holes made by the Black woodpecker (*Dryocopus martius*), are also important (Camprodon et al., 2020).

The boreal owl has a sexual dimorphism, as occurs in several predatory bird taxa, in which the female is larger than the male (Jehl & Murray, 1986). In fact, it is the most sexually dimorphic European owl in terms of size (Körpimaki, 1986). During the breeding season, the female can weigh up to 50% more than the male (Hipkiss, 2002). This can be explained by the fact that the male is the main food provider for the family and, therefore, needs efficiency in hunting. Females, on the other hand, are responsible for laying, incubating, and caring for the offspring (Newton, 1979). As a raptor, it plays a very important role in the food web, being at the top of the pyramid of energy and matter transfer. As for its diet, the

boreal owl hunts everything from mammals to birds and even insects. However, its main preys are small mammals, showing a clear preference for voles (Korpimäki et al., 2012). Fluctuations in the abundance of these rodents have been proven to be determinant in the biology and reproductive success of the species (Korpimäki, 1987; Hörnfeldt, Carlsson, Löfgren et al., 1990).

The evolution of the Boreal Owl population in Catalonia have always been difficult to estimate due to the scarce information available. The latest published data are from 2018 and seem to indicate that in Catalonia the population size is of 150 territories (European Commission, 2018). According to the IUCN category, both in the 2004 and 2021 red book of birds, it is classified as *Vulnerable*, the number of mature individuals in Spain remaining below 1000 (Mariné et al., 2004. Morcelle et al., 2021).

The general objective of the present work is to increase the scarce information available on the population of this nesting species in the Alt Pirineu Natural Park. On the one hand, we intend to carry out an exhaustive analysis of its diet through pellets collected between 2016 and 2021 in different nest boxes of Lo Calbo forest (in the municipality of Guingueta d'Àneu). We will work with some samples already analyzed in the work by Lanzaco (2022), as well as with new samples to have as wide a data base as possible. We want to study if this species is selective and if there is a key prey to stabilize its population. It is hypothesized that the boreal owl population is closely related to that of voles of the subfamily Arvicolinae, as described above.

In addition, to determine if there is an association between boreal owl prey and small mammal populations in the field, the SEMICE (Monitoring of small common mammals in Spain) samples from the three stations located in the Alt Pirineu Natural Park (Pla de l'Orri, Lo Calbo and Cireres) will be analyzed.

On the other hand, the other general objective of the thesis is to study the reproductive success of this population in the area. The aim is to analyze if the reproductive success of this population is related to the abundance of any family or species of micromammal found in their diet. The reproductive success will be measured by the number of chicks fledged each year. The starting hypothesis is that breeding success will be positively correlated with prey of the subfamily Arvicolinae, specifically with the genera *Microtus* and *Myodes*.

Moreover, we will also analyze whether reproductive success can be related to other variables besides the abundance of micromammals, such as the specific biodiversity of the area (measured with the Shannon index).

Materials and methods

Study area

This forest is located between the municipal area of Guingueta d'Àneu and the municipal area of the Cardós Valley, in Pallars Sobirà, within the area covered by Alt Pirineu Natural Park (APNP) (Fig. 1). Lo Calbo occupies a territory of approximately 586 Ha and is a forest dominated by mature black pine (*Pinus uncinata*) with thick trunks, with a lax undergrowth of Alpenrose (*Rhododendron ferrugineum*) and other herbaceous plants, occasionally with European blueberry (*Vaccinium myrtillus*). Within the limits of the forest is the peak of Montcaubo with 2291 m of altitude (42.598298, 1.179246).

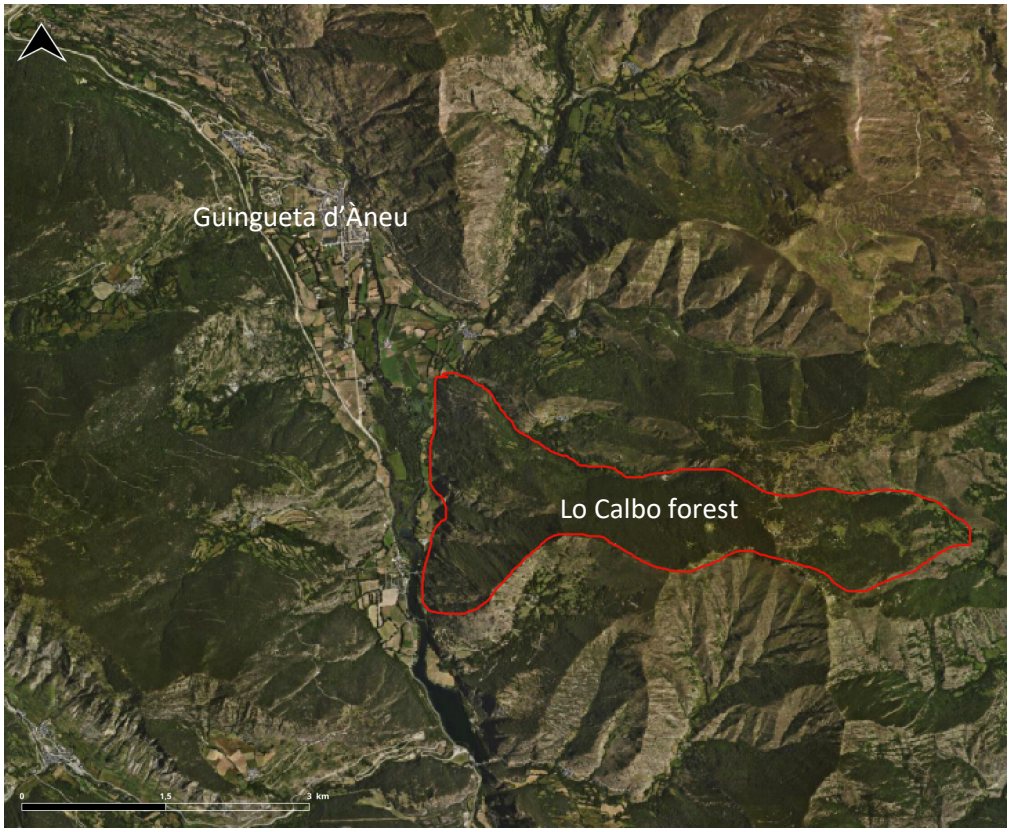

Fig. 1: Location map of the forest of Lo Calbo, in the municipality of Guingueta d'Àneu, Pallars Sobirà.

