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TESI DI LAUREA

Factors affecting differences in the diet of pygmy owl *Glaucidium passerinum* during the breeding period in the Aosta Valley (western Italian Alps).

Fattori influenzanti le differenze nella dieta della civetta nana Glaucidium passerinum durante il periodo riproduttivo in Valle d'Aosta (Alpi italiane occidentali).

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1. INTRODUCTION AND AIM OF THE THESIS

The Eurasian pygmy owl, *Glaucidium passerinum*, is the smallest owl in Europe, but it is also one of the most ruthless avian predators of our mountain forests (Fig. 1 and 2). Indeed, despite its small size, it usually hunts prey that are quite big if compared with its size (e.g., a bank vole *Myodes glareolus* weights 1/3 of pygmy owl on average, data from Enciclopedy of Life), while larger owls like tawny owl *Strix aluco* hunt prey that usually are from 1/10 to 1/40 of its weight (Zalewski 1994; Capizzi 2000). Moreover, in pygmy owl prey remains it is not rare to find species larger than the owl itself. Another peculiar feature is its activity peak, as this species is active during the day rather than during the night. The pygmy owl is a cavity dwelling species, requiring the presence of natural tree cavities, like woodpecker excavated cavities, for nesting, feeding and food-hoarding. In the Alps, the pygmy owl can be considered a glacial relict and it can be found in the forests above 1000m of altitude (usually above 1700m), up to the treeline (Cramp 1985). In Italian western Alps, the pygmy owl populations are increasing, after a strong decrement during the XX century, as a consequence of the use and exploitation of forests (Brichetti 1987; Bocca & Maffei 1997; Maffei *et al.* 2018).
In my thesis, I had the opportunity to study this bird of prey in its habitat, in the lower Aosta Valley. I carried out this research in the Mont Avic Natural Park and some neighbouring areas.
The studies on the ecology and ethology of Eurasian pygmy owl in Mont Avic Natural Park started in 2019, when a long-term research project started in collaboration between the University of Turku (Finland) and the Mont Avic Natural Park. Before 2019, the pygmy owl has been only reported and the population abundance was roughly estimated (Bocca 2002; Beraudo *et al.* 2012). However, a lack of knowledge still exists about the differences between southern and northern populations of this elusive species, despite the habitat and climate differences.
In this thesis, I have described for the first time the diet of this avian predator during and before the breeding season in the Alps. I have therefore surveyed 11 breeding pairs of this species, collecting data about the diet, the breeding success and the nest site characteristics. In addition, I also collected additional data about pygmy owl's food hoards and cavity occupancy by other cavity dwelling species like woodpeckers or tits. I carried out statistical analyses to test possible existing differences in the breeding success related to nest site surrounding habitat or the diet. The main aim of the thesis is to describe the diet of the pygmy owl during the breeding period, and to find out if differences in the diet composition or other factors can influence the breeding success. If our hypothesis is correct, we expect to observe variations in the breeding success changing with the proportion of

micromammal prey. Finally, all the results have been compared with data from studies about northern population.

Figure 1 and 2: pygmy owl females, photographed in Mont Avic Natural Park during the breeding period.

2. THE EURASIAN PYGMY OWL

The Eurasian pygmy owl *G. passerinum* is the smallest owl species in Europe. It is widely distributed in the Eurasian boreal forest, from the Scandinavian peninsula to eastern Asia, and its range approximately overlaps to the taiga zone and the geographic range of *Picea abies*. In Europe, the pygmy owl's distribution range is fragmented, and species is found in the humid and continental temperate regions and in the main mountainous systems of southern Europe (Fig. 4) (Cramp 1985; Peel *et al.* 2007). It is an obligate secondary cavity nester, breeding in medium-sized cavities, mainly excavated by the great spotted *Dendrocopos major* and the three-toed woodpecker *Picoides tridactylus*. Unlike most of the typical owl species, the pygmy owl is mainly a diurnal and crepuscular species, with the main activity peaks from dawn till dusk (Kullberg 1995; Baroni *et al.* 2021).

2.1 **Morphology**

Pygmy owl's body sizes slightly exceed the ones of a starling, *Sturnus vulgaris*, but hardly bulkier: its length from the tip of the tail to the apex of the beak is around 15-19 cm, while its wingspan is from 32cm to 39 cm (Svensson 2017). It's a sexually size dimorphic species, with females slightly larger and heavier than males (Lewis 2020). The appearance is typical of Strigidae, in proportions very similar to the little owl *Athene noctua* (Fig. 1 and 2) The head is tiny compared to other owls, hemispherical, and slightly flatted. The facial disc is dark and not distinct, whereas almost white eyebrows are evident (Svensson 2017). Eyes are small with a yellow iris, encircled by dark and linear concentrical drawings. The bill is pale yellow, noticeably long compared to other owls and surrounded by poorly discernible whiskers. On the low nape is visible a dark drawing with pale rims that outline a false face composed by two ocelli, also called "eyespot" or "occipital face" (Negro *et al.* 2007; Lewis 2020). There are two hypotheses about the functions of this ocelli (Negro *et al.* 2007). The first one is to protect the owl while roosting or hunting from predators and mobbers, making it seem more vigilant (Cott 1940; Hafner & Hafner 1977). Indeed, when birds mob a predator, they can attack it, especially from the back, even injuring or killing it (Flasskamp 1994; Deppe *et al.* 2003). The eyespot seems to be particularly effective against them, preventing attacks or reducing their intensity. The second function would be an aid to predation, stirring mobbers, that are often prey, and making them more exposed (Hinde 1954a, 1954b). Nevertheless, this second hypothesis proposed by Hinde has not been verified yet and seems to be not relevant. The plumage is greyish brown on the head, back and wings, with white spots, particularly small and dense on the head. It recalls the darker races of *A. noctua* but differs in barred chest-sides in the adults.

The belly is white, longitudinally and irregularly streaked and shows a uniform greyish-brown “bib” under the neck. The tail is relatively longer than that of a little owl, with horizontal buff-white bars. Until the post-juvenile mute, the juvenile plumage is very different from the adult one. It’s more homogeneous, chocolate brown on the upperpart, indistinctly spotted on the forecrown, with unbarred patches on chest-sides and thinner streaks on underparts (Cramp 1985).

Tarsi and the base of the yellowish toes are feathered, coloured white to brownish-white. The foot is typical of an owl, with four short and strong talons that evolved to grapple and kill prey by asphyxiation. Indeed, although the black claws are very sharp, evidence suggest that they are mainly used to clench the body of the prey to not let it escape. At the same time the tight and muscular grip suffocate the prey, also performing a “twist” at the base of its neck (Csermely & Rossi 2006; Fowler *et al.* 2009; Lewis 2020, n.d.).

2.2 **Habitat and distribution**

The pygmy owl is a forest specialist, inhabiting forest habitats during both breeding and non-breeding periods (Strøm & Sonerud 2001; Baroni *et al.* 2021). In the Alps it can be found above 1000 m, up to 2150 m, which is the highest breeding site found in Valais, Switzerland (Cramp 1985). It prefers mature forests, dominated by coniferous trees, especially *P. abies*, but also mixed with broad-leaved trees like *Fagus sp.*, *Populus tremula* and *Betula sp.*(Strøm & Sonerud 2001). However, evidence suggests that habitat requirements of pygmy owls vary between the cavities used by this species for food hoarding and during the breeding season. In particular, cavities used for roosting and food hoarding are more likely to be surrounded by a lower proportion of forest in the surroundings, with access to clearings, moors, meadows, avalanche pathways and water (Cramp 1985; Baroni *et al.* 2021). In this case, they can also be close to agricultural areas and houses. Nesting sites, instead, are usually in denser forests with a higher biomass of trees, but also with a higher proportion of clear-cut areas and young stands, and a higher percentage of canopy cover. Moreover, two others mutual and non-exclusive factor concur in the habitat choice: the distribution and density of prey and the risk of predation (Baroni *et al.* 2021).

2.3 **Yearly life cycle**

Most of the years, Eurasian pygmy owl is a resident species (Cramp 1985), but during some years large number of individuals migrate. In general, the cause is assumed to be high population densities (e.g. due to a good breeding success), or the lack of food. Moreover, young and female individuals are more prone to migrate

Figure 3: pygmy owl adult facing on the entrance of its nest cavity. Photographed by Sofia Koliopoulos in Finland.

