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Habitat management for the

BOREAL OWL

A handbook

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"Conserving and managing the habitats of the bioindicator bird species of the Pyrenees"

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Chapter 1. Biology and ecology of the boreal owl

Figure 1. Boreal owl in a mountain pine in Aransa (Cerdanya, eastern Pyrenees). Author: David Potrony.

1.1. Distribution and population status

The boreal owl or Tengmalm's owl (*Aegolius funereus*) is a species that is widely distributed across the boreal forests of the Northern Hemisphere (Cramp, 1984; Mikkola, 1983). In Europe, it is also heterogeneously distributed across several forested mountain ranges, and at the southern edge of its distribution it is located on the Iberian Peninsula, in Greece and in Turkey (Hagemeijer and Blair, 1997; Díaz et al., 1999), the limit of its European distribution area being the Pyrenees (Figure 1).

In the Pyrenees, the current distribution of the boreal owl encompasses the axial Pyrenees and the pre-Pyrenees, although we cannot rule out possible populations in the Cantabrian Mountains, where there have been sporadic sightings of the species. To date, it has been sighted in the Pyrenean areas of Catalonia, Aragon and Navarre. The species is also widely distributed in the Principality of Andorra and all the way along the French side of the Pyrenees (Figure 2).

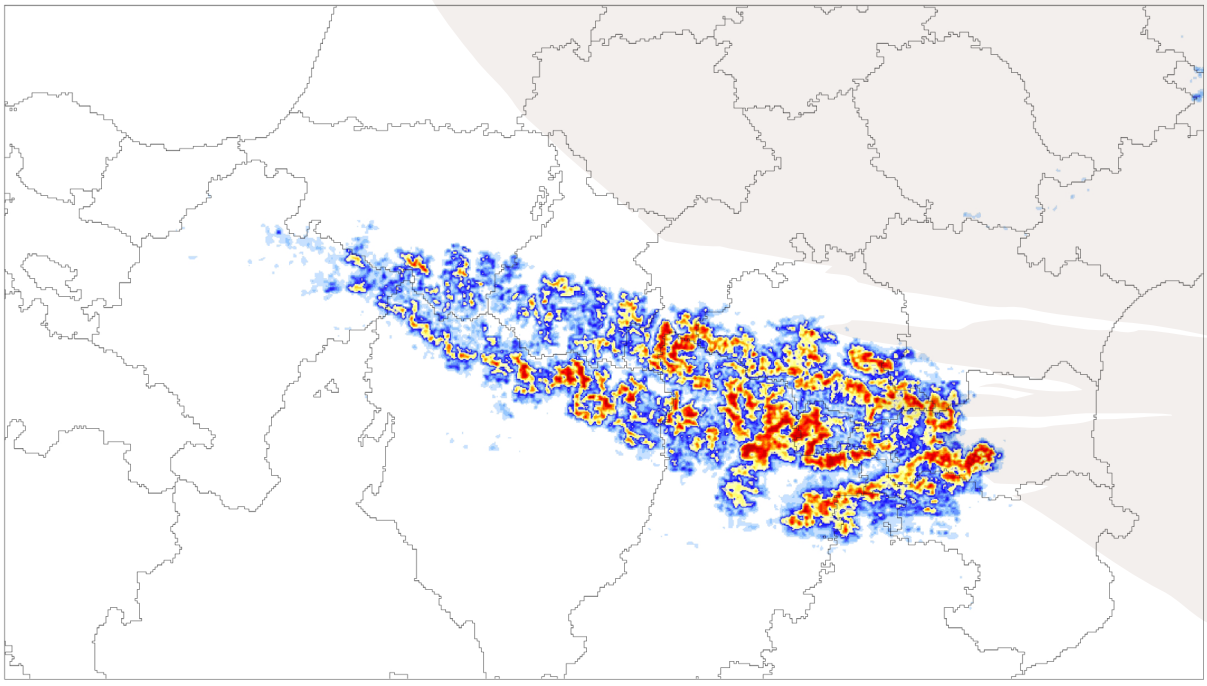

Figure 2. Map of the quality of the potential habitat of the boreal owl in the Pyrenees (Recoder and Villero, 2018). The map has been produced using habitat modelling techniques that make it possible to establish statistical relationships between information on the distribution data of the species and environmental information, through which it is then possible to plot the populations found across the entire mountain range. The obtained map represents a quantitative index of the areas that best represent, in environmental terms, the potential areas where the species may be found. Units of the map: Index of quality of the habitat that varies between of 0 (minimum) and 1 (maximum). The variations in this quality value are represented through a colour palette ranging from white (low quality) to red (high quality). Resolution 1x1 km. In order to improve the visual interpretation of the models, the final map is presented with a resolution of 500x500 m, assigning each pixel the average value of the eight adjacent pixels.

The first sighting of the boreal owl in the Pyrenees, with an unequivocal description, is the one by Bleach (1892). The species was known in Catalan as the *òliba calçada* ("shoed owl"). After that sighting, the species went unnoticed by scientists until 1963, when Van der Vloet (1964) found a nest in Font Romeu (eastern Pyrenees).

At the end of the 1960s, the boreal owl began to be included in Iberian ornithology studies (Bernis, 1966-1971), although with no knowledge whatsoever about its phenology and populational status. In 1981 the species still remained largely unknown (Maluquer, 1981) and doubts remained about whether it bred in the Pyrenees. As regards the Catalan Pyrenees, it was not until the 1980s that the first study of the species was published, the result of a more or less constant research project (Alamany, 1988, 1989). The conclusion drawn from this study was that between 29 and 32 pairs of boreal owls existed on the Iberian Peninsula.

Prodon et al. (1990) published a review of the then-existing data on the presence of the species on the two sides of the Pyrenees. Up until the publication of the aforementioned review, there were 120 known territories and the Pyrenean population at that time was around 300 pairs.

Between 1990 and the present day, various teams have continued to study this species in different areas of the Pyrenees. Brought together, the information contributed by these teams has made it possible to calculate a total number of 360 known territories in the Pyrenees as a whole (Table 1). Other Pyrenean-wide estimates have calculated between 500 and 600 territories (Prodon et al., 1990; Mariné and Dalmau, 2000).

Table 1. Known territories of the boreal owl in the Pyrenees.

Pyrenean region	Known territories
Andorra	27
Aragon	54
Catalonia	144
France	128
Navarre	9
Total Pyrenees	**362**

The census unit used for this species is "territory". Each territory is held throughout the year by a male. In each breeding season, the male attempts to attract a female. If there are consistent signs of breeding or calls detected in listening stations in the same area over several breeding seasons, this area can be classified as a territory. It is important to point out that in many instances it has been possible to confirm the reoccupation of territories after the death of the male. This would explain why some historical territories have existed for more than 30 years.

1.2. Habitat

The boreal owl is strictly a forest bird. In the Palearctic it mainly inhabits Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), mountain pine (*Pinus uncinata*) and silver fur (*Abies alba*) coniferous forests (Figure 3). It is also found in forests with a combination of the aforementioned conifers and deciduous species (Figure 4), such as silver birch (*Betula pendula*), European beech (*Fagus sylvatica*) and aspen (*Populus tremula*). In Siberia it has also been described in riverside deciduous forests.

Figure 3. Habitat of the boreal owl in high mountain areas of the south-eastern Pyrenees. Subalpine mountain pine forests. Serra del Verd (Catalonia). Author: David Guixé.

Figure 4. Habitat of the boreal owl in high mountain areas of the northern side of Pyrenees. Fir forests, beech forests and their combinations. Pyrénées Ariégeoises Regional Natural Park. Author: Quentin Giry.

When it comes to the distribution of the boreal owl, three factors are much more important than the type of forest. The first of these is the average temperature of the warmest months. In Catalonia, 100 % of the known territories are above the average maximum temperature isotherm (<18 ºC) of the month of July (Mariné et al., 2003). The second factor is the existence of nesting cavities, preferably created by the black woodpecker (*Dryocopus martius*), and the third factor is the availability of prey on which to feed (Figure 6). On the south side of the Catalan Pyrenees, 64 % of the distribution of the boreal owl coincides with that of the black woodpecker, according to the abundance models (Cartobio-CTFC project). If we concentrate exclusively on the areas that the model predicts as optimal (Figure 5), the percentage of coincidence rises to 77 %.

Figure 5 shows a model of the importance of the different areas occupied by the species in respect of the degree of habitat quality (Recoder and Villero, 2018). We can see that the most optimal areas are distributed in the central and eastern Pyrenees.

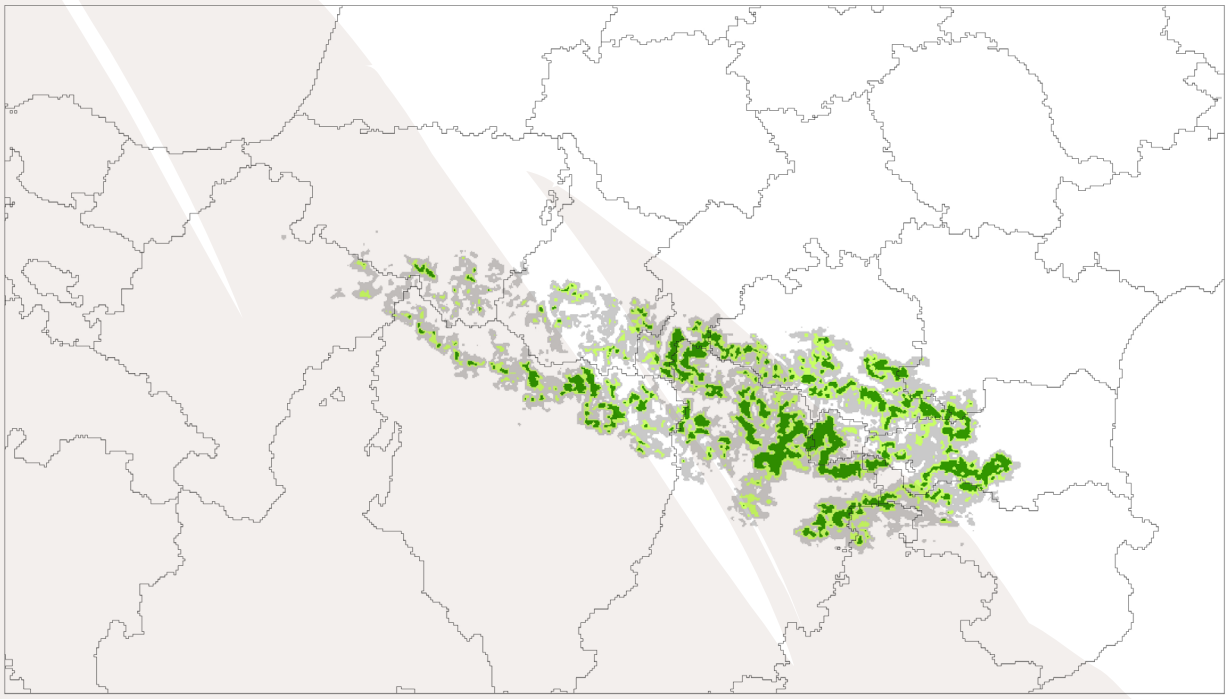

Figure 5. Identification of the important areas for the boreal owl in the Pyrenees. The Acceptable Zones (728,007 ha, 61 %) are defined as the areas with a habitat quality above the average of 10 % of the places where the species is present, but with a worse habitat quality according to the models; that is, areas with a low quality of habitat where the species is residually present or in low abundances. The Good Zones (250,185 ha, 21 %) are the areas with a habitat quality level above the average habitat quality level of the Acceptable Zones; that is, areas where the species is frequent or moderately abundant. The Optimal Zones (214,498 ha, 18 %) are the areas with a habitat quality level above the average habitat quality level of the Good Zones; that is, areas with the best environmental conditions within the studied area, where the species may be very abundant (Recoder and Villero, 2018).

1.3. Nesting

The mating period of the boreal owl begins in the middle of winter (Table 2). The territorial males start singing in December and are highly active until March. In good breeding years, some can continue singing until June. The females are nomads, while the males tend to be territorial. This means that dominant males defend a territory throughout their life, while females and young males in their first year move around during each breeding season in search of territories where there is an abundance of small mammals to prey on (Korpimäki and Hakkarainen, 2012). Nevertheless, in Belgium it has been observed that males may gather together (Sorbi, 2013). Young males probably move to better territories when they become dominant (S. Laguet, pers. com.).

Table 2. Phenological table of the boreal owl in the Pyrenees. Original by David Potrony.

	February	March	January	April	May	June	July	August	September	October	November	December
Singing of the male												
Incubation 26-28 days												
Chicks in nest 29-36 days												
Fully fledged 3 months												
Dispersal of females												

The boreal owl breeds in tree trunk cavities mainly created by woodpeckers, in mountain pine and Scots pine forests or in beech-fir forests and their pure formations (see Chapter 2). Meanwhile, this bird also readily accepts nest boxes. According to López et al., 2010, they occupy nest boxes in forests with very gentle slopes and preferably facing north and north-west, avoiding sun-facing orientations. Furthermore, the likelihood of occupation of a nest box is greater if it has been occupied in previous years or if there are nearby territories.

Figure 6. Interior of two nest cavities with clutch and chicks. In both cases accompanied by their prey, *Apodemus* sp. Photographs: Jordi Guillén.