Monitoring of the species

To carry out the monitoring of the species, 10 nest boxes were installed in the study area, the Lo Calbo Forest. Through the installation of these boxes, samples could be collected to analyze the diet of the species, as well as to mark individuals and study their morphology and behavior. The nest boxes are made of natural logs hollowed out on the inside (Fig. 2) They have a lid that is used to manipulate the inside of the nest when sampling and a hole of 8.5 cm in diameter,

through which the owlets enter and exit. The size of the box ranges from 16 to 30 cm in diameter. The inside is covered with moss to create a bed for laying and rearing chicks.

The 10 boxes were fixed to black pine trees (*Pinus uncinata*) between 4 and 8 meters above the ground and are not oriented towards any specific point. A metal sheet is also placed between the ground and the box, surrounding the entire trunk. The objective is to protect the box from possible predation by pine marten (*Martes martes*) or beech marten (*Martes foina*), preventing them from climbing. In some cases, some branches also must be cut to prevent predation from above.

The nests are checked a minimum of 4 times a year, and in these checks, it is verified if the nest box is occupied and if so, an attempt is made to band the individuals. During the last check is when pellet samples are collected, coinciding with the abandonment of the nest by the nestlings.

Fig. 2: Nest box located in the Lo Calbo Forest area.

During monitoring over the years, it has also been possible to obtain data such as chicks fledged per year and box, total chicks per year and box, and eggs laid per year and box, among other parameters. These 3 variables are treated together with the abundance of small mammals taken from the pellets, to try to explain their relationship.

Monitoring of small mammals (Semice)

The objective of this action is to establish the abundance of prey species (small mammals) in the study area and to establish how they contribute to the Tengmalm's owl diet.

Sampling is carried out twice a year, once in July-August and once in October-November. In each sampling, 36 Sherman or Longworth traps are set up to capture and release these small mammals. The sampled station has a useful area of approximately 0.81 Ha, which will be one of the values used to calculate indicators.

In each monitoring, the traps remain active for a total of 3 consecutive days. Although the protocol recommends checking the traps twice a day, in this case traps were checked only once due to lack of personnel. Inside the trap, absorbent cotton is used so that the individual can be

more insulated from the cold and a paste composed of tuna and sardine oil and flour is introduced.

When an individual is captured, the process is to identify it, sex it, weigh it, check its reproductive status, and mark it. If it is not a recaptured small mammal (i.e., it does not have any markings), it is tagged with an earring with a unique serial number, in the case of murids, arvicolinian and glirids, or a little hair is cut off, in the case of sorids.

Around and inside the borders of the study area, there are 3 different monitoring stations: Lo Calbo (in the municipality of Guingueta d'Àneu), Cireres (in the municipality of Alt Àneu) and l'Orri (in the municipality of Rialp). To try to make a more extensive analysis of the diet of the boreal owl in the area, we treat the Semice data collected in recent years in these different stations. From this monitoring we have data ranging from 2011 to 2022, intermittently. Even so, they are samplings with few captures, so it was decided to join the 3 stations and show them as abundance data by years, without distinction.

The objective of comparing the Semice data with those of the boreal owl diet is to study whether the proportion of small mammals in the field assimilates to the proportion of small mammals found in the pellets each year. However, in this process there are complications as only two years (2020 and 2021) of Semice sampling coincide with the nest box samples. In any case, the captures of this micromammal monitoring are analyzed.

Pellet analyses

To analyze the diet of the boreal owl, the pellets collected during the sampling of the nest boxes were also used. Tengmalm's owl females usually keep their nests clean during incubation and brooding (Kuhk 1969; Korpimäki 1981; Zárybnická et al. 2013). However, they do not remove preys remains and pellets, bark and other materials accumulates in a layer at the bottom of the nestbox during the nestling period (Zárybnická et al. 2013).

These are collected once the chicks have already left the nest. The accumulation of organic remains found inside the nest box is emptied into a large zip bag. Considering that in this organic mass there are feathers, bones, vegetable remains, hairs, parasites, ... The bag was identified and frozen for at least 24 hours.

The analysis of the diet through the pellets was done by identifying the lower jaws of small mammals found in the bag. The identification is carried out with the help of the guide of Noguera, JC. (1987). The mandibles are classified by family and then by species, and a separate inventory was generated by years and nest boxes. We counted as a whole individual when a right jaw and a left jaw were found.

A total of 15 pellet samples were analyzed during 2016 and 2021. However, there is not an equal number of samples per year. In 2016 we obtained 4 pellet samples from different nest boxes and in 2017, 2 samples. In 2018 there was only one sample from a nest box, its contents were analyzed, but no small mammal's skull were obtained. This was because the box from which it was obtained was depredated and the pair of boreal owlets that inhabited it abandoned the nest. We also analyzed 3 samples dating from 2019, 4 samples from 2020 and the last 2 samples from 2021. In order to know the specific diversity of each box, the Shannon index is also calculated.

Considering the limited data from this population, it is valued as the most comprehensive diet database available so far.

Statistical analysis

Through the diet of the boreal owl, the abundance of micromammals in each year is noted. To study if there is any temporal pattern by which the micromammal population is abundant, the meteorological data of these years are analyzed. Specifically, the mean annual precipitation variable (independent variable) and the mean annual temperature variable (independent variable) are used. The data used come from the closest meteorological station to the study area: the Bonaigua station (2.266 m), located in the municipality of Alt Áneu. The archives of the meteorological service of Catalonia (Servicio Agrometeorológico de Catalunya (n.d)) are consulted to make use of them.

With these two variables, first, the relationship coefficients (RStudio, R Core Team 2021) of each of the variables with respect to the abundance of micromammals in the diet are analyzed. Next, a simple regression analysis is carried out with each variable separately to see if mean annual precipitation or mean annual temperature has a significant relationship with the abundance of micromammals. Then a multiple regression analysis is performed to see if the set of the two variables can be significant as well.