Figure 4: Distribution range of G. passerinum in Europe. Image from www.iucnredlist.org (visited 7/11/2022)

during those events, while adult males tend to be tied to their territories (Lehikoinen *et al.* 2011). Anyway, during normal conditions, the species shows a marked territorialism and a monogamous mating system that lasts for one season or more. Males defend their territories, also called "home ranges", for the whole year, in case helped by females, and all hunting, feeding and breeding activities take place within the territory. In southern Europe, territories have an average extension of 1,4 km^2 (range 0,45-1,9 km^2), while in northern Europe are larger, with 2.4 km^2 on average (range 0,5-6 ,2 km^2) (Cramp 1985, Baroni 2021).

2.4 **Behaviour**

This species is mainly living in the canopy, rarely seen on ground. Its flight is erratic and active, dashing with fast wing beats and sudden turns. Over long distances it noticeably bounds, similarly to woodpeckers *Dendrocopos*, flying at ground level. It often perches on top of the trees, waving tail (like flycatcher *Ficedula*) and flicking it upwards (like Eurasian wren *Troglodytes troglodytes*) (Cramp 1985).
This species is a hole-nesting bird, but not being able to excavate cavities, as it is an obligated secondary cavity nester, using holes built by medium-size woodpeckers, like the great spotted woodpecker, *D. major*, or the three-toed woodpecker, *P. tridactylus* (Baroni *et al.* 2020, 2021). Only *D. major* is present in the study areas (Bocca 2002). The owl makes use of tree cavities both for nesting and for food hoarding (Fig. 3 and 5). Anyway, there is evidence that holes excavated by larger woodpeckers (e.g. the black woodpecker *Drycopus martius*) are used as feeding sites too (unpublished data).
Hunting mainly occurs during the day, with a peak of this activity at dawn and at dusk. On the other hand, foraging behaviour doesn't occur at night. Its hunting habits seem to be different if its prey is a bird or a mammal. When hunting birds, it locates flocks of birds by their contact calls, then moves closer and roams along the fringe of the bird flock until an opportunity to attack from ambush appears. When hunting mammals, the owl acts as sit-and-wait predators, staying perched quite close to the ground for long periods before attacking, dropping or gliding on the prey, or moving on (Kullberg 1995). Apparently, the pygmy owl relies on surprise and does not pursue the prey if first attack is unsuccessful (Cramp 1985).
During winter, the pygmy owl is not able to hunt his mammalian prey because they are often hidden by a snow layer, and therefore it hoards small mammals and birds in the cavities during late autumn (Baroni *et al.* 2021). Data from unpublished work by Baroni *et al.* suggest that this threat is less relevant for the southern European populations, where food hoarding behaviour is less common than in the boreal forest.

Figure 5: graphic representation of a pygmy owl inside a cavity used as nest site. It is possible to see the "pillow" of prey remains on the bottom of the cavity.

2.5 **Trophic relationships**

Pygmy owl is a very aggressive predator. It's a non-specialist predator, and its prey usually are small mammals, especially voles, and small passerines, but it is not unusual to find remains of prey larger than itself, such as Turdidae or Picidae (Cramp 1985; Lewis 2020).

The following mammalian prey have been most commonly recorded in western Paleartic: shrews (*Sorex minutus*, *S. araneus*, *S. caecutiens*, *S. minutissimus*, *S. alpinus*, *Neomys fodiens*), voles (*M. glareolus*, *Arvicola terrestris*, *Pitymys subterraneus*, *Microtus multiplex*, *M. arvalis*, *M. agrestis*, *M. oeconomus*, *Chionomys nivalis*) and mices (*Apodemus agrarius*, *A. flavicollis*, *A. sylvaticus*, *Mycromys minutus*). Moreover, it's possible to find traces of predation of bat, larger rodents like rats (e.g. *Rattus norvegicus*) and dormice (e.g. *Elyomis quercinus*), and even weasels *Mustela nivalis*. Regarding passerines, it hunts all small birds up to the size of finches (Fringillidae); the most common are finches, tits (Paridae), and warblers (Sylviidae, Phylloscopidae). However, larger avian prey such as small species of Turdidae and woodpeckers are not atypical (e.g. *Turdus phylomelos*, *T. vicivorus*, *D. major*, *Jynx torquilla*) (Kellomäki 1977; Schönn 1978; Cramp 1985; Lewis 2020). One case of cronism has also been described in one couple (Klaus *et al.* 1982; Pačenovský & Šotnár 2010). In the Alps, the diet of the pygmy owl has never been thoroughly studied. The only other complete survey of prey remains from pygmy owl nest in Italian Alps was recorded by Bonvicini and Della Ferrara (1991). The sampled material was from a single nest, found in the Bergamasque Alps.

This species is able to lower the predation risk thanks to behavioural adaptions. First of all, its mostly diurnal behaviour and nesting habits allow the pygmy owl to avoid larger owls (Sonerud 1985). Furthermore, some studies suggest that it chooses deeper cavities for nesting as an adaptation to decrease the predation risk (Wiesner & Rudat 1986; Baroni *et al.* 2020, 2021). Most of its habitat overlap to the habitat of the Tengmalm's owl *Aegolius funereus* (Suhonen *et al.* 2007): an interesting proof of predation event by this species is seen on the cover of "The Boreal owl. Ecology, Behaviour, and Conservation of Forest Dwelling Predator"(Korpimäki & Hakkarainen 2012), where a Tengmalm's owl keeps in its claws a dead pygmy owl. Interestingly, the pygmy owl doesn't avoid the neighbourhood of intraguild species nests in the choice of the nest cavity (Pačenovský & Šotnár 2010; Morosinotto *et al.* 2017). Only weasel and stoats are potentially able to predate nests of the pygmy owl, indeed they manage to enter inside the narrow entrance of cavities because of their size, but these mustelids are mainly living in open habitats and they are not so common in the dense forests where the pygmy owls are breeding (Baroni *et al.* 2021).

Predation from Sparrowhawks *Accipiter nisus* and Goshawks *Accipiter gentilis* is likely the biggest threat for the pygmy owls. Indeed, *G. passerinum* is a highly suitable prey for these two Accipitridaes due to its size. Moreover, because of the almost complete overlap of the diets of pygmy owl and the other two predators, they may compete for food. Anyway, there are evidence that highlight the preference of pygmy owl for mature forests: this minimises the competition with sparrowhawk and goshawk, both preferring middle-aged forests (Strøm & Sonerud 2001).
Eventually, another type of competition subsists in the cavity choice for nest. The other cavity-dwelling species like *D. major*, *Sitta europaea* and *S. vulgaris* may compete in the use of cavities, in some cases preventing nesting by the pygmy owl (Pačenovský & Šotnár 2010).

2.6 **Breeding biology**

During the breeding season, nest showing is performed by males, beginning 2 months before egg laying, and the females select the nest site. The chosen hole has an average height of 3m (from 1m to 8m). Before laying eggs, the female cleans the bottom of the cavity and builds the nest with feathers and fur of her prey (Baroni *et al.* 2020). Eggs laying begins in mid April at the earliest and the incubation period lasts from 28 to 30 days. The eggs are laid asynchronously and begin to hatch in the first days of June (Fig. 6). The female broods eggs and nestlings for the entire period, while hunt is done almost exclusively by male. He often hoards them in a temporaneous cavity until dusk, when brings them to his female. He gives the prey to the female on a branch 10-30 m away from the nest, in a "sojourning sector". When nestlings hatch, the female cleans the cavity, carrying out food remains and the nest bottom made of prey remains, dropping it at the foot of the nest tree. The chicks fledge after 28-34 days and become independent 4 weeks later, living in the vicinity of the nest in the following weeks. The breeding success is quite variable depending on the area, but in southern Europe is around 3 fledged chicks per nest (Kellomäki 1977).