Incubation lasts between 26 and 28 days (Estrada et al, 2004; Korpimäki and Hakkarainen, 2012), which means that the first clutches are laid at the end of March (the earliest date recorded in the Pyrenees is 15 February, J. C. Auria, pers. com.). However, most clutches are laid in April, May and June. The number of eggs per clutch in the south-eastern Pyrenees (Cerdanya-Alt Urgell) has been recorded as 4.4 eggs (n = 41 clutches), 7 being the maximum and 2 the minimum (Figure 6). In the Pallars Sobirà area (central Pyrenees), the average clutch size has been recorded as 3.8 eggs (n = 39 clutches). The clutch size range in this area varies between 1 and 10 eggs, although the 10 eggs may belong to two different clutches. Clutch sizes vary greatly depending on the year (Figures 8 and 9). In nest boxes, the number of eggs per clutch is larger than in natural cavities (López et al., 2010), probably due to the larger amount of space in nest boxes in respect of natural cavities (Figure 7).

Figure 7. Owl breeding in a wooden nest box and owl breeding in an old natural cavity created by a black woodpecker. Authors: David Potrony and Jean-Claude Auria.

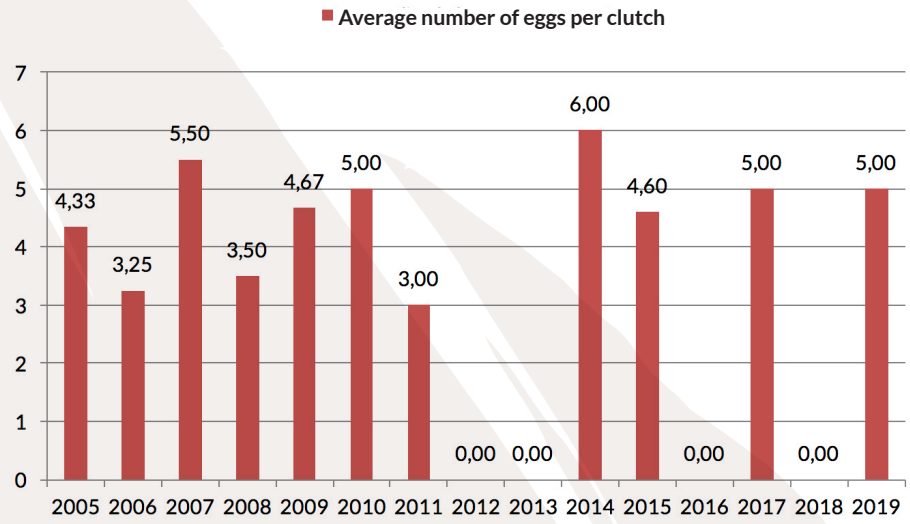

Figure 8. Average number of eggs per clutch and year of the boreal owl breeding in natural cavities and in nest boxes in the south-eastern Pyrenees (Cerdanya-Alt Urgell, Catalonia). The prospection effort is the same for all the years. Source: D. Potrony and E. Badosa, unpublished data.

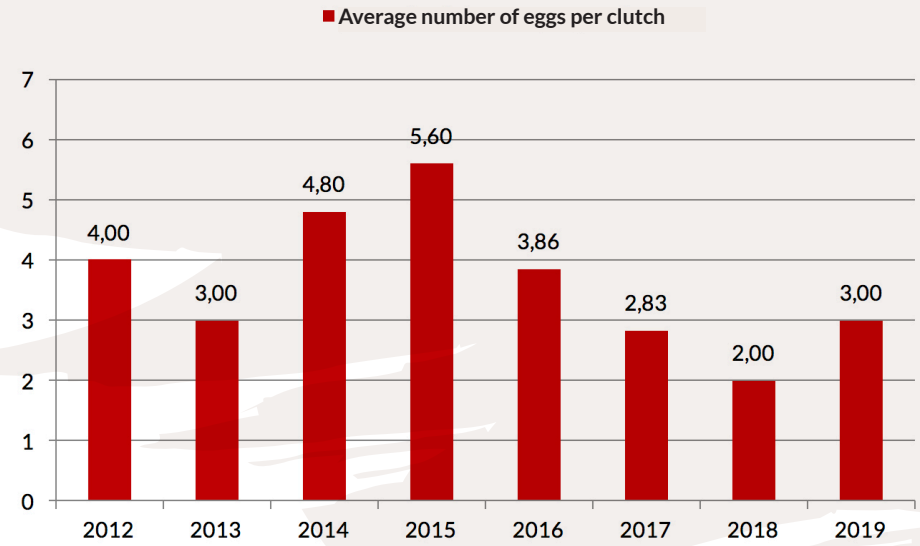

Figure 9. Average number of eggs per clutch and year of the boreal owl breeding in nest boxes in the central Pyrenees (Pallars Sobirà, Catalonia). The prospection effort is the same for all the years. Source: J. Fernandez and J. Guillén, unpublished data.

The breeding season is long, stretching from the end of February (although more habitually from the end of March) to mid-August on the southern side of the Pyrenees, and from mid-February to mid-July in the Pyrénées-Atlantiques region of France. The ringing period for south-eastern populations begins at the end of April, when the first females are already brooding or have chicks of a few weeks old, May being the month with the largest number of brooding females or females with young chicks (Figure 10). The earliest date on which chicks have been found is 24 April, while the latest is 2 August, although most of them are found in June and July. The chicks stay in the nest for between three and four weeks (Korpimäki and Hakkarainen, 2012).

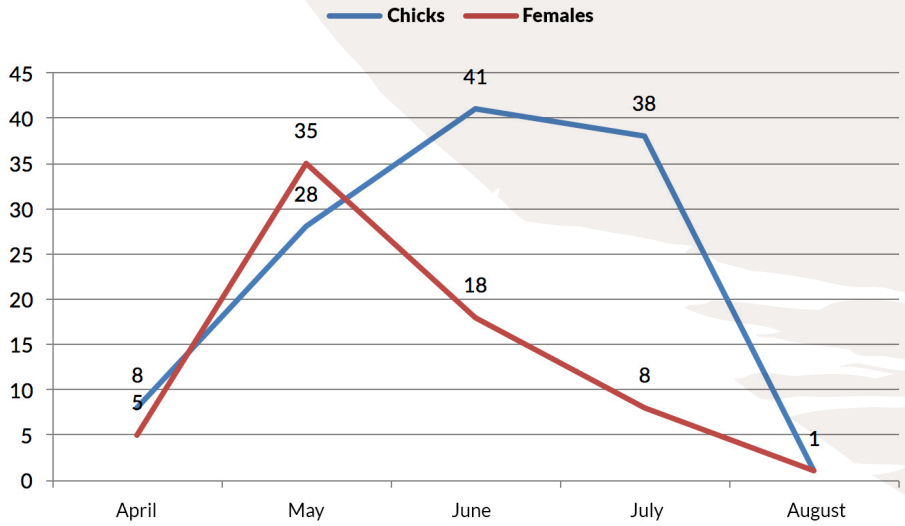

Figure 10. Number of ringed nesting chicks and females according to the month of the year in the south-eastern Pyrenees (Cerdanya-Alt Urgell, Catalonia) between 2005 and 2019. Source: D. Potrony and E. Badosa, unpublished data.

The average number of chicks per nest in the south-eastern Pyrenees is 3.6 (n = 32 nests), the minimum and maximum numbers being 1 and 6, respectively, while in the central Pyrenees, the average number of chicks per nest is 2.5 (n = 41 nests). As in the case of the number of eggs, the number of chicks, the number of ringed females and the average number of fledged chicks per female varies enormously depending on the year (Figures 11 and 12).

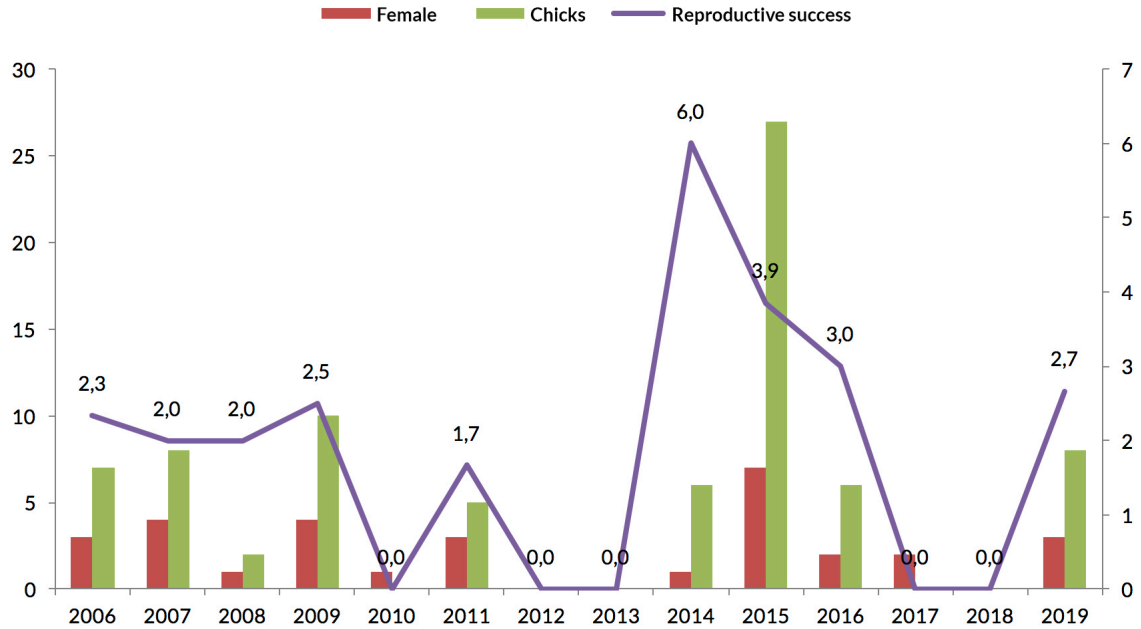

Figure 11. Number of ringed females and chicks and reproductive success (fledged chicks, right axis) between 2006 and 2019 in the south-eastern Pyrenees (Cerdanya-Alt Urgell, Catalonia). Source: D. Potrony and E. Badosa, unpublished data.

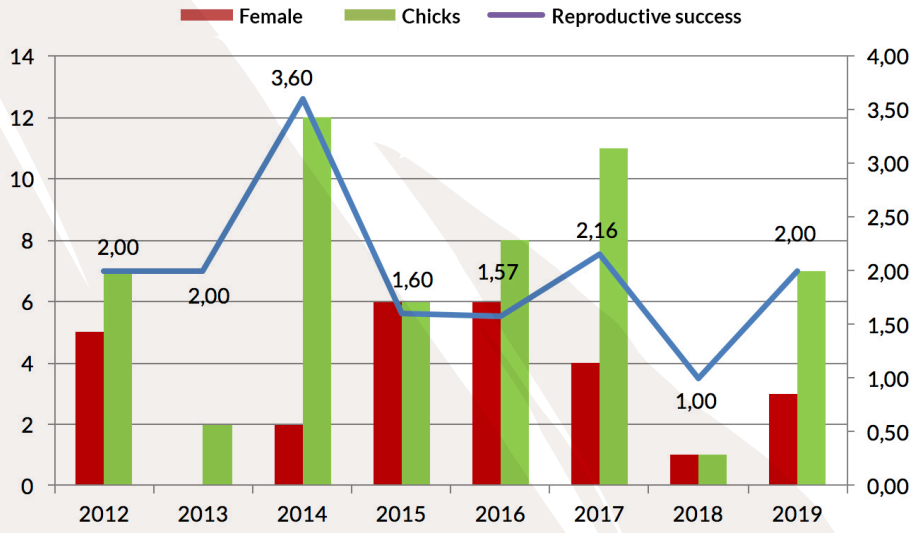

Figure 12. Number of ringed females and chicks and reproductive success (fledged chicks, right axis) between 2012 and 2019 in the central Pyrenees (Pallars Sobirà). Source: J. Fernández and J. Guillén, unpublished data.

1.4. Feeding

The boreal owl feeds on birds and mammals, including insects. However, its diet mainly consists of small mammals, basically rodents (Muridae and Microtidae, Figure 13) (Korpimäki and Hakkarainen, 2012; Robion, 2012). This bird's diet has been extensively studied in Scandinavia (Jäderholm, 1987; Korpimäki, 1988), in the Alps (Joveniaux and Duran, 1987; Ravussin et al., 2001, 2016) and in North America (Hayward, 1993). It has also been studied in the Balkans (Rajkovic, 2018). In the Pyrenees, few studies have been carried out of the boreal owl's diet. On the French side of the Pyrenees, 59 % of the prey of this species is made up of mice of the *Apodemus* genus and field moles (*Microtus agrestis*). Bank voles (*Myodes glareolus*) constitute 7 %, while a further 10 % is made up of different shrew species (29 prey items of 15 pellets, according to Duchateau, 2013). The breeding of boreal owls in Navarre has recently been confirmed, with the available information indicating an abundance of rodents in its diet, above all bank voles and mice of the *Apodemus* genus (Ibáñez et al., 2020). The studies conducted in France and Navarre link the abundance of small mammals to the fructification of the European beech species in the previous year. In the case of the Catalan Pyrenees, the boreal owl is monitored in mountain pine and silver fur forests, which means that this link to the European beech has not been found.