Using Spearman rank correlations an attempt is made to analyze the relationships between individuals of the murid, arvicolinian and soricid families. However, there is little data to draw conclusive results from this analysis.

Using a linear regression analysis, we examined the relationships between mean annual small-mammal abundances (independent variable) and reproductive success (dependent

variable). This relationship has been studied by family and by species. The relationship between the specific biodiversity of each nest box and each year (independent variable) and the reproductive success (dependent variable) of the species has also been studied.

Results

This study relies on the analysis of 15 pellet samples, dated between 2016 and 2021, from 9 different nest boxes. Even so, not all samples have been analyzed for this study, some of which were previously analyzed by Lanzaco in his master thesis published in 2022. Combining the sampling effort of both, the following results are published.

Diet composition

A total of 11 species were detected in the pellets analyzed. Nine species of small mammals (Rodentia and Eulipotyphla), and two of birds. The presence of the latter is scarce and anecdotal, so it was not used for later comparisons. The species of small mammals analyzed belong to 4 different families: Muridae (*Apodemus sylvaticus*); Cricetids, specifically of the subfamily Arvicolinae (*Myodes glaerolus*, *Microtus arvalis*, *Microtus agrestis* and *Arvicola sapidus*); Soricidae (*Sorex araneus*, *Sorex coronatus* and *Crocidura russula*) and Gliridae (*Eliomys quercinus*).

Table 1: Small-mammal abundances by species in the diet composition of breeding Tengmalm's owls (n = 9 nest box) in Lo Calbo Forest, Catalonia during 2016–2021

Prey species or group	N	% Abundance	% Presence
Apodemus sylvaticus	161	20,72	100,00
Unidentified Muridae	92	11,84	66,67
Myodes glareolus	93	11,97	100,00
Microtus arvalis	124	15,96	77,78
Microtus agrestis	142	18,27	100,00
Arvicola sapidus	6	0,77	22,22
Unidentified Arvicolinae	57	7,33	77,78
Sorex araneus	50	6,43	66,67
Sorex coronatus	31	3,99	66,67
Crocidura russula	11	1,41	33,33
Unidentified Soricidae	8	1,03	44,44
Eliomys quercinus	2	0,26	11,11

Of the 777 individuals sampled over time, the most abundant are individuals of the subfamily Arvicolinae with 54.31% abundance, followed by 32.56% which are murids and 12.87% and 0.26% of soricids and glirids, respectively (Table 1). There is a clear preference for prey of the subfamily Arvicolinae, since they represent more than half of the skulls found in the pellets sampled.

As for the percentage of presence, the wood mouse (*Apodemus sylvaticus*), the bank vole (*Myodes glareolus*) and the field vole (*Microtus agrestis*) are present in the pellets of the 9 nest boxes analyzed. Common vole (*Microtus arvalis*) is present in 77.78% of the boxes, and common shrew (*Sorex araneus*) and millet's shrew (*Sorex coronatus*) are present in 66.67% of the boxes. The species that is least present is the garden dormouse (*Elyomis quercinus*), which is only found in one nest box, followed by the southern water vole (*Arvicola sapidus*), present in 2 nest boxes and the greater white-toothed shrew (*Crocidura russula*), which is found in samples from 3 different boxes.

As shown in the box plot (Fig. 3), the most abundant individuals in the Tenglam's owl diet samples belong to the species *Apodemus sylvaticus*. Next, voles of the genus Microtus have the highest abundance. The least abundant species in the pellets were *Eliomys quercinus* and *Arvicola sapidus*, respectively. As mentioned above, a total of 777 individuals have been found within these 15 diet samples available to us. An average of 87.55 individuals are found in each nest box. The mean Shannon's index is S = 4.17.

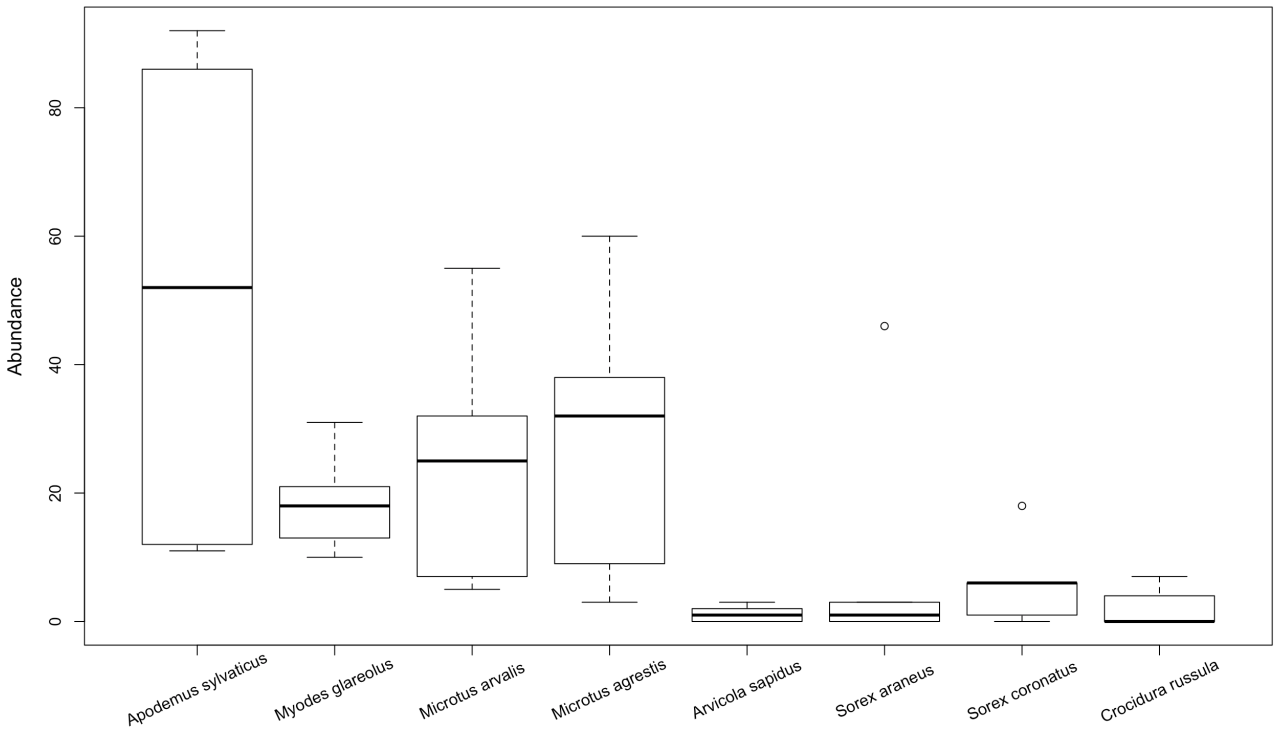

Fig. 3: Small-mammal abundances by species in the diet composition of breeding Tengmalm's owls (n = 9 nest box) in Lo Calbo Forest, Catalonia during 2016–2021