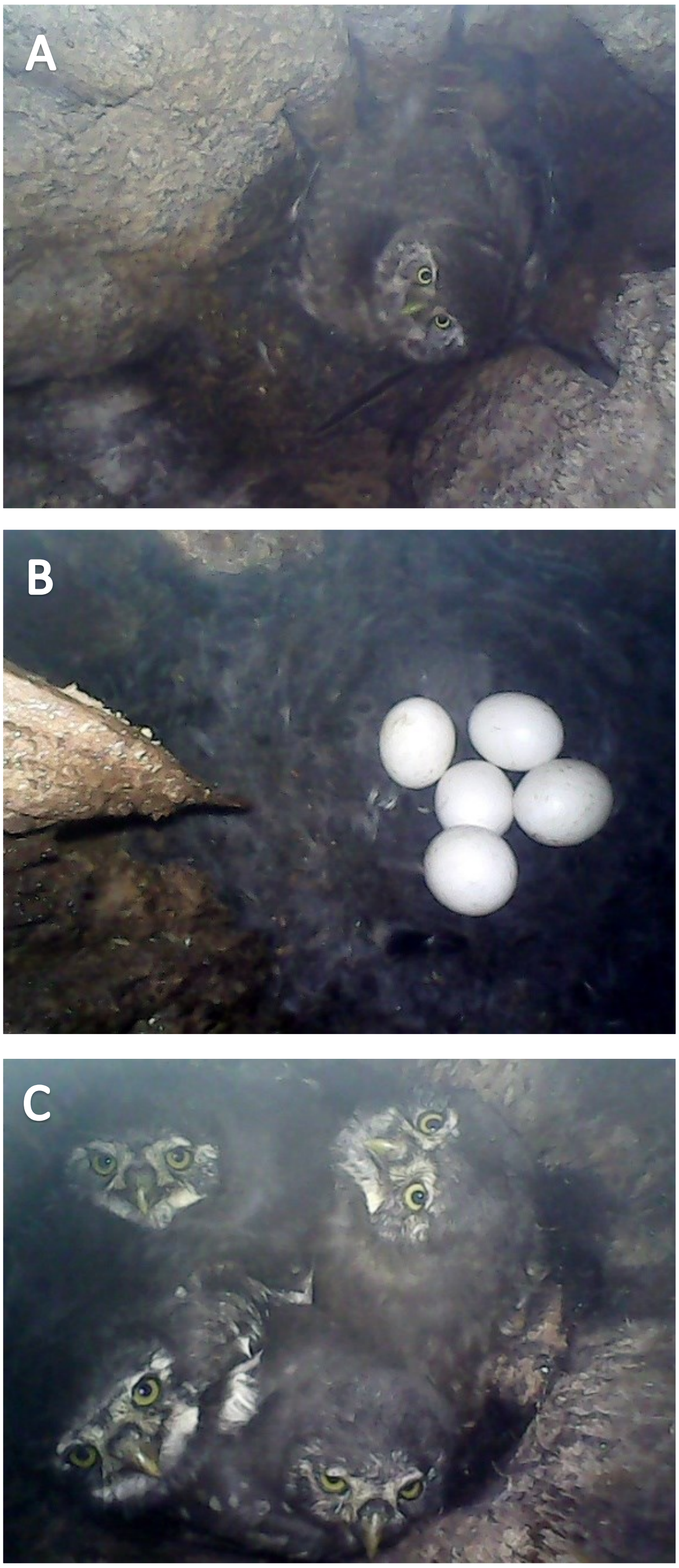

Figure 6: the inner chamber of a pygmy owl nest during different stages of the breeding period; all the pictures are taken in the Mont Avic Natural Park. A) female pygmy owl hatching inside its nest cavity, Nest11; B) pygmy owl eggs laid on the prey remain nest, Nest10; C) pygmy owl chicks, almost ready to fledge, Nest01.

3. STUDY AREA

The study area is located in the lower Aosta Valley, in the western Italian Alps, divided between the Graie and Pennine Alps (Fig. 7). The surveyed area rises from 1500m a.s.l,, to 2090m a.s.l., where has been found the highest number of cavities checked. The area has been chosen according first to the presence of the pygmy owl itself, and second to the presence of woodpecker-excavated cavities suitable for the owl.

The study area can be divided in smaller sub-sections: the Mont Avic Natural Park (Chalamy Valley) and its surroundings (Clavalitè Valley and Champorcher Valley) and left and right orographic sides of the Aosta Valley (Bellecombe and Tete de Comagne). Moreover, to cover most of the pygmy owl distribution range in the Aosta Valley, an additional territory at Aymavilles has been added.

The study sites are mainly covered by coniferous forests, with only a small proportion of open habitats or mixed forests. The Mont Avic Natural Park and its surroundings are characterized by dominant mountain pine *Pinus uncinata* forests (see also *Pinus mugo* subsp. *uncinata*), the Aymavilles site shows a vast coverage of spruce *P. abies*, while in the Aosta Valley the habitat composition is more various, with mixed forests of spruce *P. abies* and larch *Larix decidua* trees (Fig. 8). The sunlight exposure of study sites has also been evaluated during this work: Clavalitè, half of Chalamy Valley and Tete de Comagne are south-oriented, while Bellecombe, Champorcher, the other half of Chalamy Valley and Aymavilles are north-oriented.

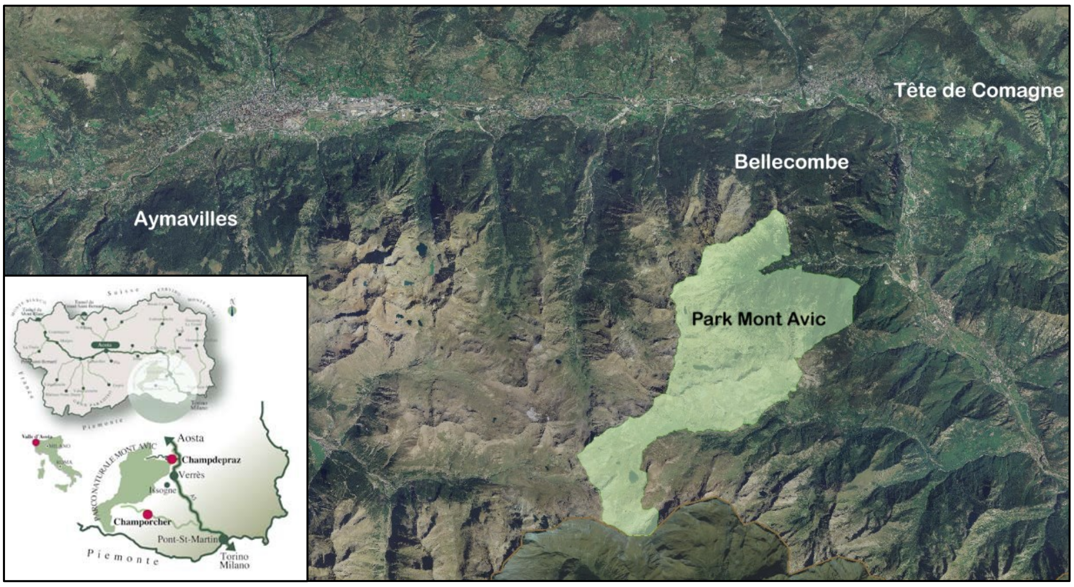

Figure 7: map of the study area and location of Mont Avic Natural Park. Park map and satellite imagery taken from park official web site (www.montavic.it) and from Aosta Valley Geoportal (geoportale.regione.vda.it), modified.