Figure 13. Prey items accumulated in a mountain pine cavity by a male boreal owl. The items belong to five different vole species: Clethrionomys glareolus, Chionomys nivalis, Microtus arvalis, M. agrestis and M. gerbei. Aránser Forest, Cerdanya, eastern Pyrenees. Author: Anna Gallés.

In the Catalan Pyrenees, the ringing and breeding monitoring data (number of captured females, ringed chicks, chicks/female) has been linked to the number of small mammals (rodents and insectivores) found in the monitoring activities of the SEMICE (Monitoring of Common Small Mammals in Spain) project (Figure 14). The data used for this purpose is that of the county of Alt Urgell and the Cerdanya region, along with that of the nearest SEMICE station (Talltendre, which has only been gathering data since 2011). It is clear that females do not breed in years in which the number of small mammals is extremely low. Conversely, they do breed in years in which there is an abundance of this prey, although it seems that they do so with a delay of one year in respect of the population peak of small mammals. The same occurs with the total number of chicks. However, in this case, the number of small mammals has an immediate effect on breeding success (chicks/female) in the same year (Figure 14).

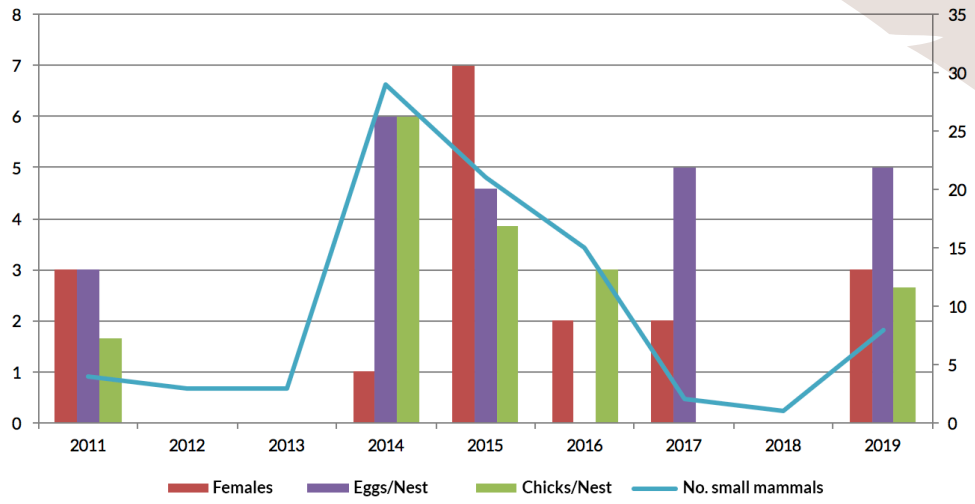

Figure 14. Variables of the breeding monitoring of the boreal owl and the data of the SEMICE project (from 2011 to 2019). Source: D. Potrony and E. Badosa, unpublished data.

1.5. Predators

Among birds of prey, the worst enemies of the boreal owl are the Eurasian eagle-owl (*Bubo bubo*), the Ural owl (*Strix uralensis*) and the northern goshawk (*Accipiter gentilis*). It is not unusual to find the boreal owl among their prey (Korpimäki and Sulkava, 1987; Korpimäki et al., 1990; Tornberg et al., 2005). The presence of the Ural owl reduces the density of boreal owl nests and increases the failure of nesting attempts, although the boreal owl only constitutes 0.2 % of the Ural owl's prey, which means that above all it represents competition for other prey and nesting cavities (Korpimäki and Hakkarainen, 2012). In the Pyrenees, the role of the Ural owl, absent in the south of the Europe, might be performed by the tawny owl (*Strix aluco*), although we do not have specific information in this respect. In years of abundant prey, breeding tawny owls have been observed close to the boreal owl (P. Pola, pers. com.).

Meanwhile, the European pine marten (*Martes martes*) is a general predator that sporadically or frequently preys on the boreal owl (De Marinis and Masseti, 1995; Ravussin et al., 2015), to such an extent that it could be considered its main predator (López et al., 2010). It normally preys upon eggs, chicks and, when it can, females (Baudvin et al., 1985; Marchesi and Mermod, 1989; J. C. Auria, pers. com.). In the Pyrenees, natural cavities are more preyed upon than nest boxes: 50 % versus 15 % (López et al., 2010). This is not the case in the French Jura (Ravussin et al., 2015) , which suggests that the anti-predation measures of nests are a decisive factor. Nevertheless, a brood of chicks killed by a woodpecker, in all likelihood a great spotted woodpecker (*Dendrocopos major*) (Figure 15), has been found on one occasion in Alt Urgell (Catalonia).

Figure 15. Dead chicks in a nest box, possibly due to an attack by a great spotted woodpecker. Photograph: Enric Badosa.

1.6. Mobility

The postnatal dispersal of this species has been extensively studied in Finland. On analysing 4,443 recoveries from 89,829 birds ringed, the average dispersal of the males was 19 km (maximum 382 km) and that of the females was 110 km (maximum 588 km) (Korpimäki et al., 1987; Saurola, 2002). There is evidence that the females are capable of dispersing more than the males in their first year of life, between abandoning the nest and reaching their first breeding place (Figure 16).

Figure 16. Boreal owl fledged in the Pyrénées-Atlantiques region of France. Author: Jean-Claude Auria.

Furthermore, post-breeding dispersal is greater or lesser depending on the abundance of voles (Korpimäki and Hakkarainen, 2012). According to these authors, Finnish male birds disperse less when there is an abundance of voles (0.8 km on average) and a little more when they are in scarce supply (1.3 km on average). Female birds disperse to a much greater degree, displaying nomadic behaviour. They can typically move anywhere between a short distance and 400 kilometres, but can even travel much greater distances, such as 787 km in Germany (Gerber and Bassin, 2001).

Although few birds have been ringed in the Pyrenees (Figure 17), the dispersal of several females in different breeding seasons has been observed: one bird moved 1.8 km away in Cerdanya (eastern Pyrennes), a second bird was located 24 km away between Andorra and Cerdanya, and a third bird, captured and ringed in Sahún (central Pyrennes), was recaptured 333 days later in Setcases (eastern Pyrennes), 216 km away (Badosa et al., 2007). Nevertheless, it is possible that this mobility or dispersal is less extensive in certain populations. The small amount of data available on recaptures in Pallars Sobirà (central Pyrenees) seems to indicate a philopatric trend among female chicks and a homing trend among females in certain areas. A female marked as a chick in 2014 was recaptured in 2016, breeding in a nest box located 166 me from where it was born. Data is also available on two other recovered females. The first one was marked in 2015 and recovered in 2016 (1.8 km from the previous location) and again in 2017 (446 m from the 2016 nest and 1.5 km from the 2015 nest). All the locations were in the same forest. The second one was marked in 2016, when breeding in a nest box, and recaptured in 2018, breeding in another nest box located 565 m away in the same forest. No external monitoring records exist for the 84 birds ringed in Pallars Sobirà between 2012 and 2019 (J. Fernández and J. Guillen, unpublished data).

Figure 17. Ringing of boreal owl captured in its refuge. All the necessary administrative permits for this task have been issued. During the process all the necessary steps are taken, such as minimising the handling time, in order to ensure that the bird comes to no harm. Cerdanya. Author: Enric Badosa.

1.7. Main problems

The boreal owl is strongly associated with mature boreal forests. There is evidence that the decline of these forests is related to the decline of boreal owl populations (Korpimäki and Hakkarainen, 2012). Mature forests constitute a habitat that offers this species protection from competitors and predators alike. Populations are declining across Europe (in Finland, between - 2.1 and - 2.3 per year). Therefore, forestry management also has an influence on whether the habitat is suitable or not for the species (Mariné and Dalmau, 2000).

One of the main threats to Pyrenean boreal owl populations is the lack of knowledge until very recently of their presence in the area. This circumstance means that management failings have occurred, due to the lack of planning in forest uses, which until recently have not applied conservation criteria that consider the needs of this species. As such, authorisation has been granted for the felling of trees with cavities essential for breeding

purposes. If there is a lack of cavities created by the black woodpecker, the owl can occupy those created by the great spotted woodpecker, although the smaller size of these cavities can have a negative impact on the productivity of the species (Dalmau et al., 2000). On the other hand, the narrower hole makes it much more difficult for the pine marten to prey on these nests.

The density of cavities is another crucial factor for the conservation of this species in the Pyrenees. The boreal owl tends to occupy a different cavity each year, in order to avoid parasites and predators, especially the pine marten (*Martes martes*) and the beech marten (*Martes foina*) (Korpimaki, 1981; Sonerud, 1985). The occupation of the same cavity in consecutive years increases the risk of being preyed upon, especially in the case of chicks (more rarely in the case of adults) (Sonerud, 1985). The predation rate in Catalonia is remarkably high, occasionally reaching around 70 % (Mariné and Dalmau, 2001; Dalmau et al., 2000), which may be related to the low availability of cavities.

Another clear threat is related to the fact that the distribution of the boreal owl is at its southern palearctic limit in the Pyrenees. The bird is adapted to extremely cold climates, which means that it suffers from physiological stress associated with high summer temperatures (Hayward et al., 1993). Predictive models of future climate change indicate that there will be a reduction in the climatically suitable surface area for the mountain pine in the Catalan Pyrenees of between 14 % and 22 % within 50 years' time, and of between 28 % and 51 % within 90 years' time (Q. Canelles, Ecoland Lab, unpublished data). The influence of climate change will progressively push this conifer up to higher altitudes, taking it to unsuitable areas (with poorer soil, exposed to the wind, with less atmospheric pressure, etc.), where it may grow much less in terms of both height and girth. It will be much more difficult for the black woodpecker and even the great spotted woodpecker to colonise formations of thinner pines. It is predicted that the Scots pine will progressively occupy higher elevations, which means it might offer a replacement habitat for the boreal owl.

Finally, it is worth pointing out that communities of small mammals (the main prey of this species) of the subalpine environments inhabited by the boreal owl are, generally speaking, scarce in terms of abundances (Torre et al., 2013). Furthermore, they are modulated by multi-annual populational cycles. In years when mice and voles are less abundant, the productivity of the boreal owl is reduced. Furthermore, the negative impact of forest carnivores on the species increases considerably.

Chapter 2. Important aspects in the habitat of the boreal owl

Four crucial aspects determine the presence of boreal owls: climate factors, abundance of prey, availability of nesting cavities created by woodpeckers (especially the black woodpecker), and how easy it is to locate and capture prey.In the Pyrenees, the species is associated with altitudes of above 1,500 m on the south side and 1,100 m on the north side, and with north orientations, especially at the lowest altitudes of the altitudinal range.

- The abundance of prey has a negative relationship with altitude and a positive one with the abundance of ecotones, elements such as screes, and the abundance of roosts in the form of shrubland and deadwood in forests.
- The abundance of nesting cavities created by woodpeckers depends on the presence of stumps and trees of the minimum necessary diameter.
- It is easier to locate and capture prey in open forests, the possibilities being increased by the availability of low perches from which to spot prey and scarce shrubland coverage.

2.1. Important aspects at a landscape or forest estate scale

2.1.1. Importance of the forest estate scale

In the management of the habitat of the boreal owl, it is crucial to consider the landscape scale due to the large surface area of hunting territories. The hunting territory of a single owl may encompass more than 200 ha, with frequented areas located further than 1.3 km from the nest (Sonerud et al., 1986). By way of example, it has been estimated in Finland that male owls nightly explore a territory of between 54 and 268 ha, and have a home range (on 9 consecutive nights) of between 73 and 499 ha (Korpimäki and Hakkarainen, 2012). The maximum distance in a straight line from the nest to the hunting area was found to be 1,310 m in Norway and 2,880 m in Finland (Korpimäki and Hakkarainen, 2012; Sonerud et al., 1986). This data must be treated with caution in respect of the Pyrenees, since it corresponds to boreal forests with a specific habitat structure and landscape, where the forest management is very often more intensive than in Pyrenean forests

Meanwhile, in addition to the structure of the forest, the abundance of prey depends to a large extent on aspects that go beyond the forest structure of the stands (Figure 18), such as mosaic patterns, abundance of ecotones, presence of pasture areas and structures such as screes (Tellería et al., 1991; Hakkarainen et al., 1996; Hakkarainen et al., 1997; Alonso et al., 1998; Mariné et al., 2007).

Figure 18. Example of an optimal habitat for the boreal owl on the south side of the eastern Pyrenees. Lles de Cerdanya (Catalonia). Source: Ortofoto 1:5,000, Cartographic and Geological Institute of Catalonia.

2.1.2. Altitudinal range and topography

Climate is the variable that best explains the distribution of the boreal owl in Spain (Castro et al., 2008). The species suffers stress during the summer associated with high temperatures (Hayward et al., 1993). It presents a continuous distribution in areas with a favourable climate, whereas in unfavourable areas in the south of Europe it is restricted to mountainous massifs.

The species compensates for the unfavourable climate with the topography of the area, in such a way that the altitudinal distribution is asymmetrical on either side of the Pyrenees (Figures 19 and 20). On the south side of the Pyrenees, the altitudinal distribution range of the species is situated between 1,500 m and 2,200 m (Joveneaux and Durand, 1987; Dejaifve et al., 1990; Dalmau et al., 1998). In most territories it is situated between 1,800 m and 2,000 m (Mariné et al., 2007). Meanwhile, on the north side, it may be present at an altitude as low as 800 m, although in most territories it is found between 1,100 m and 1,600 m (Dejaifve et al., 1990; Mariné et al., 2004; Auria, 2013).