A principal component analysis (Fig. 4) is plotted to graphically represent the abundance of each family during the 5 years that diet samples are available.

Looking at the distribution of years in the graph, the years 2019 and 2020 have had similar abundances, 179 and 169 in total, respectively. The other pair of years with similar counts

would be 2017 and 2021, with 36 and 56 respectively. The year with an abundance less likes the rest would be 2016, since it is far away from the rest of the points, with a total of 336 individuals counted.

The inclination of the axes of each family indicates that the major contributors to PC1 are soricidae and arvicolinae. These are the families with the greatest variability between years. The axes that contribute the most to PC2 are muridae and gliridae, and it can be affirmed as their abundances remain more constant between years.

Analyzing the position of the points with respect to the axes of each family, the notable separation between points indicates that the abundance patterns between years are not very similar to each other.

The points corresponding to the years 2019 and 2020 are close to the axes of the muridae and arvicolinae families, which means a higher abundance of these families during those years. The year 2016 is observed in a more balanced position with respect to each of the axes since it is the year with a higher count of individuals of each family. On the other hand, 2017 and 2021 are the years with the lowest abundance and therefore are located further away from the axes. However, 2021 is the only year along with 2016 with an individual of the gliridae family, and it is observed in the graph given its proximity to the respective axis.

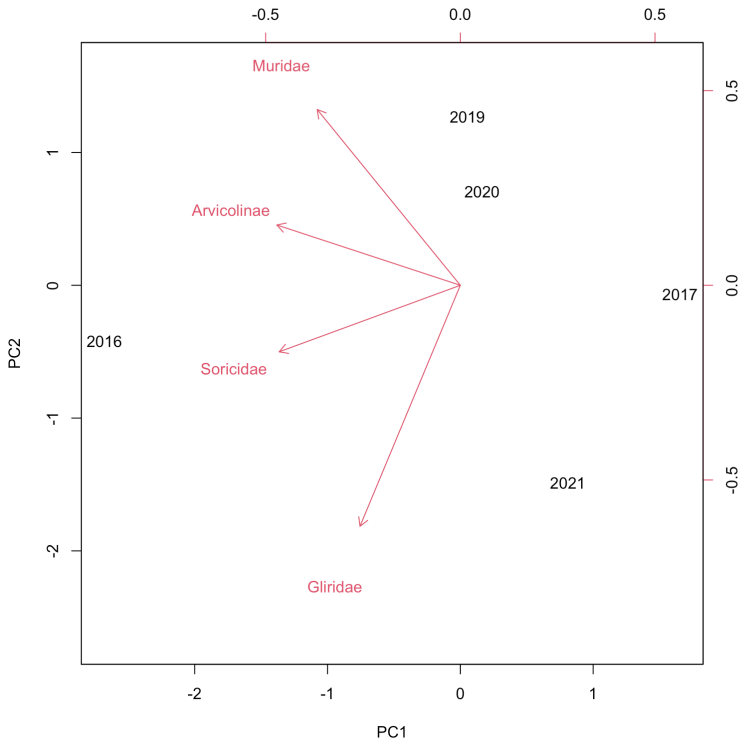

Fig. 4: Principal component analysis of the abundance of small mammals between 2016-2021.

To study whether the abundance of micromammals in the diet of the boreal owl is related to any temporal pattern, the mean precipitation and temperature variables for each year (2016-2021) are used. The coefficients of relationship with the variable abundance of micromammals are analyzed. The correlation between abundance and mean annual precipitation is negative (r = -0.27). The correlation between abundance and mean annual temperature is very close to 0 (r = -0.02). The simple regression analysis with the variables precipitation and abundance was not significant (R^2= 0.07, p value = 0.65). The same analysis, but with the temperature variable was also not significant (R^2= 0.0003, p value = 0.93). The multiple regression analysis to determine whether the two variables together affect the abundance of micromammals was not significant (R^2= 0.26, p value = 0.73).

As can be seen in Table 2, the only two years in which the diet of the nest boxes sampled can be compared with the captures of the Semice monitoring program are 2020 and 2021. In 2020, the two most abundant species present in the diet of Tenglam's owl were field vole and wood mouse, followed by common vole and bank vole. The least abundant species were southern water vole and common shrew. Comparing these data with the small mammal monitoring of the same year, the two species with more captures are the wood mouse and the bank vole. One individual of common shrew was also captured. Although the numbers of individuals do not coincide exactly, the species that have been abundant in the diet of Tenglam's owl have also been abundant in the field sampling.

It is similar in 2021, as the most abundant species in the pellets is the bank vole. It is also the only one captured that year in the micromammal monitoring campaign, and with a very similar number of individuals.

Table 2: Small-mammal abundances in the field and diet composition of breeding Tengmalm's owls during 2020 and 2021

	2020		**2021**	
	N (Pellets)	**N (Semice)**	**N (Pellets)**	**N (Semice)**
Apodemus sylvaticus	37	17	9	0
Myodes glareolus	21	20	13	18
Microtus arvalis	32	0	7	0
Microtus agrestis	38	0	9	0
Arvicola sapidus	1	0	2	0
Sorex araneus	1	1	0	0
Sorex coronatus	6	0	6	0
Crocidura russula	4	0	0	0
Eliomys quercinus	0	0	1	0

The results of the monitoring of micromammals over time (Fig. 5) show that the species most frequently captured is the wood mouse (*Apodemus sylvaticus*), which belongs to the Muridae family. It represents 48.52% of total captures. It is followed by the bank vole (*Myodes glareolus*), with 39.05%. The only two species of the soricidae family captured during the monitoring campaigns have been the common shrew (*Sorex araneus*), with 12,33% of the total abundance, and pygmy shrew (*Sorex minutus*) with 1%. Of the latter species, only one individual is known to have been captured in 2022, and it does not appear in the pellet samples of any year.