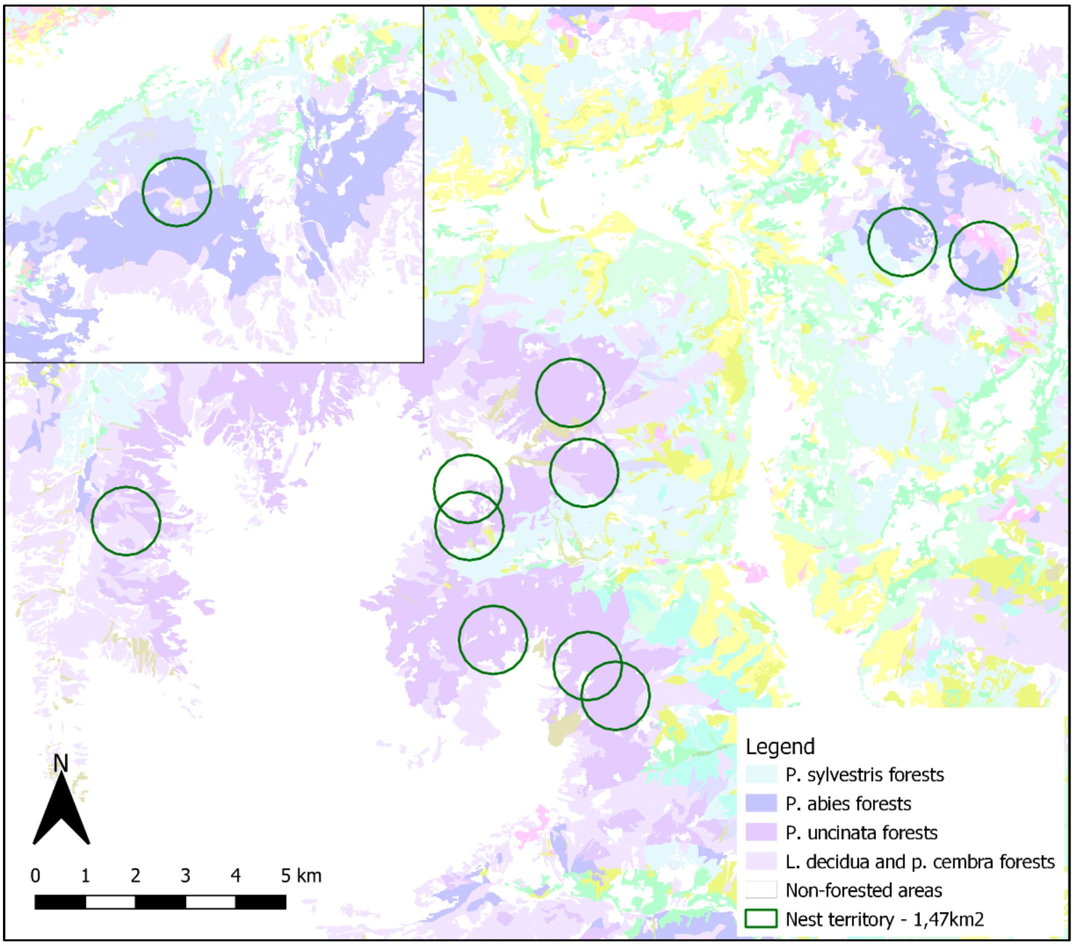

Figure 8: Forest type map and the 11 study sites in the Aosta Valley. The green circles delimit the territory surrounding each nest.

4. MATERIAL AND METHODS

4.1 **Data collection**

More than 1300 cavities, both suitable and unsuitable for pygmy owl, have been previously georeferenced. Unsuitable ones have been excluded as they are not real cavities, but simply small platforms that are not deep enough to be considered potential nesting sites. Most of them are tree-holes excavated by great spotted woodpeckers *D. major*, with only few cavities excavated by black woodpeckers *D. martius* and a few excavated by green woodpeckers *Picus viridis*. Moreover, some of the non-suitable ones are natural cracks on trees. All suitable cavities have been inspected at least twice between September to August to survey the occupancy and possible activities of pygmy owls. The presence of other cavity-dwelling species has been also recorded. During autumn and winter, the main signs of pygmy owl cavity use are food hoards and feeding sites, while from the middle of April, nest sites were searched. It has been possible to recognize feeding sites thanks to the relatively big amounts of feathers or fur and sometimes pellets inside a cavity. Often the cavities assigned at this use are food holes of woodpeckers. The food hoards were recognizable thanks to the presence of whole dead micromammals and birds on the bottom of a fully built cavity. Lastly, if the adults were not nearby, nests have been identified by the presence of a "pillow" of fur and feathers from prey on the bottom of the cavity.
Thanks to a small camera mounted on a telescopic pole, it has been possible to look inside the holes and to take pictures and videos of the content (Fig. 9).
In this study, I collected the prey remains from 11 nest sites to identify the species. Remains found in food hoard were not sampled, due to the difficulty to reach the cavities, but only analysed through images from the camera if possible.

4.2 **Prey identification**

After each nest inspections, the prey remains gathered were dried if necessary, and cleaned from pieces of moss, leaves and bark (Fig. 10). After that, fur, bone, body pieces and feathers were divided to better analyse them following the method described by Kellomäki (1977). Each sample that was possible to relate to an individual has been put in a tube and numbered with the code of the nest site, the date of collection (day, month, year) and a progressive numeration (e.g. NC0630_27052021_01).

Figure 9: example of tree cavities built by great spotted woodpecker. At the base of the tree is visible the video camera used to film inside the cavities muonted on the telescopic pole.

Figure 10: prey remains from Nest05, collected in July 2021. It is visible is composition of fur, feathers and moss

4.2.1 Birds

Birds were mainly identified using their feathers (Kellomäki 1977). The remains were examined by comparing them with photo and descriptions from books and online collections (Fraigneau 2021; Guia Blasco Zumeta de Aves; Featherbase - Haase *et al.*). Sometimes, remains of species from the family Paridae and from the genus *Emberiza*, *Phylloscopus*, *Regulus,* and *Turdus* were impossible to be certainly distinguished. In addition, all the non-recognizable feathers have been divided by their sizes, patterns, and colours, and treated as Passeriformes sp.. Bird bones have not been used to determine the species, due to their fragmentation and difficulty to discriminate from mammal bones, except in two cases.

4.2.2 Mammals

The number and species of mammals contained in the remains was determined from their bones, especially their jaws, analysing them according to the book "Mammiferi terrestri d'Italia" (Paulucci & Bon 2022). The shape of the molars and the size of the jaws were the main characteristics used to identify the species. Moreover, leg bones like tibia and fibula, tails, or body pieces were also used to determine the number of mammals in each sample. However, this method probably underestimates the real number of preyed mammals: indeed, in some sample, hairs were present but not bones.
To overcome this problem and to assess the amount of small mammals, the weight of fur has been measured, with an accuracy of 0,01 grams.

4.3 Statistical analyses

In this work, all data have been used to find a possible influence on the breeding success of pygmy owl from ecological factors, in particular from its trophic niche.

4.3.1 Diet analysis

The main aim of this thesis is to describe the diet during the breeding period in the different forest habitats of the Alps, and to check if the diet differences may influence the pygmy owl breeding success. To demonstrate the presence of possible correlation, two software for statistical analyses have been used: R, one of the most common programming languages for statistical computing used among biologists, and Past, a simple-to-use software specific for ecological use (Hammer *et al.* 2001; Le Meur & Gentleman 2012).
In this work, the efficacy of the sampling method has been evaluated through a correlation test between the number of remains and the number of sampling visits per site and through generalized linear models (GLMs) (Kellomäki 1977).

Before inserting the data on R and Past, the following variables were used to organize data of each nest: total number of prey, total number of avian prey, total number of mammals prey, weight of fur. Additionally, to better estimate the biomass eaten by the owls, the total weight of the birds preyed per nest has been estimated, using the mean body mass of each species (weight data from Encyclopedia of Life). For unidentified passerines, weight of 20g has been used (mean weight of small passerines) (Kellomäki 1977). Finally, it has been calculated the biodiversity index (Simpson index 1-D) per nest, to find if a more varied diet can influence the breeding success. All the variables are given in Table 1.
A cluster analysis was performed to categorize the nests using variables obtained by collected data. The differences in diet composition of year 2021 and year 2022 were surveyed through boxplots and afterward Wilcoxon tests were run where a difference was noticeable.
To find a possible correlation between breeding success and the other variables, correlation tests were performed. The null hypothesis of these tests has been set as "true correlation is not equal to 0". After those earliest analyses, the collected data were analysed more accurately with GLMs, fitted using maximum likelihood (Laplace approximation) and gaussian likelihood family.
Subsequently, to better highlight potential relations and interaction between variables, the breeding success has been categorised into two classes: 'negative' (or 0) if the number of fledged chicks was minor than 3, 'positive' (or 1) if the number was 4 or more (Fig. 14). The data with this new variable were analysed using GLMs with binomial likelihood family (Zuur *et al.* 2009).

4.3.2 Habitat analysis

Another important factor that can impact on the breeding success is prey availability, both in term of presence, contactability and ease of capture. The prey availability is tightly related to habitat characteristics, such as density of vegetation or forest structure (Thirgood *et al.* 2002, 2003). Therefore, the territories around the nests were examined through QGIS to obtain the forest typologies. This has been done by calculating the percentage of forest cover in an area of $1.42km^2$ around each nest. Data on the forest cover of the region were taken from the Aosta Valley Geoportal. Finally, the results were submitted to cluster analysis with Past and R, to highlight groups of territories with distinct characteristics. The cluster analysis was run using Euclidean distance as similarity index and Ward's method algorithm. Higher rank clusters obtained have been related to breeding success and diet with boxplots.