The Pyrenean territories are located in forests in which the average of the maximum temperatures in July does not exceed 17 ºC and where the average temperature for the month of January is between 1 and - 3 ºC (López et al., 2010). The same authors suggest that the threshold of - 3 ºC probably only reflects the temperature of the forest limit and that it is only indicating that limitation at the location of the nests.

Figure 19. Mountain pine forest in the upper zone of the subalpine floor on the south side of the central Pyrenees. Alt Pirineu Natural Park. Author: Jordi Bas.

Figure 20. Upper limits of the forest on the north side of the Pyrenees, dominated by beech and fir groves. Ariège-Agièja. Auhtor: Quentin Giry.

Although altitude has a significant effect on the occupation of nest boxes (López et al., 2010), this fact may be more related to the scarcity of woodland at high altitudes than to climate factors. It has also been suggested that another reason for the high altitude at which most of the boreal owl populations are found on the south side of the Pyrenees may be the competition the species faces from other nocturnal raptors, such as the tawny owl (Mariné et al., 2007). In the southernmost part of the eastern pre-Pyrenees, the abundance of predators such as the beech marten and the pine marten, and of competitors such as the tawny owl, may be one of the factors that explains the low density of the boreal owl (D. Guixé, unpublished data).

Furthermore, the climate factor alone does not explain the distribution of this species on the Iberian Peninsula, since there are other areas of Iberia with a more favourable climate (Castro et al., 2008). The low reproduction rate of the species on the south side of the Pyrenees, added to the high predation rates, indicates that the south side of the Pyrenees acts as a sink (Mariné et al., 2004) and depends on the French populations, which would explain why the species has not managed to colonise other mountain systems of the Iberian Peninsula.

This positive selection of the highest areas runs counter to the density of the main prey of the species, since although there is a wide diversity of small mammals in the subalpine environment (Torre et al., 2013), there is generally a low density of prey species in comparison with the montane area, due to the fact that altitude has a negative effect on the abundance of small mammals (Alcántara, 1989), especially on that of the field mouse, the most common species in forest habitats of the Iberian Peninsula (Torre et al., 2013, see Figure 21).

At the altitudinal level of 1,500-2,000 m, the most abundant species is the field mouse (*Apodemus sylvaticus*), followed by the bank vole (*Myodes glareolus*) and, at some distance, by the greater white-toothed shrew (*Crocidura russula*). Meanwhile, at the altitudinal level of 2,000-2,500 m, the most abundant species is the European snow vole (*Chionomys nivalis*), closely followed by the common shrew (*Sorex araneus*) and the bank vole (Torre et al., 2013).

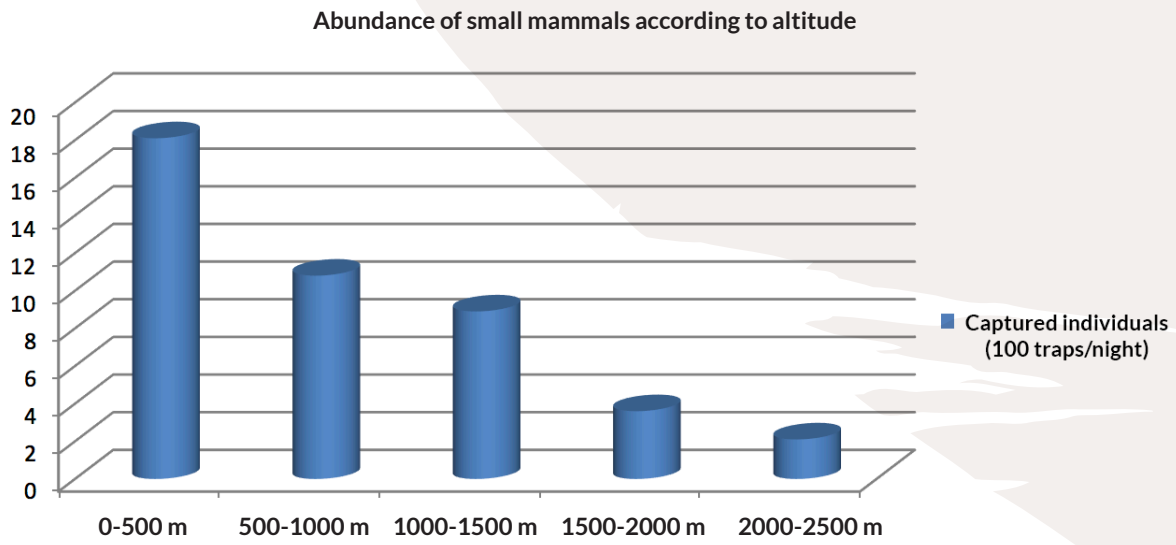

Figure 21. Average abundance of small mammals per plot in relation to altitude, obtained by the SEMICE project (Torre et al., 2013).

2.1.3. Exposure and slope

In the Pyrénées-Atlantiques region (Figure 22), the ONF (French National Forests Office) found that most of the stands where the boreal owl is present have a preponderantly northern exposure (Auria, 2013). This circumstance seems to be related to the search for colder exposures, although it must be borne in mind that in the French Pyrenees, most of the mountain forests have a northern exposure given that the production of pastureland has mostly been carried out in areas with southern exposure (Auria, 2013). In the Catalan Pyrenees, studies have shown that south-eastern, southern and (to a lesser extent) western exposures had a negative effect on the occupation of nest boxes (López et al., 2010).

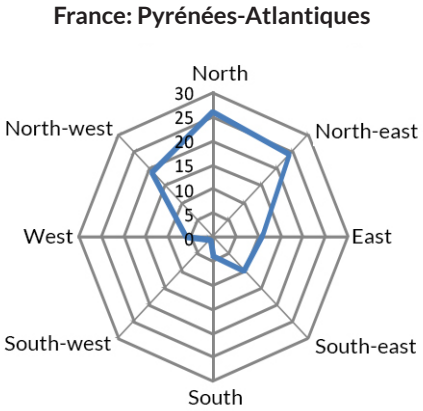

Figure 22. Orientation of the territories in Pyrénées-Atlantiques region of France (Auria, 2013).

Most of the stands studied in the Pyrénées-Atlantiques region of France (65 %) have medium gradients, of between 30 and 60 %, while 18 % of the locations are on steeper slopes and 17 % are on gentler ones (Auria, 2013). The selection of slopes seems well matched to habitat availability, although it is not possible to state that positive selection takes place. Nevertheless, the 13 nests found in this area were in zones with steep slopes (Auria, 2013). It is possible that breeding territories are located in northern exposures with steep slopes in order to minimise exposure to the sun.

2.1.4. Fragmentation, mosaic patterns, paths, ecotones, screes and livestock uses

The aggregated distribution of some territories is significantly related to the proximity of screes, meadows, paths, forest edges and, in general, several ecotonal areas (Mariné et al., 2007; Figures 23 and 24). The importance of these elements is related to the abundance of several species of small mammals. The abundance of the field mouse, an important resource for the boreal owl, is conditioned greatly by edge effects and is therefore favoured by sparse forests and those with clearings (Tellería et al., 1991; Alonso et al., 1998). The field mouse is capable of exploiting —simultaneously or using circadian rhythms— different adjacent habitats that provide it with food and roost both within and outside the forest (Alonso et al., 1998). In open areas, the closer it is to the forest, the greater the abundance, while inside the forest it is found in greater abundance close to edge (Alonso et al., 1998).

Figure 23. Sparse mountain pine forest with pastureland on the south slope of eastern Pyrenees. Author: David Guixé.

Figure 24. Ecotonal areas of shrubland between mountain pine forest and pastureland. Capçaleres del Ter i del Freser Natural Park, eastern Pyrenees. Author: Jordi Camprodon.

Forest clearings covering several hectares create an ecotonal effect. In Finland, in extensive and homogenous wooded areas, the number of chicks that fly is greater in areas with a large number of clearings of felled trees (> 30 %) covering a large area (several hectares) than in areas in which few clearings have been created (Hakkarainen et al., 1996; Hakkarainen et al., 1997). Nevertheless, these hunting areas are temporary, since they cease to be of interest once the regenerated woodland starts to thicken. In the Catalan Pyrenees, open spaces of pastureland, shrubland and screes represent 10 and 15 % of the habitat (the remaining 85 and 90 % is woodland), in a radius around nests of 400 m and 1,000 m, respectively (CTFC, unpublished data, 2020). By way of example, see Figure 18. In 117 territories analysed in the Catalan Pyrenees, the open spaces are composed of Pyrenean broom (*Genista balansae*) shrublands, semi-natural Medio-European meadows, high-mountain and subalpine hay and grazing meadows, Atlantic and sub-Atlantic heathland, *Festuca eskia* grasslands and siliceous screes with rupicolous vegetation (habitats of the CORINE biotopes project).

The screes are home to rich and remarkably diverse communities of small mammals (Figure 25). Whether due to the abundance of roosts, to the abundance of food or to both factors, screes attract a density, richness and biomass of small mammals unrivalled by any other subalpine environment (Mariné et al., 2007).

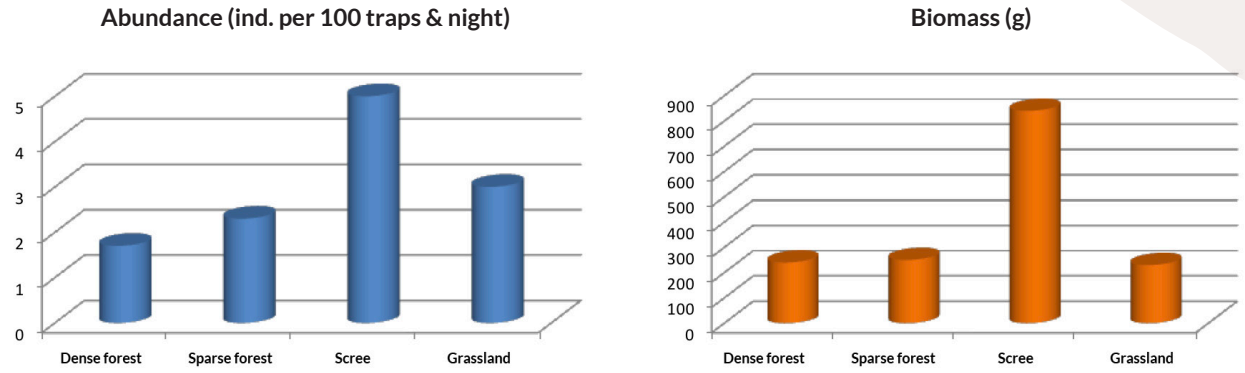

Figure 25. Abundance (in blue) and biomass (in orange) of small mammals in four subalpine environments (Mariné et al., 2007).

The abundance of burrowing small mammals may be limited by the type and quality of the soil, since it is much easier to dig burrow galleries in soft, deep soil that is largely free of rocks, although this may be disadvantageous to species that live above ground (Mariné et al., 2007). Domestic livestock may compact the soil and degrade the vegetation, which may limit the presence of burrowing species and above-ground species such as the field mouse and the greater white-toothed shrew (Torre et al., 1999 in Mariné et al., 2007). Deadwood on the ground, including residue from felling activities, may encourage the abundance of rodents.

2.1.5. Connectivity

The genetic differences between the various European subpopulations are exceedingly small, which indicates a high level of connectivity and a high long-distance dispersal rate (Koopman et al., 2005). In respect of mitochondrial DNA genetic structure, there are no differences between the westernmost population of the species, located in the Pyrenees, and the populations in the centre of Europe. This suggests that contacts exist with the main population or that there has been contact until very recently (Broggi et al., 2013). The lack of genetic differentiation between different boreal owl populations, regardless of matrix type and extent, indicates that the unforested matrix does not act as a barrier to dispersal for this vagile species (Koopman et al., 2007).

2. 2. Important aspects at a plot or stand scale

2.2.1. Tree layer. Forest parameters

❖ Tree species

On the south side of the eastern Pyrenees, the boreal owl is mainly located in subalpine forests of mountain pines, although they can occasionally be found in Scots pine and fir forests (Mariné et al., 2007). On the north side, the species has mostly been found in beech-fir forests (63.5 %), as well as in pure fir forests (11.5 %), pure beech forests (15.5 %) and fir-beech forests (6.5 %), in line with the main types of forest found in the Pyrénées-Atlantiques region of France (Auria, 2013; Figure 26).

Figure 26. Habitat of the boreal owl on the north side of the Pyrenees. Pyrénées Ariégeoises Regional Natural Park. Author: Quentin Giry.

❖ Tree cover density and canopy opening

Tree cover density is defined as the number of trees with a diameter at breast height (DBH) of between 10 and 20 cm per hectare. High values normally indicate dense forests; conversely, a mature stand of large trees will have a low density depending on several parameters, such as the silvicultural treatments carried out. In the Pyrénées-Atlantiques region, the species was detected in 28 % of cases in beech and fir forests with more than 400 stems/ha, in 44 % of cases in forests with densities of between 200 and 400 stems/ha, and in 28 % of cases in forests with less than 200 stems/ha (trees ≥ 20 cm DBH) (Auria, 2013).