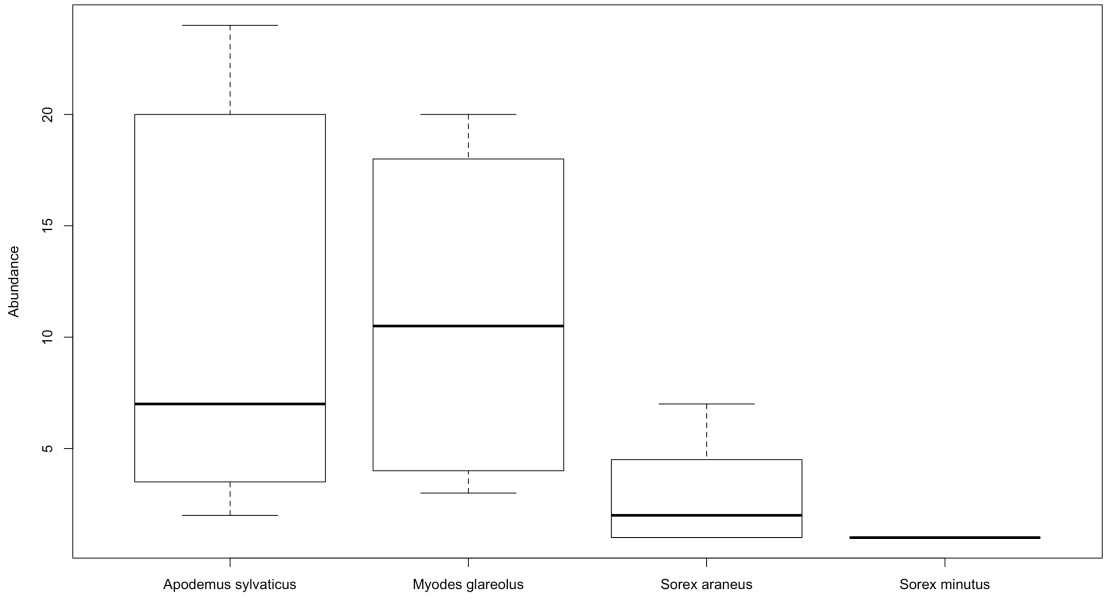

Fig. 5: Proportions of small-mammal abundances in the field in 3 stations (Pla de l'Orri, Lo Calbo and Cireres) within the boundaries of l'alt pirineu natural park from 2011 to 2022.

Finally, the relationships between the abundances of almost all the species in the diet of the boreal owl are studied. A Spearman correlation matrix is performed Table 3. Neither *Crocidura russula* nor *Eliomys quercinus* are analyzed since they are only present in two different years and are not considered sufficient data to be able to compare the relationships with the other species. In addition, the two species of microtids (*Microtus arvalis* and *Microtus agrestis*) are analyzed together as they have quite similar abundances.

The proportion of wood mice (*Apodemus sylvaticus*) is positively correlated with all species, the only significant relationship is with *Sorex araneus* (r_s= 0.87, p value ≤ 0.05). The species *Myodes glareolus* correlates positively with all species except *Arvicola sapidus* (r_s=-0.10), although it is not significant. The relationship that does come out significant is with both Microtus groups (r_s=0,80, pvalue < 0.05). The Microtus group also correlates positively with all species except *Arvicola sapidus* (rs=-0.10) and the relationship is significant with *Sorex*

araneus (r_s= 0.87, p value ≤ 0.05*)*. The species *Sorex araneus* is negatively related to *Arvicola sapidus* and *Sorex coronatus*.

Table 3: Spearman rank correlations (r_s) and p values (P) between the abundance of the species in 2016-2021

	Myodes glareolus		Microtus spp		*Arvicola sapidus*		*Sorex araneus*		*Sorex coronatus*	
	r_s	*P*	r_s	*P*	r_s	*P*	r_s	*P*	r_s	*P*
Apodemus sylvaticus	0,70	0,23	0,70	0,23	0,46	0,43	0,87	**0,05**	0,36	0,55
Myodes glareolus			0,80	**0,02**	-0,10	0,87	0,87	**0,05**	0,82	0,08
Microtus spp					-0,10	0,87	0,87	**0,05**	0,82	0,08
Arvicola sapidus							-0,03	0,97	-0,16	0,80
Sorex araneus									0,55	0,33

Reproductive success of the species

The occupancy rate of the nesting boxes ranges from 10 to 66%, and rarely exceeds 50% (Table 4). These data also show that, although the boxes have eggs, 28.12% of the offspring do not hatch. During the incubation and breeding period, the females are provided with food almost exclusively by the males. If the male is insufficient in his task, the females may even abandon the nest, thus failing their offspring (Zárybnická et al. 2013).

Productivity is calculated by dividing the number of chicks with the number of occupied nest boxes. The highest value is in 2017, when 9 fledged chicks were reached, the highest number in the entire study period.

Table 4: Number of the total nest boxes, number of occupied nest boxes, occupancy rate, number of nest boxes with eggs, number of nest boxes with flying chicks, number of fludged chicks and productivity rate.