5. RESULTS

5.1 Cavity survey

In the earliest part of this internship data have been collected about the pygmy owl and its activities, in the form of images, videos, notes, and collection of samples. The result is probably the largest amount of data about diet of this species in Italian Alps, in addition to some important data that are added to others about behaviour in its southern territories.
Before the breeding season (from November to January), the main data collected were about food hoards and feeding sites: 2 food hoards and 10 feeding sites were found (Fig. 11 and 12). Moreover, 2 food hoards and 2 feeding sites have been found during the breeding season. All food hoards contained from 1 to 4 prey.
Throughout this thesis, the main theme is to evaluate if diet and other factors could affect the breeding success, so the major field activity was to obtain data from nests. At the end of April 2022 the search of nest sites started; in the territories treated in this work, 7 nest sites were found, named later as the locality where they were located: 6 nests were located in Mont Avic Park and 1 in the Central Valley, on the right orographic side. In this thesis, all the nests have been renamed in order to not disclose their location and to preserve the nesting territories of this species. The most interesting nest sites for their geographical position were Nest10, with an elevation of 2052m and 765m far from Nest11, and Nest09 and Nest01, 820m far from each other. Moreover, evidence suggested the presence of another nest near Nest09 and Nest01. Indeed, fledged chicks were found near these nests while their hatchlings were not fledged yet.
The breeding success of the treated nests goes to a maximum of 5 chicks fledged from a minimum of 2, with only one nest, Nest07, where the breeding was unsuccessful. Interestingly, this nest was close to a *D. major* nest site. In the categorization of breeding success during the statistical analyses, it results 4 nests as “negative” and 7 nests as “positive”.
In the territories around nests, traces of other cavity dwellings birds have been found: one nest of coal tit *Periparus ater* and one nest of great spotted woodpecker (in the same tree of a food hoard) near Nest07, and one nest of European green woodpecker *P. viridis* close to Nest11. Moreover, one individual of weasel *M. nivalis* was seen in a locality near Nest01 nest during the breeding period, proving the presence of this possible predator of pygmy owl nestlings.
The data from 4 nests from year 2021 have been added to 2022 nest, to make comparison between different years and different habitat.

Figure 11: pygmy owl feeding site found in May 2022. It's possible to identify feathers of different species, like chaffinch, tit and siskin (cavity NC0013, in Val Chalamy)

Figure 12: example of a food hoard. On the bottom of the cavity are recognizable 2 rodents, probably a wood mouse and a vole (cavity NC0099, in Val Chalamy).

Sites	Total birds	Fur weight (g)	Total small mammals	Total prey	Breeding success	Bird weight (g)	Sampling	Diveristy index
NEST01	12	13,06	4	16	4	318,12	2	0,9219
NEST02	11	34,72	7	18	2	166,15	3	0,8765
NEST03	17	2,81	6	23	5	335,84	2	0,862
NEST04	10	7,13	11	21	4	228,15	3	0,8571
NEST05	10	11,84	6	18	4	261,31	2	0,8359
NEST06	50	23,32	11	61	5	1019,89	4	0,8508
NEST07	11	4,05	2	13	0	202,68	2	0,8757
NEST08	8	9,22	2	10	5	124,85	1	0,76
NEST09	14	2,55	4	18	5	378,87	2	0,8457
NEST10	16	12,77	5	22	2	458,78	3	0,8571
NEST11	27	14,8	6	34	2	513,82	3	0,8062

Table 1: variables threated for each nest during the statistical analyses.

5.2 Diet analysis

5.2.1 Diet composition

The diet of pygmy owls studied consists in birds (Aves), mostly of the order Passeriformes, small mammals from the orders Rodentia and Soricomorpha, and a very little percentage of insect Insecta (Tab.2).
Among the bird species that were possible to identify, the most are chaffinch *F. coelebs*, Eurasian wren *T. troglodytes,* and red crossbill *Loxia curvirostra*. Between the birds not identified at the level of species, the genus *Phylloscopus* must be included in the frequent avian prey. Moreover, the species of tits Paridae (great tit *Parus major*, coal tit *P. ater*, willow tit *Poecile montanus*, blue tit *Cyanistes caeruleus* and crested tit *Lophophanes cristatus*), if treated as an unique group, are the prevalent avian prey. Moreover, a lot of birds identified as "Passeriformes sp." are probably tits. The only non-passerine species is the great spotted woodpecker *D. major*, yet quite common in the food remains. Eventually, it was not possible to identify about 40.2% of the bird preyed, due to the bad conditions of the remains or the presence of feathers lacking specific features.
The small mammals were often difficult to count, due to the scarcity of useful rests (e.g. in some samples fur was present but not bones). Additionally, about 40.6% of mammal remains was not identifiable at level of species. Anyway, the most frequent species of mammals found are bank vole *M. glareolus*, followed by snow vole *C. nivalis*. Besides voles, also mice *Apodemus* and shrew *Sorex* occurred in small numbers.
In terms of numbers of individuals, birds are the main group in diet of pygmy owl, representing the 73.5% of total prey. Anyway, both the number of birds and mammals are probably underestimated.
Finally, no significant differences were found from the cluster analysis of nest using diet as categorizing factor (Fig. 16).

5.2.2 Effect of diet on the breeding success

The preliminary analyses to probe the quality of the data were a correlation test and a GLM about the influence of samplings on the total prey sampled. Unluckily a positive and quite significant correlation (p-value 0.003, correlation estimated of 0.7) between the amount prey and the number of sampling visits is present. Further analyses with GLMs shows that the number of samplings effect only the number of prey (especially the number of small mammals), and not influencing significatively other variables like weight of fur and biodiversity index (p-value > 0.05).
About the main aim of this thesis, performed correlation tests do not reveal any possible significant influences of diet on the breeding success, with p-value always greater than 0.4 (Fig. 13). Boxplots and GLMs were useful to better understand the

Table 2: The diet of pygmy owl at the 11 nests surveyed in this work. To these, two feeding sites, NC0240 and NC0784, have been added to integrate the check list of pygmy owl prey in the Alps. They both contain one species because it was the only one identifiable through the photo.

Prey	NEST01	NEST02	NEST03	NEST04	NEST05	NEST06	NEST07	NEST08	NEST09	NEST10	NEST11	NC240*	NC784*
D. major	1		1	1		1			1	1	1		
P. ater	1					2			1		1		
L. cristatus												1	
P. montanus					1								
Poecile sp.						2							
C. caeruleus			1			1	1						
P. major	1					1	1		1				
A. caudatus		1		2		1					1		
Phylloscopus sp.	1	2				4	2				1		
S. atricapilla						1							
R. regulus						1					1		
Regulus sp.			1	1	1	1					1		
T. troglodytes	1	1	2	1	1	1	1	1	1		1		
C. familiaris	1	1	1			1		1			1		
T. philomelos	1					1							
Turdus sp.						1			1				
E. rubecula		1				1			1	1	1		
F. hypoleuca						1							
P. ochruros			1			1				1			
F. coelebs	2	1	1		1	2			1	2	2		
F. montifringilla											1		
P. pyrrhula						1	1	1					
L. curvirostra	1		1	1		1	1		1	2			
C. carduelis													1
C. citrinella					1	1					1		
S. spinus			1					1					
E. cia						1				2	1		
Emberiza sp.							1						
Passeriformes sp.	2	4	7	4	5	22	3	4	6	6	13		
Total birds	9	11	15	9	9	43	9	8	11	14	25	-	-
Sorex sp.			1			1							
S. minutus	1												
M. glareolus	1	2	1	3	3	1			1	3	1		
Microtus subg. Terricola sp.					1	2				1			
C. nivalis	1		1	5									
Apodemus sp.		3		1	1	1							
M. arvalis						1							
Cricetidae sp.									1				
Rodentia sp.	1	2	3	2	1	5	2	2	2	1	5		
Total small mammals	2	5	4	8	2	7	2	2	3	1	5	-	-
Insecta sp.					2					1	1		
Total prey	11	16	19	17	13	50	11	10	14	16	31	-	-
Total fur weight (g)	13,06	34,72	2,81	7,13	11,84	23,32	4,05	9,22	2,55	12,77	14,8	-	-