On the south side of the Pyrenees, there are a lower number of dense forest stands and a higher number of open forest stands adjacent to boreal owl nesting places, in respect of other zones chosen at random (Mariné et al., 2007). In Catalonia, the CTFC (unpublished data, 2020) found an average canopy cover of 51.3 ± 15.1 % in the 100 metres adjacent to the nest, and a slightly higher 56.6 ± 16.6 % when including the data of singing males. The canopy cover is the fraction of ground area covered by the vertical projection of tree crown perimeters. It is a measurement of the canopy opening and indicates how much light reaches the ground, which is a particularly important parameter in the development of shrubland and herbaceous vegetation (Figure 27).

Figure 27. Pole-stage forest of mountain pines, with trees spaced apart and clearings, a good hunting habitat for the boreal owl. Baiasca Forest, Alt Pirineu Natural Park. Author: Jordi Camprodon.

❖ Unevenness of forest cover

In the Pyrénées-Atlantiques region of France, the sightings of boreal owls have been in beech and fir stands (Figure 28) that have a mainly uneven-aged structure (at least 3 age categories) or a regulated even-aged structure (1-2 age categories). The 13 nests located in this region were found in uneven-aged stands (Auria, 2013).

Figure 28. Boreal owl territory in beech-fir forest of the Pyrénées-Atlantiques region of France. Author: Jean-Claude Auria.

❖ Tree size

24 % of the sightings in the Pyrénées-Atlantiques region were in beech and fir forest stands with predominantly thick trunks (Table 3), 23 % were in stands with predominantly medium trunks, 30 % were in stands with predominantly thin trunks, 15 % were in balanced stands and 9 % were in largely or entirely non-forest areas. Nevertheless, the 13 nests found in this region were located in stands with predominantly thick trunks (Auria, 2013).

Table 3. Distribution of boreal owl sightings in the French Pyrenees according to the structure of the forest (Auria, 2013). The diameter classes (DC) are as follows: thin trunk, DC 20-25 cm; medium trunk, DC 30-40 cm; thick trunk, DC 45-65 cm.

Structure	%	Predominant type	%
Uneven-aged	38	Thick trunk	10
		Medium trunk	3
		Thin trunk	10
		No predominance	15
Regulated even-aged	35	Thick + medium trunk	5
		Thick + thin trunk	3
		Medium + thick trunk	9
		Medium + thin trunk	4
		Thin + medium trunk	14
Even-aged	19	Thick trunk	6
		Medium trunk	7
		Thin trunk	6
Non-forest	9	Pastureland	2
		Heathland	3
		Rocky land	2
		Wetlands	2

In the Pyrenees, the stands occupied by the boreal owl have a significantly greater average trunk diameter than in areas where it is not present. In Catalonia, the CTFC (unpublished data, 2020) found, in pine forests, a normal average diameter of 32.8 ± 3.1 cm in the 100 metres adjacent to the nest. The size of the trees was on average slightly smaller (30.4 ± 3.3 cm) when including the data on singing males.

The cavities created by woodpeckers on which the boreal owl depends in order to nest are generally distributed in aggregate form in mature forest stands, due to the concentration of dead and large-diameter trees (Joveniaux and Durand, 1987; Mariné et al., 2007). Almost all the nests occupied in the Pyrénées-Atlantiques region of France have been found in groups of beech trees in which the black woodpecker has created cavities (J. C. Auria, pers. com.). It has been shown that the greater the proportion of mature forest in the territory, the higher the survival rate of adult males (Hakkarainen et al., 2008); the authors suggest that this can be explained by the fact that mature forests are home to a greater density of prey and, furthermore, provide better roost against predation by raptors. Moreover, in Finland, a positive correlation has been identified between the maturity of the forest and life-long reproductive success (number of breeding events in a lifetime), a parameter that links survival to reproductive success (Laaksonen et al., 2004).

❖ Site quality / tree heights

The site quality is an indicator of the productive capacity (fertility and depth of soil) of a place for a certain forest species. The indicator most frequently used is tree height (total dominant height or total average height). The greater the height, the better the quality of the ecological site. In the French Pyrenees, it was observed that most of the locations (65 %) are found in beech and beech-fir stands with a height of 20 to 30 m, which is indicative of deep soil and average fertility. Meanwhile, 20 % of the locations are found in stands with short trees (less than 20 m) and the remaining 15 % are found in stands with tall and thin trees (more than 30 m) (Auria, 2013). In Catalonia, the CTFC (unpublished data, 2020) found an average height in pine forests of 11.1 ± 1.23 m in the 100 metres adjacent to the nest and 10.4 ± 1.2 m, in respect of the total number of observations (Figure 29).

Figure 29. Boreal owl territory in a high pole forest of Scots pines with good-sized trees, good spacing between stems, regeneration groups of different ages and a mosaic of herbaceous undergrowth and heather shrubland. Andorra. Author: Jordi Dalmau.

❖ Basal area

The basal area is one of the key variables of forest cover and is universally used in the management of forest density. This parameter is calculated by expressing in m^2/ha the relationship between the sum of the normal sections of the forest tree cover and the surface area of the land they occupy. The basal area is an indicator that links the diameter of trees with the surface area occupied; for a zone and certain tree age in order to give an idea of density. In the Pyrénées-Atlantiques region of France, 23 % of the locations were found in beech and fir stands with a basal area of less than 20 m^2/ha; most (54 %) were found in stands with a basal area of between 20 and 30 m^2/ha (stems with a diameter class of ≥ 20 cm); and 23 % were found in stands of more than 30 m^2/ha. The 13 located nests were found in stands with a basal area of between 23 and 30 m^2/ha (Auria, 2013). In mountain pine forests of Catalonia, the species is found in an average basal area of 45.5 ± 11.1 m^2/ha (stems with a diameter class of ≥ 10 cm), in the 100 metres adjacent to the nest (Figure 30). On including the data related to singing males, the area is a slightly smaller 43.9 ± 11.4 m^2/ha (CTFC unpublished data, 2020). This basal area is calculated on the basis of LIDAR data, which is subject to very loose confidence intervals. It is estimated to be too high for these forests, which means that it should be treated with caution.

Figure 30. High forest of mountain pines with characteristics of maturity (large trees). Author: David Guixé.

- Volume per hectare

This is the accumulated wood volume of all the trees of one hectare. It is calculated by multiplying the basal area by the average height of the trees and by a correction coefficient that depends on the type of forest (generally speaking, a value of around 0.5). In beech and fir forests in the French Pyrenees, 18 % of the locations were found in stands of less than 250 m^3/ha, 61 % were found in stands of between 250 and 400 m^3/ha (in forests that are fairly standard in the area) and, finally, 21 % of the locations were found in stands of more than 400 m^3/ha, which is often (but not always) an indication that the stand has not been exploited (Auria, 2013). The nests found in this area (13 nests) are located in stands with a growing stock volume of between 350 and 425 m^3/ha (Auria, 2013).

2.2.2. Presence of clearings

Another noteworthy structural characteristic of the reproductive habitat of the boreal owl on the south side of the Pyrenees is that the forests are relatively open, with plenty of spacing between trees or with a large number of clearings (Mariné et al., 2007). In the Pyrénées-Atlantiques region of France, the presence is this species is linked to the proximity of forest clearings and pastureland (J. C. Auria, pers. com.).

The presence of clearings created by the downing of large-diameter trees (Figure 31) or by the downing of groups of trees is of great interest for hunting purposes, since these clearings constitute ecotonal areas with a wider variety of prey (López et al., 2010). Thinning and regeneration felling operations that favour the thickest trees and create more open structures provide the boreal owl with more hunting areas, especially on forest estates with large surface areas of young or medium pole forest with a high stem density. After final felling takes place, the owl may be able to exploit the ecotones, but they are not especially useful if the seed trees and high stumps that it uses as perches are not retained. Meanwhile, the presence of clearings created by the downing of trees facilitates the owl's hunting strategy within the forest, removing obstacles, providing perches, and facilitating the spotting and capture of prey (Mariné et al., 2007).

Figure 31. Clearing created by a downed large-diameter mountain pine in a monospecific pine forest. Author: David Guixé.

2.2.3. Cavities and deadwood

The presence of cavities in trees is another factor that conditions the distribution of the boreal owl in Pyrenean subalpine forests. Stands with nests have a larger number of cavities than stands chosen at random (Mariné et al., 2007). The lack of availability of suitable nesting activities and the abundance cycles of small mammals are important conditioning factors that lead males to show territorial behaviours and females to be nomadic (Korpimaki, 1987).

One of the structural variables that can best predict the presence of the boreal owl in a mountain pine forest is the abundance of deadwood (Mariné et al., 2007). Deadwood is a crucial element that determines the presence and abundance of woodpeckers on the south side of the Pyrenees: decaying and dead standing trees provide the preferred nesting substrate of woodpeckers. These nests will later be used by the boreal owl, by another secondary cavity-nesting bird, by bats or by other mammals (Figure 32). The beech and beech-fir forests in the Pyrénées-Atlantiques region of France present a different scenario. Here, the black woodpecker excavates its nests mainly in living beech trees (either healthy or decaying) and rarely in fir trees (Figure 33). Meanwhile, deadwood (both downed and standing) provides a source of food for woodpeckers. In its exploration campaigns in the Pyrénées-Atlantiques region of France, the French National Forest Office (ONF) found that there were 18 and 11 cavities/ha in the two main breeding places (Auria, 2013), which gives an idea of the importance of the abundance of woodpeckers and deadwood. Explorations on the south side of the Pyrenees (Cerdanya-Ripollès) by a team of the Forest Science and Technology Centre of Catalonia (CTFC) and the University of Vic (UVic-UCC) found an average of 1.7 cavities/ha and 1.1 tree-nests/ha in the 12 best-known territories of the boreal owl (Rota, 2021).

Figure 32. Black woodpecker nests in dead pines at two different stages of decomposition. Left: Beraní (Alt Pirineu Natural Park); right: Setcases (Capçaleres del Ter Natural Park). Authors: Jordi Dalmau and CEINR.

Figure 33. Old cavity in thick beech tree occupied by the boreal owl. Pyrénées-Atlantiques region, France. Author: Jean-Claude Auria

Deadwood is also an important element for the abundance of owl prey, since downed dead trees serve as roost and as breeding places for small forest mammals, especially in stands with a low abundance of shrubs and moss (Mariné et al., 2007).

Deadwood is also an important element for the hunting strategy of owls, since it provides hunting perches. The abundance of vantage points is a characteristic element of forests occupied by the boreal owl in the Pyrenees (Mariné et al., 2007). According to Norberg (1970), the owl uses low perches (1.7 m high on average) and changes perch fairly frequently (every 1 hr 48 min on average), moving to another perch located at an average height of 17 m. Hayward (1993) describes vantage points as stumps and snags of more than 50 cm in height, small pines of less than 1.5 m and roots of downed trees (Figure 34). The availability of prey may be lower inside the forest and the presence of obstacles may impede hunting activity significantly. However, the hunting strategy of using low perches is an adaptive strategy of the boreal owl that enables it to hunt in sparse forests (Sonerud et al., 1986).

Figure 34. Boreal owl on its hunting perch in a young pine tree. Author: Jordi Bermejo.

2.2.4. Shrub and herb layers

The most suitable forest cover for small mammals is that in which the ground is covered by shrubs and mosses, and/or there is abundant deadwood in the form of accumulated branches and trunks. These elements afford protection from predators and constitute food sources (Mariné et al., 2007).

Forests with little shrub and scrub cover have low densities of small mammals, in comparison with an undergrowth with a large amount of shrub cover and with open spaces. Nevertheless, they are the areas selected as breeding territories, since prey can be more easily spotted and captured there (Sonerud et al., 1986). This situation is observed on both sides of the Pyrenees (Mariné et al., 2007; J. C. Auria, pers. com.). For hunting, the owl prefers well developed high forest stands with a certain amount of shrub undergrowth in mosaic patterns (Figure 35), with a predominance of spaces free of vegetation cover or where the undergrowth is sparse, such as that dominated by European blueberry.

Figure 35. Left: mosaic of European blueberry and rhododendron, a good habitat for western capercaillie and highly suitable as a place of refuge and source of food for small mammals, but a little too dense to facilitate the capture of rodents and insectivores by the boreal owl. Right: area without scrub, close to the area shown in the previous image, with a lower density of small mammals but highly suitable for the capture of prey. The low branches make good hunting perches for the bird of prey. Authors: David Guixé and Jordi Camprodon.

2.3. Important aspects at a tree scale

2.3.1. Parameters of the tree

The main factor that limits the presence of the species in a forest is, in all likelihood, the lack of availability of natural cavities or the lack of those excavated by woodpeckers of sufficient diameter to be occupied by the boreal owl for nesting (Mariné and Dalmau, 2000).