Year	Sector	Number of nest boxes	Occupied nest boxes	Occupancy rate	Nest boxes with eggs	Nest boxes with flying chicks	Fledged chicks	Productivity
2012	Lo Calbo	7	3	42,82%	3	1	3	1
2013	Lo Calbo	7	1	14,28%	1	1	2	2
2014	Lo Calbo	10	2	20,00%	2	2	8	4
2015	Lo Calbo	10	2	20,00%	2	2	4	2

2016	Lo Calbo	9	6	66,66%	6	4	9	1,5
2017	Lo Calbo	10	3	30,00%	3	3	9	3
2018	Lo Calbo	10	1	10,00%	1	1	1	1
2019	Lo Calbo	10	5	50,00%	5	4	7	1,4
2020	Lo Calbo	10	4	40,00%	4	3	9	2,25
2021	Lo Calbo	10	3	30,00%	3	2	6	2
2022	Lo Calbo	10	2	20,00%	2	0	0	0

Having explored the diet of the boreal owl, we want to study whether the abundance of a certain family or species is significantly related to the reproductive success of this population. Reproductive success is represented by the number of chicks fledged each year from the 15 nest boxes tested.

To study whether the abundance of a certain family or species is significantly related to the reproductive success of Tengmalm's owl, a linear regression model is done. The reproductive success variable (dependent variable) is represented by the number of chicks fledged each year from the 15 nest boxes tested.

From the models done first by families, no abundance was found to be significant in relation to reproductive success. The relationship with the family gliridae is not studied because there are only 2 individuals in the samples.

However, the individuals of the subfamily arvicolinae are the ones that seem to stand out from the other two families, since they have the lowest p value of all (p value = 0.17) (Fig. 6).

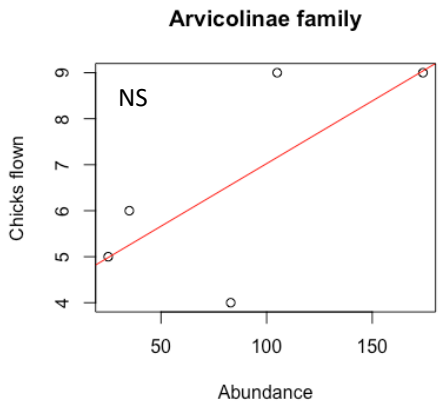

Fig. 6: Relationships between the number of chicks flown and the

abundance of Arvicolinae voles in the diet of the Tengmalm's owl

In relation to the models made with the different species (Fig. 7), there is no species that is significantly related to the reproductive success of the boreal owl. Except for the species *Crocidura russula*, with a p value<0.05, but it may be negligible since we only have 2 years with the presence of this species in the diet. Even so, the species that show more signs of being more related, and, therefore with a lower p-value, are *Sorex coronatus* (p value = 0,11) and *Myodes glareolus* (p value = 0,16).

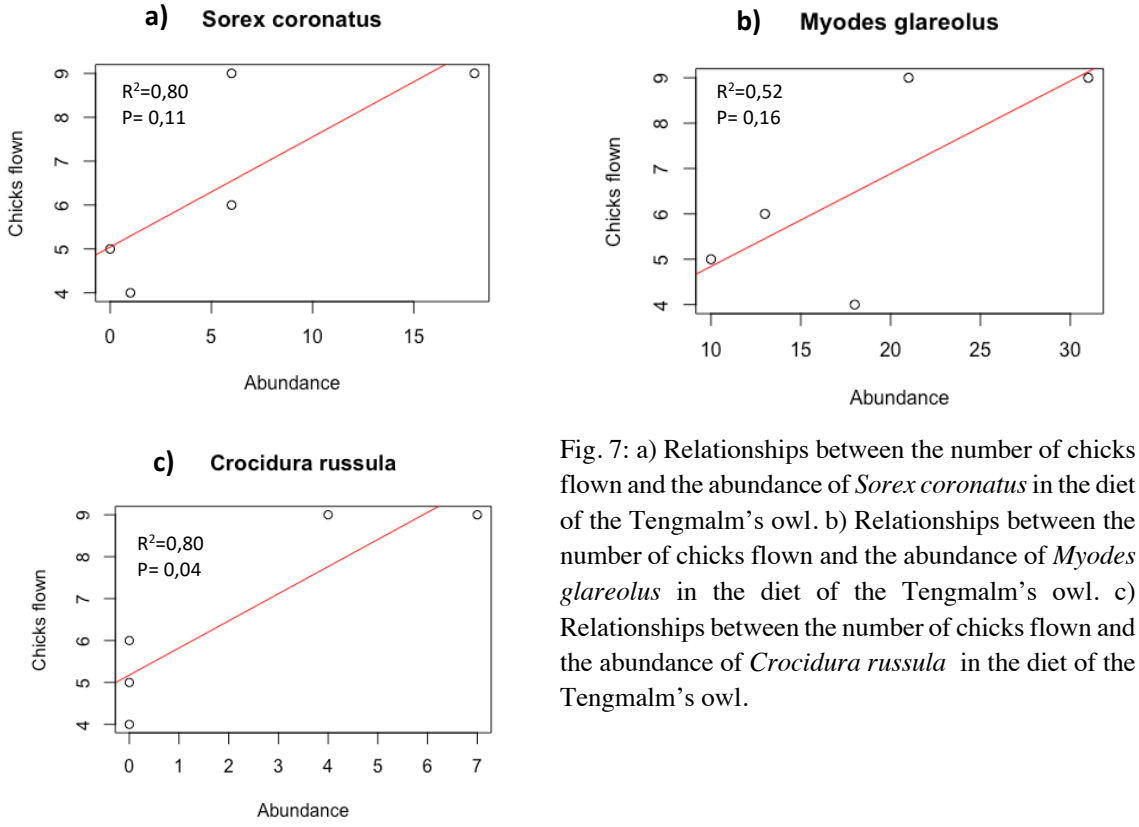

Fig. 7: a) Relationships between the number of chicks flown and the abundance of *Sorex coronatus* in the diet of the Tengmalm's owl. b) Relationships between the number of chicks flown and the abundance of *Myodes glareolus* in the diet of the Tengmalm's owl. c) Relationships between the number of chicks flown and the abundance of *Crocidura russula* in the diet of the Tengmalm's owl.

In addition, to performing regression models to try to study which family or species is related to the variable owlets fledged per year, other variables related to diet are also plotted.

Fig. 8 shows the abundance of individuals in the pellet samples between 2016-2021 and the number of total chicks, the number of chicks fledged, and the number of eggs laid. In general, there is a tendency for these 3 variables to increase as the abundance of prey in the diet increases. That is, in most years when there is a greater abundance of micromammals, there are also more chicks and more eggs laid in the nest boxes.