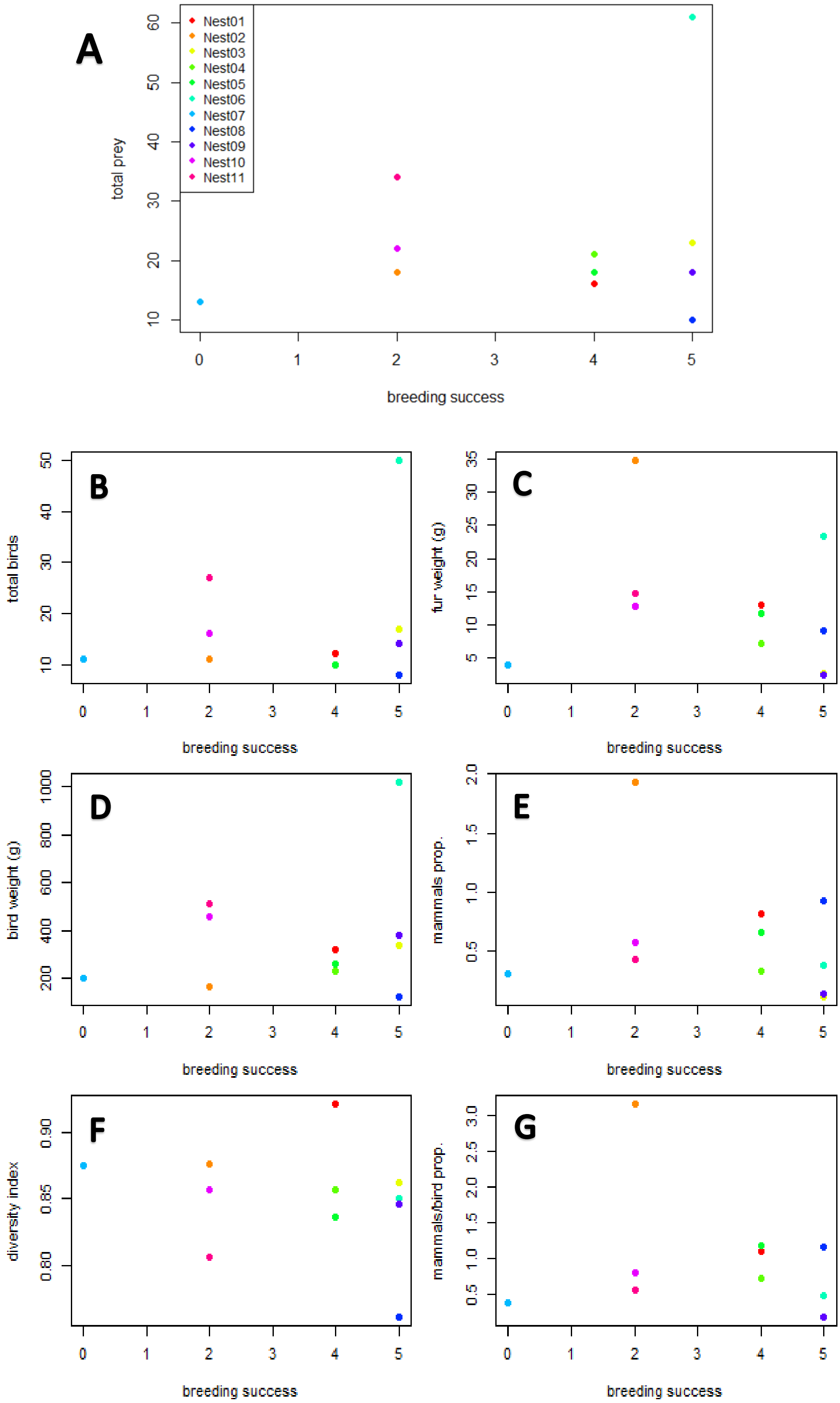

Figure 13: plot of breeding success of each nest with other variables from diet: A) total number of prey, B) total number of avian prey, C) weight of mammal's fur, D) estimated bird weight eaten, E) proportion of mammals prey on the total of prey, F) biodiversity index (Simpson index, 1-D) of prey, G) proportion of mammals prey on total number of avian prey.

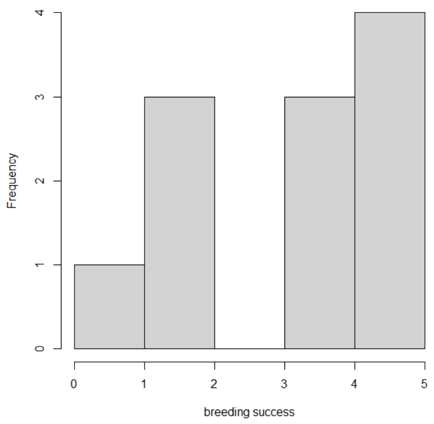

Figure 14: histogram of the breeding success that brought to categorization of breeding success.

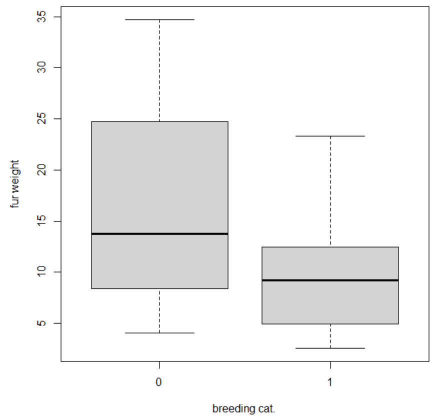

Figure 15: boxplot of the weight of mammal's fur in relation to the two breeding categories (0 for negative, 1 for positive).

Figure 16: cluster analysis of the nest sites using variables from diet as clustering factors.

influence of each variable on breeding success and to probe the presence of interactions among them, but the only variable that resulted as almost significant was the weight of mammal's fur (p-values of 0.06 and 0.04 in two different GLMs). This light relation is also visible in the boxplot of Figure 15.
The same GLMs, with binomial likelihood family and the categorization of breeding success (4 nests "negative" and 7 nests "positive"), returned the same results, without showing effects on reproduction.

5.3 Habitat effects and habitat analyses

The first habitat cover analysis had the purpose of better describe vegetation in the territories surrounding the nests. The forest typologies distinguished in surveyed areas through QGIS are (in order of abundance): *P. uncinata* forests, non-forested areas, *P. abies* forests, *L. decidua* and *P. cembra* forests, *P. sylvestris* forests and other types of forest cover. In Table 3 are given the cover percentage for each nest territory. The dendrogram from cluster analysis highlights two group of similar territories: one dominated by *P. uncinata* and one with more heterogeneous and mixed forests (named "uncinata" and "mixed" in the subsequent analyses, Fig. 18). From the GLMs including the habitat, no correlation is observed with the breeding success. One GLM with bird estimated weight as response variable, shows a little but significant influence of habitat and mountainside exposure on this variable (p – value of 0.03 for habitat and 0.02 for exposure). This relation is also noticeable in boxplots shown in Figure 17. Anyway, the bias of the number of samplings slightly effects this relation.

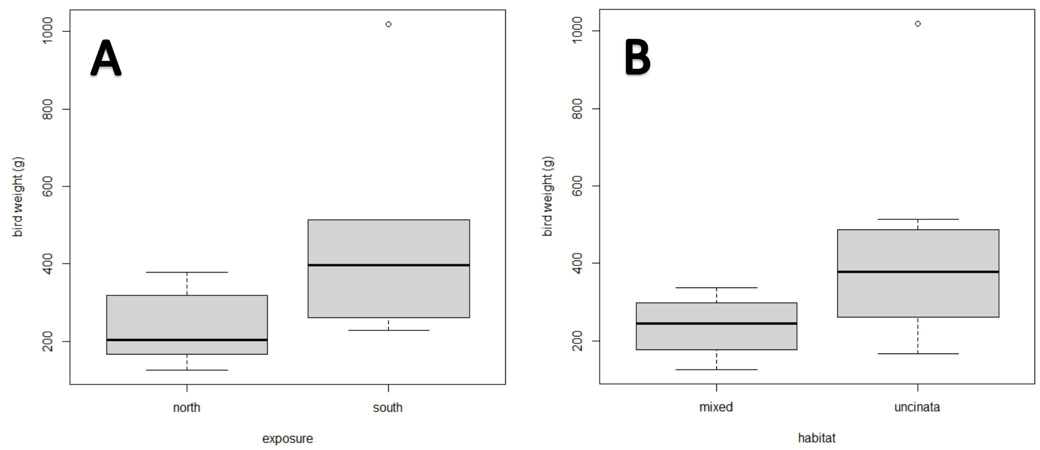

Figure 17: boxplot representing the trend of bird weight in relation to A) the exposure of mountainside, B) habitat clusters.