In almost the entirety of its European distribution area, the boreal owl mainly nests in cavities excavated by the black woodpecker (*Dryocopus martius*) (Figure 36). On occasions it occupies cavities excavated by the great spotted woodpecker (*Dendrodopos major*) or by the European green woodpecker (*Picus viridis*) (Mariné et al., 2007). In the Pyrénées-Atlantiques region of France, 80 % of the nests are found in cavities made by the black woodpecker, while the remaining 20 % of nests are found in natural cavities (Figure 37). Furthermore, 60 % are found in old beech trunks with several holes hollowed out in successive years, which are connected to each other inside the trunk, providing wider cavities and escape routes in the event of an attack by a predator (J. C. Auria, pers. com.). The trees selected by the black woodpecker have diameters of more than 35 cm (51 cm on average) (Camprodon et al., 2007; Pirovano and Zecca, 2014). In the Pyrénées-Atlantiques region, all the located nests (13 nests) were found in large-diameter living beech trees (46-61 cm), with cavities excavated at a height of between 9 and 12 m (Auria, 2013). In 12 territories of mountain pine forests (two of which also contain fir trees) in Cerdanya and Ripollès, Catalonia, the normal average diameter of trees with cavities suitable for the boreal owl (n = 67 potential tree-nests) was 42.2 ± 10.6 cm. The holes were hollowed out at an average height of 4.2 ± 2.1 m. 21.8 % of the potential cavities were excavated by the black woodpecker, 61.4 % by the great spotted woodpecker and 6.9 % by the European green woodpecker, while 9.9 % were natural cavities. All the cavities were in mountain pines, except for one cavity excavated by a great spotted woodpecker in a fir tree. 10.4 % of the cavities were in living trees, 22.4 % were in decaying trees and 67.2 % were in dead trees (Rota, 2021). In order to reduce the risk of predation, it is important for there to be an absence of branches below the nest hole and for there to be enough distance from nearby trees to prevent a pine marten or beech marten from leaping onto the tree-nest (Ravussin et al., 2001).

Figure 36. Black woodpecker in its nest in an aspen and young boreal owls peeping out of two holes of old interconnected nests excavated by the black woodpecker in a beech tree. Authors: Eudald Solà and Jean-Claude Auria.

Figure 37. Boreal owl at the entrance to a natural cavity in an old fir tree. Author: Jean-Claude Auria.

2.3.2. Parameters of the nest

Within its altitudinal range of distribution, the abundance of cavities is the characteristic that can best predict the extent to which a forest meets the requirements of the boreal owl (Mariné et al., 2007).

The fact that, in the Pyrenees, the boreal owl uses nests excavated by the European green woodpecker and the great spotted woodpecker is probably due to the lack of availability of nest cavities created by the black woodpecker. This reduction in the density of cavities made by the black woodpecker is due to the scarcity of large-diameter trees and of the rectilinear trees that exist at the highest altitudes of a low-quality forest ecological site (Mariné et al., 2007), as well as to the reuse of nests by the black woodpecker, which means that few old cavities are available, despite the fact that, on occasions, there may be suitable large-diameter stumps that have not been excavated.

In years with an abundance of voles, the clutch size of the boreal owl and the survival of its chicks are strongly linked to the size of the nesting hollow, which is related to the prey storage capacity of medium and large hollows (Korpimäki, 1985). This would explain the preference for the larger nests created by the black woodpecker.

Chapter 3. Forest management to favour the boreal owl

3.1. General planning

In order to ensure the proper planning of the management of forest estates, natural environment managers must have the necessary information concerning the populations of endangered species of the forest estates they manage. Given that, in practice, they do not tend to have all the necessary resources, it makes sense to start by drawing up a strategic prioritization plan. Priorities can be established according to the categories of threat to the species and the level of severity of these threats in the areas to be managed, in respect of the reference contexts: biological ("Do my populations constitute a metapopulation and is this population viable in itself?"; "Are my populations genetically isolated from other subpopulations") and administrative ("To what extent to the forest estates that I manage contribute to the conservation of the species at a regional scale?") Accordingly, the planning and management of a forest estate with the boreal owl or any other endangered species must be coherent with that of the neighbouring estates run by another manager.

Turning now to the forest estate scale, the manager must have up-to-date maps of the territories of the boreal owl, the nest boxes and tree-nests occupied by the boreal owl, and censuses and population trends calculated by experts. Once all this information is available, it is possible to plan forestry work in such a way that it does not reduce the availability of optimum habitat at the forest estate scale. In order to carry out this work, it is essential to have the support of experts on the species.

In light of the foregoing, we come up against a limiting factor: the as-yet-scarce knowledge of aspects of the biology of the boreal owl species in the Pyrenees. A certain amount of monitoring has been carried out by a group of naturalists with extremely limited resources but plenty of determination. That is why in these management guidelines we must occasionally use data from Central and Northern Europe. We hope to be able to fine-tune this data as more information is obtained at a Pyrenean scale. It is important to point out that the boreal owl acts as an umbrella species, given that its survival depends on key species such as small mammals and woodpeckers. Furthermore, in many aspects these recommendations can be applied to other protected species, such as the western capercaillie, the Eurasian treecreeper, the black woodpecker or tree bats.

The forestry management that integrates the conservation of the boreal owl must comply with the legislation in force. This includes the Spanish Catalogue of Endangered Species (Royal Decree 139/2011), where the boreal owl is listed in the "Vulnerable" category, and Law 42/2007 on Natural Heritage and Biodiversity, which incorporates Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora. With the goal of protecting the species afforded special protection, the aforementioned law prohibits "the destruction of the habitat of vulnerable species, in particular their place of breeding, hibernating and feeding, and their home range." The French legislation (Decrees of 29/10/2009, concerning the list of protected birds and protection methods) prohibits throughout the metropolitan territory and at all times: a) the intentional destruction or removal of eggs and nests; b) the intentional disturbance of birds, especially during the breeding and rearing period, whenever the disturbance endangers the proper completion of the biological cycles of the species under consideration; c) the destruction, alteration or spoiling of breeding places and resting places of animals. These prohibitions are applied to the physical or biological elements considered necessary for the reproduction or rest of the species under consideration, whenever they are used or may be used during the successive reproduction or rest cycles of the species under consideration and place them at risk.

3.2. Management in critical areas and breeding places

The management of the forest estate must integrate the conservation of the critical areas and the breeding places defined for the boreal owl in the list of objectives of sustainable forest management.

- **Critical area.** The Law on Natural Heritage and Biodiversity defines critical areas as "the sectors included in the distribution area that contain habitats which are essential for fostering the conservation of the species or which, due to their strategic location for the conservation of the species, require proper maintenance." In the case of the boreal owl, these areas are understood as the breeding area and the hunting or feeding areas used over the course of the year, which may or may not overlap. Forestry work is perfectly compatible with the conservation of the critical area if this work incorporates the basic conservation criteria listed in this manual.
- **Breeding place.** The breeding place comprises the tree-nests and one or several safety perimeters surrounding each tree-nest. The safety perimeter is in the form of two buffer zones, of 10 and 50 metres respectively, around the tree-nest (Figure 38).

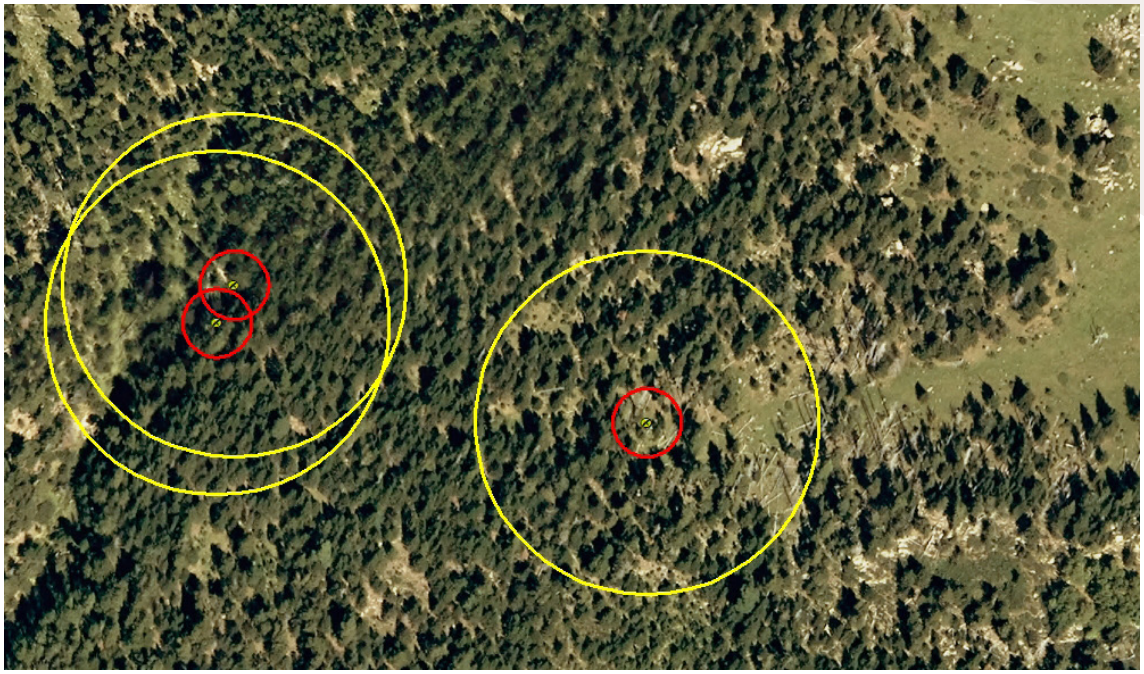

Figure 38. Buffer zones of 10 and 50 metres around known breeding places. The 10-metre buffer zone should be maintained without interventions, on a permanent basis, for the protection of the area immediately surrounding the tree-nest. In the 50-metre buffer zone, forestry work must not be carried out during the nesting season in the event of the nest being occupied.

Infrastructures, motorised access and execution of works in critical areas

• In the 10-metre buffer zone, which includes a tree-nest reoccupied in recent years and the adjacent trees, efforts must be made not to modify the forest structure, ensuring that no new forest paths or skid roads are opened.

• In the 50-metre buffer zone it is advisable not to carry out forestry work during the breeding season, including the conditioning of paths. The breeding season normally lasts from 1 March to 31 July. However, occasionally, the laying of clutches may begin in the last week of February, and chicks may not leave the nest until early August. The supervision of occupied nests from April to early June makes it possible to predict when the chicks will fly and to plan works accordingly.

• The **breeding places** of the boreal should not be subjected to disturbances, caused by excess frequentation and the construction of temporary or permanent infrastructures.

• It is necessary to prohibit motorised access to trails and paths without easement that enter **breeding places** during the breeding season (Figure 39). The use of these paths should be restricted to services.

Figure 39. Motor traffic is prohibited outside authorised paths. Author. Conservation Biology Group-CTFC.

3.3. Forest management at a landscape scale

Mosaic patterns of the landscape

- The existence of open spaces (subalpine pastureland with a mosaic of shrubs, screes and forest clearings) increases the density of small mammals. It is necessary to try to maintain open spaces that are suitable as hunting ground. For guidance purposes, around 10-20 % in an area of 500-1,000 m around nests (Figure 40).

- The areas of ecotonal transition bordering on the forest are especially important since they constitute a favourite hunting ground for the boreal owl (Figure 41). Therefore, it is necessary to foster heterogeneous ecotones in terms of the vertical structure of their vegetation.

- In large areas of continuous forest cover, it is possible to foster the existence of large clearings and the ecotone effect by means of occasional fragmentation of the cover or by turning some of the forest stands in contact with open areas into grazing land, provided that these stands are not critical areas for the western capercaillie.

- It is necessary to ensure the development and maintenance of a fringe of mature forest in ecotonal areas (scree-forest, pastureland-forest) in order to provide areas of high-quality habitat, both for the feeding and for the reproduction of boreal owls.

- The alteration of screes must be avoided when building infrastructures (paths or roads, ski slopes, etc.).

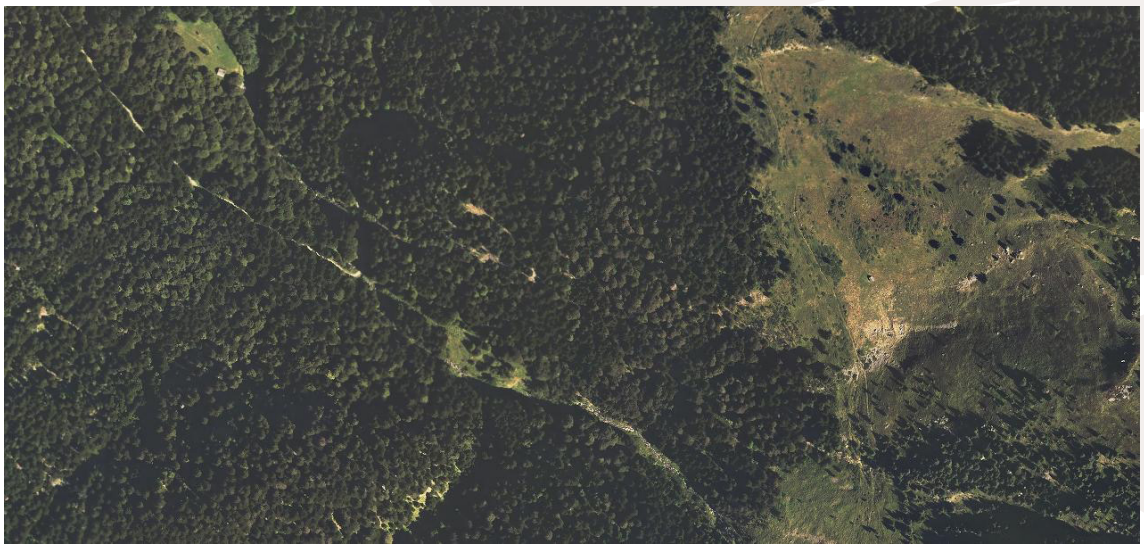

Figure 40. Structure of the landscape in the territories of the boreal owl on the north side of the Pyrenees, on the border between Val d'Aran and Arièja. Source: Ortofoto 1:5,000, Cartographic and Geological Institute of Catalonia.