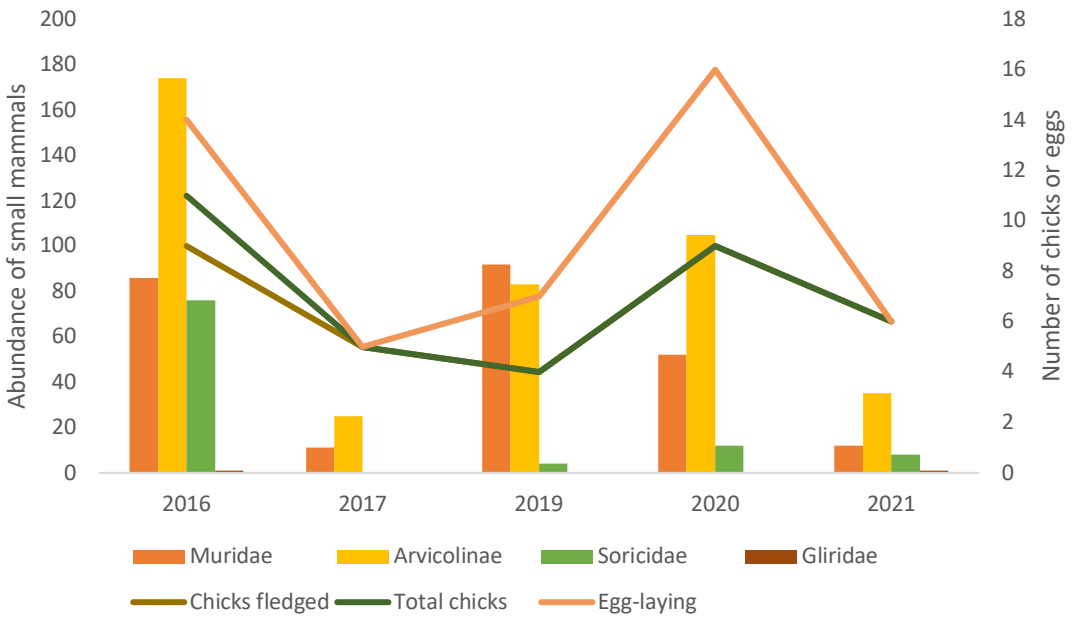

Fig.8: Proportions of small-mammal genera in the diet of the Tengmalm's owl, the number of chicks fledged, the number of total chicks and the number of eggs laying between 2016 and 2021.

Finally, a regression analysis is performed to see if diet diversity is related to the reproductive success of the species. That is why the Shannon index of the nest boxes studied is calculated, also the Shannon index of the years in which we have samples.

This variable per nest box appears to be significant (p value=0.04) for the reproductive success of the boreal owl (Fig. 9). The more diverse the diet of a nest box, the more the reproductive success seems to increase, i.e., the more chicks fledged by the owlet pair inhabiting that nest. On the other hand, the diet diversity calculated by years does not seem to be significantly related to reproductive success (p value = 0,13).

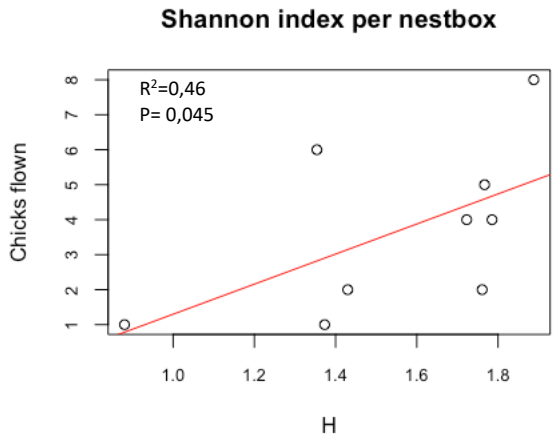

Fig. 9: Relationships between the number of chicks flown and the diet diversity of the diet of the Tengmalm's owl

Discussion

The first general objective related to the expansion of data on the diet of the boreal owl has been achieved. A total of 15 samples of pellets from 9 different nest boxes located in the Lo Calbo forest have been analyzed. It was concluded that the species feeds mainly on micromammals and occasionally on birds. The only 2 identifiable passerines in the diet are an individual of the genus *Turdus* and an individual of the genus *Certhia*. The rest are considered unidentifiable and are a total of 4 individuals.

The 3 families that support the diet of the boreal owl are the family Muridae, the subfamily Arvicolinae (which is grouped within the family Cricetidae) and the family Soriidae. Occasionally, they also feed on individuals of the family Gliridae. Specifically, in our samples there are 2 specimens of dormice (*Eliomys quercinus*). The pellet samples collected between 2016 and 2021 have resulted with a total of 777 individuals and 9 identified species of micromammals. 32.54% of the prey were classified as murids, 54.31% as Arvicolinids and 12.87% as Soricids. To study the specific diversity of the nest boxes, the mean Shannon's index (S = 4.17) is calculated. This value suggests that the community studied is diverse in terms of species and that there is no dominant species that strongly predominates over the others.

In trying to explain this abundance, we consider whether it could be related to the climatology of each year. The mean annual temperature and precipitation from 2016 to 2021, coinciding with the years that we fear abundance of micromammals in the diet of the boreal owl, are consulted. As can be seen in the results, both correlations with abundance are negative, which tells us that they would be inversely proportional. The correlation coefficient between temperature and abundance is very close to 0. This means that there would be a weak or null correlation between the two variables. Both the results of the two simple regression analyses and the multiple regression analysis are non-significant. This may be because it is a short period of time and is not representative. Since, on the contrary, it is known that species such as the bank vole is associated with high mountain humid forest environments (Torre & Arrizabalaga 2008; Torre et al. 2011). Besides, the number of pellet samples are not the same each year. This can also lead to erroneous results. However, this is a fact that cannot be changed since the number of pairs will vary each year, and with it the number of diet samples.