Sites	PN *P. uncinata* forests	LC *L. decidua* and *P. cembra* forests	PE *P. abies* forests	PS *P. sylvestris* forests	OT other forest types	NF non-forested areas
Nest01	89	9	0	0	0	2
Nest02	89	6	0	0	3	2
Nest03	46	46	0	0	0	8
Nest04	0	27	39	2	20	12
Nest05	0	4	52	28	0	16
Nest06	62	13	0	12	2	11
Nest07	79	6	0	0	0	15
Nest08	0	16	75	1	1	7
Nest09	82	5	0	0	0	13
Nest10	21	12	0	0	0	67
Nest11	47	12	0	9	4	28
Total	46,8	14,2	15,1	4,7	2,7	16,5

Table 3: forest cover percentage per nest site. Data of forest cover taken from Aosta Valley Geoportal (https://geoportale.regione.vda.it/)

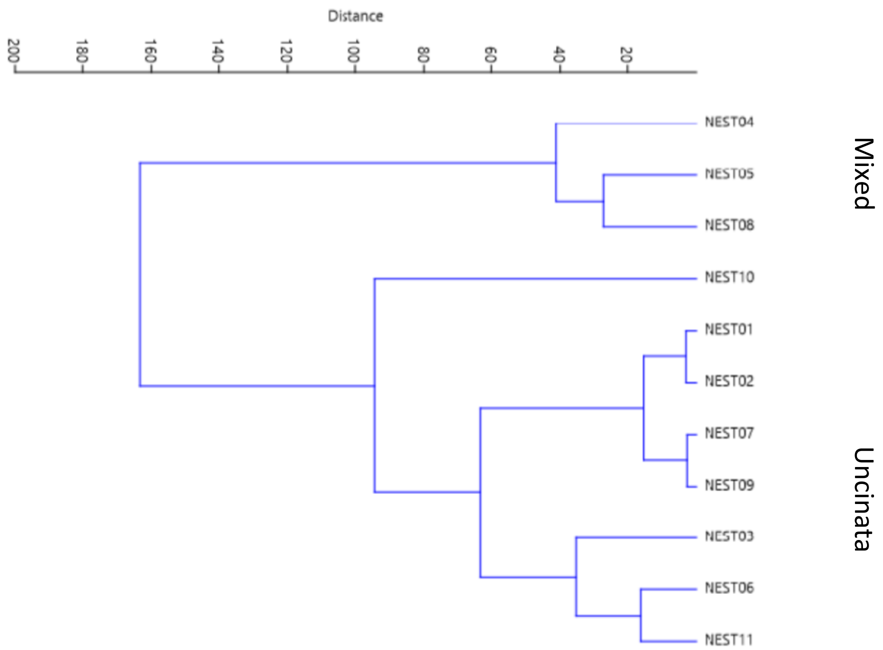

Figure 18: dendrogram from the habitat cluster analysis. Two main cluster are noticeable: the first one, “mixed”, composed by Nest04, Nest05 and Nest08, the second one, “uncinata”, composed by the other nests. The clusters have been calculated using the cover percentage as variable.

6. DISCUSSION

6.1 Diet of pygmy owl in the Alps

The first goal of the thesis is to describe for the first time in the Alps the diet composition of the pygmy owls during the nesting period. In this work, 26 species of bird and 5 species of mammals have been identified and recorded as part of pygmy owl diet, in addition to 6 bird taxa and 4 mammal taxa not identified at the species level. In these materials, no new species have been discerned as food for this owl.

The pygmy owl hunts a variety of prey that is almost unique between European owls and its trophic niche hardly overlaps with the ones of the others bird of prey. Only the Tengmalm's owl and the eagle owl *Bubo bubo* probably prey on a wider range of species. Indeed, a lot of studies on the diet of European owls highlight their preferences for a specific group of prey, dividing them into four different groups: long-eared owl and short-eared owl, characterised by a high proportion of rodents of genus *Microtus*, barn owl and tawny owl, with a higher proportion of insectivores, the little owl, preferring invertebrates, and finally eagle owl, boreal owl and pygmy owl with a high amount of birds and *Myodes* (Birrer *et al.* 2021).

The results of this work well represent the range of prey expected before the analyses: a preference for non-passerine birds, with a high proportion of forest-dwelling species. The presence of "large" prey, as thrushes and woodpeckers, is quite common and documented also in other studies, e.g. by Kellomäki (1977) and Mikusek *et al.* (2001). Interesting is the high frequency of the Eurasian wren *T. troglodytes*, a small passerine that can be compared to a mouse for its behaviour tied to undergrowth and bushes. Moreover, it is remarkable the high occurrence of juvenile (stage of chicks) birds, recognizable by the presence of moulting feathers, found in 8 out of 11 nests and representing the 22,75% of the avian prey. This is not unusual: the pygmy owl nesting period largely overlaps the fledging of many passerines, making them a perfect and easy prey for the owl. Low proportions of mammals were predicted, but their percentages are often lower than in other works, with values from 15,4% to 52,2% (mean 26,52%, median 22,73%) compared to values with a mean of 44,3% in Kellomäki (1977), Finland, and of 63,9% in Mikusek *et al*. (2001), Germany. Moreover, it has been found a slightly larger proportion of small mammals in 2021 remains: this was an expected result, due to the abundance of rodents observed during that year. Finally, the data obtained in this thesis partially reflect the tendencies found in the works of Riegert *et al.* (2021) and Birrer *et al.* (2021). In their studies on European owls diet, they support the hypothesis of a relation between geographic latitude and the food composition, and obtain a southward decrement of voles and insectivores in owl's prey, whereas birds

and mice *Apodemus* increase. In this thesis, the high amount of birds is evident: 73% on the total prey, compared to 62,9% and 52,5% in central and southern Germany respectively, to 38,2% and 32,2% in Finland and to 32,1% in Norway. The number of mice *Apodemus* on the total prey (6 out of 257, 2,3%) is more difficult to assess, but seems to be similar to some data in central Germany (3,57%) and Norway (1,96%) while clearly differ from the Finnish data (0,3%, 0% in Kellomäki 1977) and from southern German data (8%) in Scherzinger (1974) (Schönn 1978; Mikusek *et al.* 2001). In this case, the bias of sampling method may shifts the results to be more similar to the northern one.
The only other survey of prey remains from pygmy owl nest recorded in the Alps contained a high amount of mammals, about 50% of the total prey. The species observed in the work of Bonvicini and Della Ferrara (1991) but not in in this thesis are: common dormouse *Muscardinus avellanarius* (3 individuals), common shrew *S. Araneus* (3 individuals), wood mouse *A. sylvaticus* and yellow-necked mouse *A. flavicollis* (both 1 individual).