Figure 41. Ecotonal areas between pastureland and forest in Pallars Sobirà, Alt Pirineu Natural Park. Author: Jordi Bas.

Structure of the forest cover

- A forest estate may contain different forest structures depending on the prioritisation of different objectives and on the current status of forest cover, which may include uneven-aged structures, regulated even-aged structures and naturally-developing stands.
- Continuous forest cover structures at a small scale (uneven-aged structures regenerated on a tree-by-tree basis or in small group shelterwood cutting), with different degrees of tree density, favour specialised forest birds. Nevertheless, closed forest cover prevents the development of the undergrowth, which constitutes an important source of food and roost for small mammals and for undergrowth birds, like the western capercaillie. Meanwhile, it is more difficult to capture prey in stands with dense undergrowth (Figure 42).
- In stands even-aged structure stands, with regeneration units on large plots (> 0.5 ha), it is necessary to plan regeneration in such a way that the young stages (thicket, polewood, sapling) are alternated with adjacent standard tree areas or stands reserved for natural dynamics. This ensures that there are not large surface areas without a suitable habitat for the boreal owl and other endangered species, such as the western capercaillie. This is clearly the ideal situation, but the forest cover is currently uniform in large surface areas, which means that this regulation must be a long-term plan, speeding up and slowing down transitions as convenient.
- It is advisable for at least 10 % of the forest estate surface area (for example, forests of the catalogue of public utility in Spain, CUP) to be reserved for natural dynamics stands, free of interventions, with different ecological site qualities and different altitudinal ranges. These stands should be reserved in zones of high biological value, which may coincide with territories of the boreal owl and with vital zones for other endangered species, such as the western capercaillie. If possible, they should be large stands covering dozens of adjacent hectares, in order to be able to implement regeneration through the creation of clearings:
    - The stands that make up the network must be sufficiently close to each other, within a range of a few hundred metres to a few kilometres.

- The distribution of cavities in subalpine forest is frequently aggregated. It is important to include these zones with a high density of cavities in the reserve zones.
- The stands located in ecotonal areas next to natural grasslands with thickets, pastureland and screes.
- The remaining reserve zones must be located in different ecological sites, not restricted to zones without timber interest or with difficult access.

In France, the *îlots de vieux bois* (ancient or old-growth stands) network is a tool for the conservation of saproxylic biodiversity and species associated with tree cavities in public forests (ONF, 2009). In the Pyrenees, there are extensive areas of planned subalpine forest for protective purposes in forest management plans, such as 50 % of the public forest cover in the county of Ripollès (Catalonia), in the eastern Pyrenees, which is planned due to inaccessibility issues and in order to protect the flora and fauna (J. Faus, pers. com.).

Figure 42. Mountain pine forest with an uneven structure, with some deciduous trees and sparse undergrowth. This favours the diversity of small mammals, increasing prey availability for the boreal owl. Pallars Sobirà, Alt Pirineu Natural Park. Author: Jordi Bas.

Maturity of the forest

- The boreal owl adapts well to standard tree structures with a sufficient number of suitable cavities. Nevertheless, the survival rate of adults is greater the larger the proportion of ancient forest in their territory (Hakkarainen et al., 2008). The maturity of the forest is associated with a greater availability of cavities and greater capacity for offering a change of nest in the event of the downing of a cavity tree, an attack by a predator or the proliferation of parasites. Meanwhile, the phases of decay of old trees scattered across the stand go hand in hand with the formation of clearings and the heterogeneity of undergrowth cover, which favour the diversity of flora and fauna, including small mammals. As such, a mosaic-type distribution of the undergrowth will provide good hunting territories for the boreal owl (Figure 43).
- A mature forest or stand is understood as tree cover with old trees, close to the limit of their longevity, with abundant decaying and dead trees, subject to gap dynamics (the decay of staddle trees create clearings

suitable for regeneration). To be more precise, mature forests or stands can be identified by the existence of trees in a succession of advanced states of maturity, including some of an age close to the limit of their longevity and with an average age in the stand equivalent to around half of the aforementioned longevity (Fiedler et al., 2007).

- In mature stands, the preferred management option is to let ecological processes run their course (natural dynamic). In maturing stands, it may be advisable to implement certain proactive interventions aimed at fostering one or more of the elements of maturity (for example, increase the amount of deadwood, increase the surface areas of clearings or increase vertical heterogeneity) by means of silvicultural actions (EUROPARC-Spain, 2017).

Figure 43. Mature fir forest in Torla, in the Ordesa-Monte Perdido National Park. Author: Ramón Jato.

Grazing of ungulates

- Grazing by wild and domestic ungulates may be a help or a hindrance to the development of undergrowth and to regeneration, depending on the livestock load (Figure 44). A weak livestock load would be around 0.1 Livestock Units/ha (1 LU = 1 adult bovine or equine animal, 1 young cow or 6-7 ovine animals in vital places). Several empirical studies suggest that when the livestock load reaches approximately 0.5 LU/ha, there is a negative impact on the European blueberry and other species of the undergrowth. In the event of using bovine or equine animals to control the woody vegetation of good quality ecological sites, loads may be intense and concentrated for a few days until the desired effect is achieved. Wool-producing livestock should always be accompanied by a shepherd, who must have a map of the areas where grazing is permitted.
- In areas with a high density of deer population, such as Serra del Boumort (Catalan pre-Pyrenees), constant grazing over the undergrowth completely degrades it. In critical areas like this, exclusion zones in the form of small plots can be created to keep out wild and domestic ungulates, both in forest areas and on pastureland. This encourages the growth of populations of small forest mammals and of open habitats, creating important reserves of prey for the boreal owl and other predators.

Figure 44. Images of domestic and wild ungulates grazing in critical areas of the boreal owl and western capercaillie, taken by means of camera trapping. Author: Conservation Biology Group-CTFC.

3.4. Forest management at a stand scale

Tree cover and density

- Areas with standard trees, the more mature the better, should be selected as feeding and nesting territories (Figure 45). In stands with active forest management, an average canopy cover of around 50 % should be procured, distributed between 30-70 % of the area in groups of trees. The basal areas should be approximately 30-35 m^2/ha, which would be in keeping with a minimum average diameter of 30-35 cm with densities of between 450 and 650 stems/ha.

  In areas with a thick canopy, thinning may be considered for the improvement of the habitat (Figure 46). This measure may be applied in dense Scots pine and mountain pine forests (in excess of 900-1,200 stems/ha), reducing (for guidance purposes) 20-25 % of the basal area, in order to encourage the existence of forest stands with greater diameter growth.

Figure 45. *Lek* (courting ground) of the western capercaillie in a Scots pine forest, which in turn is an optimal habitat for the boreal owl. Photograph taken by means of camera trapping. Author: Conservation Biology Group-CTFC.

Figure 46. Very dense sapling stand where stems have been marked for bottom-up thinning in order to let in more light and favour the European blueberry. Capçaleres del Ter Natural Park. Author: Conservation Biology Group- CTFC.

Cover and treatment of the undergrowth

- The undergrowth should ideally form an open mosaic of shrubland and regenerated woodland that does not exceed 50 % of cover.
- The indiscriminate alteration of the undergrowth must be avoided during timber work, creating few strip roads, which additionally reduces costs. However, well controlled micro-disturbances caused by forest activities or the passing through of ungulates may favour regeneration, the microbiome of the soil and the germination or activation of the vegetative reproduction of the European blueberry and other shrub species.
- During forestry works it is necessary to respect bush and tree species that produce fruits eaten by small mammals (*Sorbus*, *Corylus*, *Rubus*, *Rosa*, etc.), particularly those that grow in abundance in clearings and along forest edges.
- Shrub growth in mosaic patterns can be facilitated through selective mixed thinning in stands of middle size or standard trees with a canopy cover of more than 75 % and the presence of scattered and not especially vital European blueberry or bearberry shrubs (Camprodon et al., 2016) or through the creation of small clearings. This stimulates the fructification and growth of short Ericaceae shrubs in mosaic patterns, creating a suitable habitat for the western capercaillie and small mammals, as well as ideal hunting ground for the boreal owl (Figure 47).
- In dense and extensive rhododendron bush formations (densities > 80 % and height > 80 cm), the hunting habitat may be improved by creating scattered small clearings (Figure 48) (for example, with a radius of around 5 m and an uneven perimeter) in the area, ensuring as far as possible that they are not connected to fauna trails in order not to facilitate the presence of ungulates and predators, and ensuring the presence of hunting perches inside the clearing or at its edges. These clearings remain functional after 10-15 years (Camprodon et al., 2016).

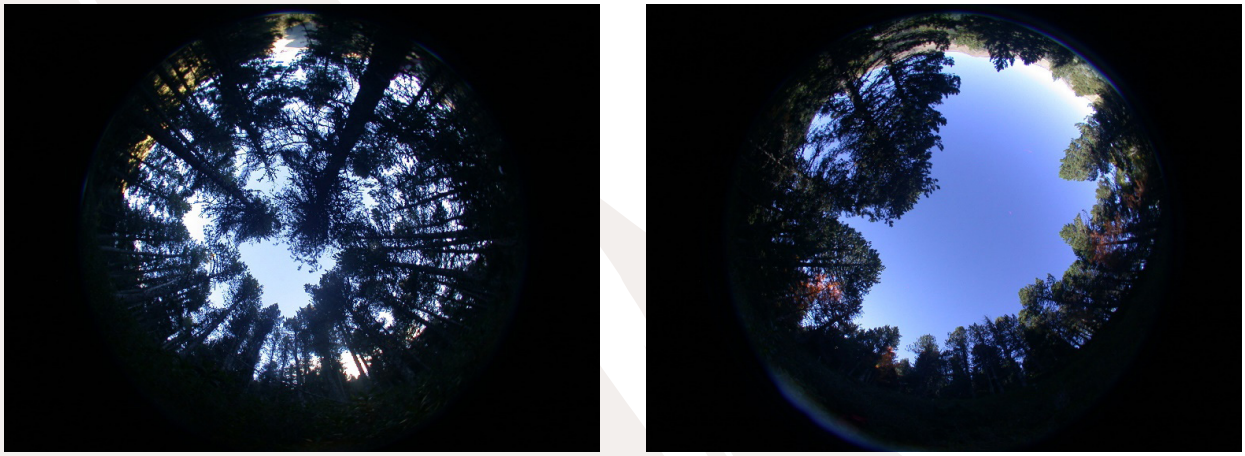

Figure 47. Hemispherical photographs of the tree canopy before and after creating clearings to favour the presence of the fleshy fruit shrub species. Author: Conservation Biology Group-CTFC.

Figure 48. Small clearings created in very dense and high rhododendron shrub cover in order to facilitate breeding by the western capercaillie and to provide optimal hunting territory for the boreal owl, since it makes it easier to capture prey. The growth and fructification of the European blueberry is favoured. The perimeter should be uneven, mimicking the natural distribution of the undergrowth in the forest estate. Author: Conservation Biology Group-CTFC.

Regeneration of the tree layer

- Regenerating uneven forest cover on the basis of individual stems, groups of trees or small groves that are adapted to the specific conditions of the terrain (ecological micro-site) makes it possible to maintain, both over time and spatially, tree structures that are favourable to the boreal owl. The creation of heterogeneous structures of different age classes in mosaic patterns is also favourable to other forest species, such as the western capercaillie or woodpeckers.
- If regeneration is carried out on the basis of groves of a certain size (roughly up to 1000 m^2), it is better for them to be distributed as stands rather than being adjacent to one another. In large groves, reserve seed trees should be maintained in small groups of 4-8 trees, encompassing approximately 10-20 % of the grove (Figure 49).
- In even or non-even structures regenerated through successive uniform thinning, preparatory cutting and removal cutting are compatible with boreal owl breeding territories, if trees with cavities are respected.

- Both these stands, after final cutting, and dense sapling and middle-size tree stands are to be avoided as breeding habitats. Once final cutting is completed, the boreal owl can use these stands as hunting areas, if perches are available (remnant pines, advanced-regenerated seedlings, high stumps, Figure 50), while the shrub cover and the recruitment of newly emerged seedlings should form an open mosaic that does not cover more than 50 % of the area, approximately. Once a dense pole stage is achieved, these stands are also to be avoided as hunting areas.