The objective of treating the data from the micromammal monitoring campaign initially, is to be able to make a comparison of the mean annual abundance of micromammals in the diet of the boreal owl and the mean annual abundance of micromammals in the field. Also, to try

to see if the abundance of these populations follows any temporal pattern. Although, it was not possible to obtain any conclusive data since there were only 2 years in which the diet collected and the results of the Semice captures coincided. In addition to the few results, another adversity that we encounter when analyzing the Semice data is that there is no continuity in the sampling. There are years when both campaigns are carried out (autumn and summer), there are years when only one is done and there are years when it is not done. This also makes it difficult to treat these data because they do not have the same effort and there is a big difference between one year and another. Nevertheless, looking at Table 2 we see that with some species the abundance in the monitoring catches coincides with those of the diet of the boreal owl. In 2020, 21 individuals of *Myodes glareolus* are analyzed in the pellets collected and it is also the species most captured in the Semice campaign of that same year. The same happens for this species in 2021. In 2020, the high abundance of *Apodemus sylvaticus* individuals in the pellet samples coincides quite well with the Semice catches. If the campaign continues to run for a few more years, it is possible that more accurate comparisons can be made between the abundance of micromammals in the field and in the diet of the Tengmalm's owl. Especially to study if the proportion of *Apodemus sylvaticus* and *Myodes glareolus* is correlated with their proportion in the diet of the boreal owl.

To try to understand how small mammal species are related to each other, a Spearman correlation analysis is plotted (Table 3). The relationship that can be considered significant is that of the species *Myodes glareolus* with the individuals of microtus spp. This analysis should be read understanding that there are few samples and that it may not be conclusive.

The other general objective of the study is to analyze the reproductive success of this species and to find out if it can be related to dietary specificities. The monitoring of this species in the Alt Pirineu Natural Park began in 2011, but it was not until 2012 that the first nest boxes were placed, and data collection could begin. Although only pellets have been available since 2016 to analyze the diet, as shown in Table 4, the evolution of the breeding density of the population has been noted.

Reproductive success is represented by the number of chicks fledged from each box during the period between 2016 and 2021. In total, there were 33 chicks. In 2016 we counted 9 chicks, in 2017 5, in 2019 4, in 2020 9 and finally in 2021 6 chicks fledged. Other variables such as total clutch or total number of chicks in each year are also known, although we work with the variable chicks fledged.

A series of linear regression models are performed to study the correlation between the abundance of micromammals and the reproductive success of the boreal owl. The objective is to find a significant relationship between the variable fledged chicks (dependent variable) and the abundance of a particular family or species.

According to previously cited studies such as that of Korpimäki et al. (2012) in boreal coniferous forests in Finland, the most important prey group for the boreal owl are voles. Specifically, they select voles of the genus *Microtus* and *Myode*s first, in order of preference. This is because individuals of Microtus are twice as heavy as individuals of *Myodes*, and up to 4 times heavier than individuals of the family Soricidae (Korpimäki 1981). In our study, we see a preference in their diet for prey of the subfamily Arvicolinae, we do not see that they select Microtus individuals earlier. This may be due to only having abundance data from 5 different years.

This is a common occurrence in other Central European raptor species (Kostrzewa and Kostrzewa 1991). The explanation that can be given is that reproductive success may be linked to other unstudied variables such as weather conditions or predation by other carnivores such as pine marten (*Martes martes*) (Zárybnická, M et al. 2013).

Conclusions

Expanding the information on the boreal owl population of the Alt Pirineu Natural Park is an arduous task due to the elusiveness of this species to study. Even so, a great task has been done by carrying out the monitoring of the nest boxes during all these years. Being such a complicated species, any data obtained is most valuable. With the present study, we hope to have been able to contribute a little more to the knowledge of the biology of these individuals. Fortunately, with the effort of a few more years, the results of the analyses will surely be more conclusive.

The conservation of this species in the Alt Pirineu Natural Park is of vital importance because it is a small and little studied population. The knowledge of this species in the Palaearctic areas is widely described, but in the Catalan Pyrenees there are hardly any data. A possible conservation measure would be to adapt the forest management of the area, considering the vital relationship that a correct use of the forest has with the abundance of micromammals, among many other species.

The great limitation of this study has been, as has been described on several occasions, the scarce data available and the short period of time that the species has been monitored. Even so, the rigorous work that has been done by the naturalist association La Paniquella and the headquarters of the Alt Pirineu Natural Park during all these years is valued. And, although not many conclusions have been reached, the information on this population has been expanded a little more and the general objectives of the study have been fulfilled.

Abstract

Through the analysis of data from the Tengmalm's Owl population that inhabits the forest of the Alt Pirineu Natural Park, its diet is studied through the skulls of its prey. The main objective is to expand the scarce information on the biology of this species, resident in the area. The data set is collected from 2016 to 2021. Using the pellet samples available, it is investigated how the abundance of main prey affects the reproductive success and feeding ecology of the species.

According to the optimal diet model, under conditions of prey abundance the species in question will select the most profitable items. Thus, the diet composition of the boreal owl will depend on the availability of its main prey items. The abundance of micromammals in the study area is then studied using data from the micromammal monitoring campaign in Catalonia (SEMICE).
The main prey of the Tengmalm's Owl in the Alt Pirineu Natural Park are individuals of the family Muridae (*Apodemus sylvaticus*), individuals of the subfamily Arvicolinae (*Microtus agresits, Microtus arvalis, Myodes glareolus* and *Arvicola sapidus*) and individuals of the family Soricidae (*Sorex araneus, Sorex coronatus* and *Crocidura russula*).

Through the analysis of the diet samples, it was found that the most abundant predatory species was wood mouse, followed by field vole and bank vole. The year with the highest abundance of small mammals was 2016 and the year with the lowest abundance was 2017.
Data from the small mammal monitoring campaign (Semice) in the area are also analyzed to try to see if the proportions of small mammals in the field match the proportions in the diet samples. However, only the abundances from two different years coincide, so the results are not conclusive.

Finally, the reproductive success of the species is studied in relation to the abundance of its diet. Linear regression models are plotted with the diet abundances and related to the chicks fledged in each year. The species found to be significant is the greater white-toothed shrew (Crocidura russula. Although if more data were available, the species Sorex coronatus and Myodes glareolus also appear to be significant in relation to this dependent variable.

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