6.2 Influences on the breeding success

The material collected during the field work does not suggest any meaningful effect of the diet on the breeding success of the pygmy owl. Although several different analyses and GLMs have been run they all resulted in low correlations estimated and non-significant p-values, except one relationship visible in Figure 19E. In the hypothesis, a better breeding success has been associated to a higher quantity if small mammals preyed, but this pattern suggests the opposite: a greater number of mammals eaten should be related to a lower breeding success instead. The origin of this trend could be a minor effort in locating and hunting birds, especially at the end of their breeding season, when juvenile passerines fledge, and the adults are often exhausted from the nesting activity. Furthermore, in these forests, the ground is often covered by *Rhododendron hirsutum* or other dense bushes and stony grounds are frequent: these represent perfect hides for small mammals from the predatory activities of pygmy owl. However, this trend is only visible in the boxplot, and, running the corresponding GLM, it does not result any significant value. In this case, further analyses are required to assess if the pattern is caused by the low number of samplings, by casualty or it is a sign of a significant correlation. To summarise, these findings indicate a great capability of pygmy owl to adapt to a wide ecologic range. All type of coniferous forests threatened in this work are suitable for pygmy owl and can sustain its reproduction.
The only nests where the breeding was unsuccessful is Nest07, which had a *D. major* nest 50m far from it. The woodpeckers are known to be opportunistic

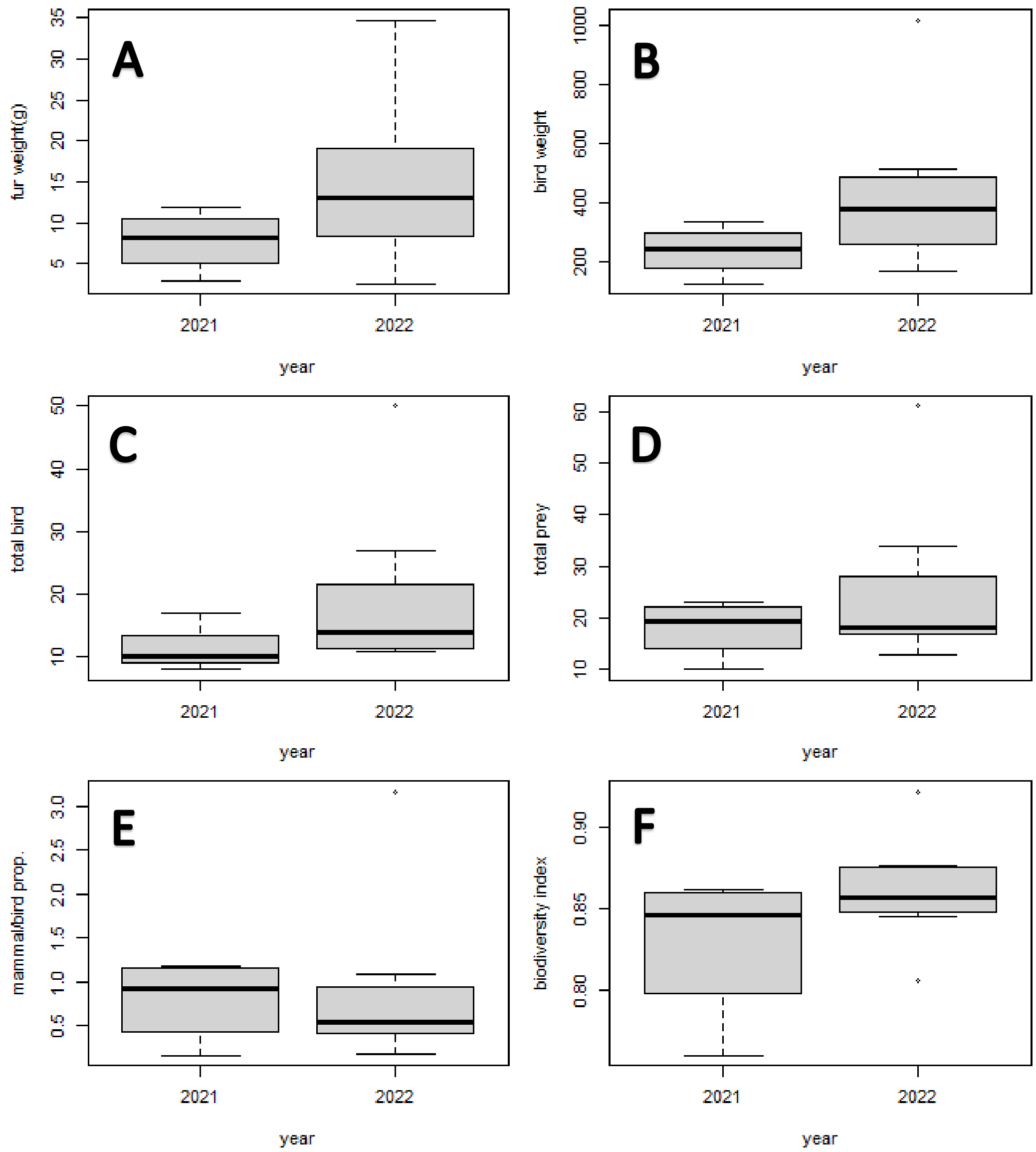

Figure 19: boxplots illustrating the difference in diet composition between nests in year 2021 and year 2022. The variable evaluated in each boxplot are A) weight of mammal's fur, B) bird estimated weight, C) number of avian prey, D) total number of prey, E) proportion between small mammals and birds in total prey, E) biodiversity index of the prey.

predators of nestling of other species, raiding their nests in search of food (Snow *et al.* 1998). Therefore, Nest07 may have been attacked by a great spotted woodpecker while the adults of pygmy owl were temporarily outside and could not defend their chicks.
Two nest that had a low breeding success were Nest10 and Nest11. The possible reason of this outcome is their closeness (765m far from each other) that caused the two couples to compete for food resources. To this, the presence of large non-forested spaces near the nests can be added as a factor that decrease the fitness, because the pygmy owl does not usually use them as hunting territories.
Nest01 and Nest09 are in a similar setting, only 820m far, but both had a high breeding success. In addition, the presence of a third nest near them has been found, with a breeding success of 2 or more nestlings (only 2 of them were seen 10m far from Nest01). Their presence in such closeness to Nest01 is challenging to explain, but it is likely that the male of this nest was bigamous. The third nest was precocious, and once the chicks fledged, they followed their father to Nest01, probably to beg food. Furthermore, Nest01 was a late nesting (chicks found inside it in July) and this gave the male the possibility to provide food to both the nests. Cases of bigamy in pygmy owl have not been documented with certainty yet, but in this case is the most likely explanation (Solheim 1984; Korpimäki 1988). Finally, this elevated density of nests is unusual for pygmy owl and can be explicated with a high productivity of the habitat in terms of biomass of prey, that prevented a high competition on food sources.

7. CONCLUSION

In this thesis 11 nests of pygmy owls have been surveyed, collecting data to evaluate the diet of the pygmy owl in the Alps. The analysis of food remains highlight the non-specialist behaviour of this bird of prey: small passerines were usually preferred upon small mammals, but the predatory activity is never oriented to a single functional group of prey. Moreover, an effect on reproductive success from various factors has been searched, exploring the data about diet and adding more about habitats. In the end, all the ‘null’ results from statistical analyses reveal once again the high ecological plasticity of the pygmy owl. The explanation to the absence of influence of diet and habitat on breeding success is that this owl is perfectly adapted to the environment in which it lives. It is a non-specialist predator, although a preference for small passerines is visible in this study, and this helps the species to breed successfully also during years and periods of prey scarcity, shifting from main prey to alternative ones when necessary. In addition, this dietary flexibility allows pygmy owl to not migrate in search of greater sources of food. From the findings of this work, the biggest threats to its reproductive success are intraspecific competition and competition with other cavity dwelling species, both for nesting sites and for food sources. As proof of its plasticity, it's well documented that the alpine population of pygmy owls rapidly recovered during the past three decades, after a strong decrement in the twentieth century (Brichetti 1987; Bocca & Maffei 1997; Maffei *et al.* 2018).

Finally, the Alps are probably a better environment than north Europe for this owl during winter, because of the less harsh climate and the higher abundance of prey (more resident avian prey). On the other hand, the global warming can heavily impact the alpine habitat of this cold-adapted owl, more than the northern European habitat. Although it demonstrates a great adaptability, it is a glacial relict and in southern Europe is present only above 1500m a.s.l.: the climate change will certainly reduce its habitat, moving its inferior limit at higher altitude, and resulting in loss of territories (Theurillat & Guisan 2001). It is challenging to predict whether the populations of pygmy owls will acclimate to warmer forests with different structure and composition. Other works demonstrate the higher efficiency and lower vulnerability to extinction of generalist species like pygmy owl, which is less costly in term of expended energy than being specialist, especially in human-induced habitats (Ferrer & Negro 2004; Korpimäki *et al.* 2020). Moreover, a possible behavioural adaptation to warmer winter already occurred in the Alps: in this season it stores a lower quantity of prey (Baroni, unpublished data). So, food hoards are often unnecessary to get through the cold season, but is this a real adaptation or a consequence of the not so low temperatures that cause the hoarded food to decay?

In conclusion, further studies are necessary to support the findings of this thesis. If the pygmy owl breeding success is not influenced by the available species of prey, this bird of prey could adapt to global warming better than other glacial relicts. Nevertheless, the habitat loss will still negatively affect the populations of this coniferous forest specialist, especially in the alpine environment.

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