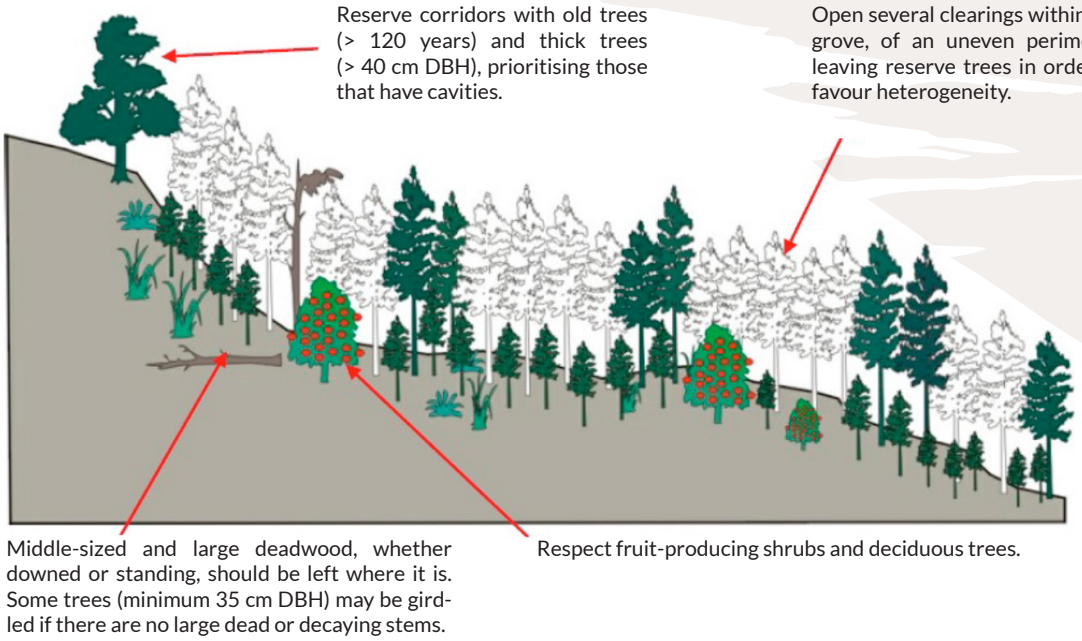

Figure 49. Distribution of important elements for biodiversity inside a standard-tree grove. Adapted from Ménoni et al. 2012.

Figure 50. High stump, in mosaic-pattern undergrowth, ideal as a perch for the boreal owl in order to spot prey. The old stump has offered microhabitats for invertebrates and an anthill has used its base for support. Author: Conservation Biology Group-CTFC.

learings within the stand

- The existence of small clearings within the stand increases the unevenness of the stand and creates zones of high interest for small mammals (Figure 51). Small clearings should be created within the stand, with a minimum diameter of 1-1.5 times the dominant height. In sloping forests of mountain pines, it is the ideal size for maintaining the stability of snow cover. Depending on what is conserved on the ground, groups of advanced regenerated seedlings and of shrubs that produce fleshy fruit should be prioritised.
- This measure is especially important in forest estates with continuous tree cover and with little or no mosaic-type cover.

Figure 51. Clearing with regenerated woodland managed by means of close-to-nature silviculture. Cerdanya, eastern Pyrenees. Author: Jordi Camprodon. Autor: Jordi Camprodon.

Deadwood

- It is necessary to preserve standing deadwood of a minimum thickness corresponding to the 25-cm diameter class, although in the case of the boreal owl, stumps of the 35-cm diameter class are a better option. Standing deadwood provides breeding and food for woodpeckers.
- It is important that all the deadwood that is downed through the natural dynamics of the forest and through small disturbances should be kept on the ground (Figure 52). This is a mandatory measure in French public forest estates. Deadwood provides food and roost for woodpeckers and small mammals. It also provides the boreal owl with hunting perches. In forests with very little undergrowth, it is the only source of roost for small mammals, which explains the importance of this measure.
- In stands affected by large disturbances (such as storm Gloria in January 2020), in which a large quantity of trees is split or downed, commercial-grade timber should be removed, while the split wood of mid-size and large trees should be left standing (preferably forming small groups scattered around the stand). Part of the downed wood should also be left on the ground. In protective forests, no intervention should be carried out, given that it is a natural process. Pheromone traps for bark beetles should be set if necessary.

Figure 52. Undergrowth mosaic with abundant deadwood on the floor resulting from felling and serving as roost for small mammals. Author: David Guixé.

3.5. Forest management at the tree-nest scale

The low availability of natural cavities for nesting, especially in conifers, means that boreal owl mainly has to use nest cavities originally excavated by woodpeckers. At this scale, the goal is to maintain the trees with woodpecker nests and have a reserve of trees of the right stature in order to replace them in the short and medium term. For this task it is essential to be able to identify the important trees for its microhabitats, such as those with cavities (trees to be reserved) and to mark trees to be cut and/or reserved.

Encouraging the presence of trees with cavities

- A good territory has a sufficient number of cavities to ensure the annual turnover of breeding, along with emergency cavities in the event of the need to reposition clutches due to predation, competition or the collapse of the tree-nest (Figure 53). In good territories in beech forests of the Pyrénées-Atlantiques region of France, between 10 and 20 stems/ha with cavities have been found (Auria, 2013), while in the mountain pine forests of the eastern Pyrenees, the maximum number was 4 trees/ha, in standard tree stands with trees of up to 120 years old (Rota, 2021), a density estimated to be relatively low. The minimum recommended density that should be provided is 5 stems/ha with cavities, the ideal number being between 10 and 20 stems/ha. For the entire set of birds that breed in cavities, the same densities have been recommended in beech forests (Camprodon, 2013), although in this case cavities of different types and sizes were included. The smallest ones are suitable for the great tit and the Eurasian blue tit, but not for nocturnal birds of prey.

- The aforementioned densities may be achieved by reserving different types of tree, which will provide cavities now along with replacement cavities in the short and medium term:

    - Trees with complete woodpecker cavities: preferably created by the black woodpecker but also complete holes created by the European green woodpecker, the great spotted woodpecker and the white-backed woodpecker (in beech-fir forests). Old nests of small woodpeckers are used when the bigger cavities of black woodpecker are not available.
    - Standing deadwood trees with a straight trunk and delimbed up to at least 4 m, with a DBM of at least 25 cm but preferably of 35 cm or greater (Figure 54).

- Trees of the same size with signs of decay; for example, those with signs of having been used by woodpeckers.
- Large trees just under or over half the natural lifespan for that species. From 150-200 years old, a conifer begins to show lesions and suffer processes of decomposition that over time create cavities that can be used by the owl.

- The trees with future cavities should be distributed along the length and breadth of the stand, in groups of 3-5 good trees that can provide natural cavities or be selected by woodpeckers in order to build their nests, especially in areas of good structure, such as hunting areas.
- Another way of providing future cavities is by girdling trees of the right aspect, with a DBH of at least 35 cm, if possible, in groups of 3-5 trees scattered around the stand. This will facilitate the excavation of nests by the black woodpecker as the trees enter into decay. If there are no trees of this size in the stand, it is possible to girdle tress in the 25-30 cm diameter class, since they are suitable for the great spotted woodpecker and the European green woodpecker (Figure 55).

Figure 53. Abundant deadwood downed in a gale. It includes tree-nests for the boreal owl. It is important to provide abundant stumps of the right thickness and height to serve as a replacement for nests. Author: Jordi Dalmau.

Figure 54. Boreal owl in its nest in an old mountain pine stump. Ripollès, Catalonia. Author: Jordi Bermejo.

Box 1. Girdling and weakening of trees

Girdling consists of the complete removal of a strip of bark and external wood of the tree (phloem and cambium). The strip has a width of around 10-20 cm and is not very deep; just enough to make the sap run. The girdled tree will decay over the years and will constitute an ideal substrate for woodpeckers to build their nests. With the goal of encouraging the presence of woodpeckers, girdled trees should be as thick as possible, preferably delimbed and with a straight trunk. Trees that sow signs of decay can also be used.

Another option is to select trees with malformations, forked at height and with hardly any commercial value, although they will not be so attractive to woodpeckers. It is preferable for them to be located away from skid roads and from paths and trails, for the safety of workers and walkers, and in order not to disturb timber activity.

Figure 55. Process of girdling a pine tree. A chainsaw or axe may be used. Author: Jordi Camprodon.

Installation of nest boxes

When the existing cavities are scarce, it is possible to install nest boxes designed specifically for the boreal owl (Figure 56). In order to prevent predation, it is highly recommendable to install a model that incorporates defence mechanisms, such as a metal sheet lining the box so that the carnivore cannot reach the hole or a metal sheet with a width of at least 1.5 m wrapped around the trunk, which prevents the predator from climbing up to the box from the ground (Figure 56). It is also important to place the box in a tree separated from other co-dominant trees, so that no mustelid can leap onto the tree with the nest box from a neighbouring tree. Some forest estate managers or researchers do not use anti-predation measures, since they consider that this is a process that forms part of the ecological dynamics of the forest. Nevertheless, if the goal is to recover an endangered species, anti-predation measures are recommended.

The installation of nest boxes must be understood as a transitory measure as a conservation tool. Meanwhile, they are an extremely useful resource for monitoring boreal owl populations; for example, in order to know its reproductive success, a variable strongly associated with the availability of prey, which in turn depends on the quality of the habitat, disturbances and interannual meteorological conditions.

Korpimäki (1985) establishes the optimal size of the next box bottom as 20x20 cm. The orientation of the nest boxes has an influence on the size of the clutch: boxes placed facing south and south-east of the trunk have larger clutches than those of other orientations (López et al., 2010), which can be attributed to greater thermal comfort. Nevertheless, nest boxes with significant exposure to the sun's rays can have problems with fleas and other parasites brought by prey (J. Guillén, pers. com.)

Figure 56. Types of next box for the boreal owl. Top left, model by the Schwegler brand made out of wood cement; top right, conventional model made out of wooden planks; bottom left, "hollowed log" model with metal sheet attached below as an anti-predation system; bottom right, the same model during an inspection using an endoscopic camera inserted in a telescopic perch. Authors: Enric Badosa (top two photographs), Jordi Guillén (bottom two photographs).

Summary of management guidelines

Managers of natural areas must have all the necessary information (maps of critical areas, locations of tree-nests and cavities, etc.) in order to know the importance of their management area for boreal owl populations and to be able to incorporate this knowledge in the planning of their forest estates.

Management in critical areas

- Critical areas: the breeding area and the hunting or feeding areas used over the course of the year, which may or may not overlap.
- Breeding place. Nests reoccupied over several years should be surrounded by a 10-m buffer zone within which the forest structure should not be altered, and by a 50-m buffer zone in which forestry work should not be carried out during the breeding season (1/03-31/07).

Forest management at the landscape scale

- The conservation of the boreal owl depends on the maintenance and development of a mosaic-type landscape that combines forests (standard tree structure), pastureland dotted with shrubs and screes.
- Boost the presence of large clearings and the ecotonal effect by means of the occasional fragmentation of forest cover or by turning some forest stands into grazing land (proportion of 10-20 % within a perimeter of approximately 400 m around the nests).
- Foster the development and maintenance of a fringe of mature forest in the ecotonal areas (scree-forest, pastureland-forest).
- Regulate livestock loads without exceeding 0.5 LU/ha. Create exclusion zones for domestic and wild ungulates in small plots, both in forest and pasture zones.
- Avoid the alteration of screes and the structural homogeneity of ecotonal areas.
- Plan regeneration in such a way that the young stages (thicket, pole, sapling stand) are alternated with adjacent standard tree areas or stands reserved for natural development.
- It is advisable for at least 10 % of the subalpine forest surface to be reserved for naturally-developing mature forests or stands, free of interventions.

Forest management at the stand scale

- The ideal tree structure in Scots pine and mountain pine stands is a canopy cover of between 30 and 70 %, with a basal area of approximately 30-35 m^2/ha, preferably concentrated in large-diameter trees (for example, between 450 and 650 stems/ha with an average diameter of between 30 and 35 cm).
- The ideal structure of the undergrowth is an open mosaic of shrubland and regenerated woodland with a cover of not more than 50 %. Thinning can be carried out to improve the cover of European blueberry, bearberry and other fruit-producing shrubs, and clearings can be created in dense rhododendron shrubland in order to facilitate the capture of prey.
- Create a 10-20 % surface area of clearings within the stand, with a minimum diameter of 1-1.5 times the height of the adjacent trees.
- Maintain all the deadwood of mid-size and large trees that is produced through natural dynamics and through disturbances of low intensity.
- Avoid the indiscriminate alteration of the undergrowth during timber work, strategically selecting skid roads.
- Provide continuous cover structures of standard/mature trees, regenerated on a stem-by-stem basis or in groups of trees or small copses. The copses should be no bigger than 1,000 m^2 and must be separated by corridors of optimal habitat.
- In large copses, seed trees should be maintained in small groups of 4-8 trees, encompassing approximately 10-20 % of the grove.
- In even-aged or semi-even-aged structures regenerated through uniform shelterwood cutting, preparatory cutting and removal cutting are compatible with boreal owl breeding territories if trees with cavities are respected. Once final felling is completed, the stands should be avoided as a breeding habitat but they can be used as hunting areas in the first stages after final felling. Once dense pole forests are formed, the stands are no longer used.

Forest management at the tree-nest scale

- A set of trees should be reserved for future use. These trees will provide replacement cavities in the long term: from 5-10 trees/ha to 20 trees/ha distributed uniformly around the stand, chosen from the following types:
  - o Trees with complete woodpecker cavities; standing deadwood trees with a straight trunk and delimbed up to at least 4 m, with a diameter class of at least 25 cm but preferably of 35 cm or greater; trees of the same size with signs of decay; large trees just under or over half the natural lifespan for that species.
  - o Distribute the trees in areas of good structure such as hunting sites.
  - o When few trees are available to reserve for the future, the creation of new cavities can be fostered by girdling straight stems with a diameter class of at least 35 cm. If no trees of this size are available in the stand, trees with a diameter class of 25-30 cm can be used.
- When the existing cavities are scarce, nest boxes designed especially for the boreal owl can be installed.
- The incorporation of anti-predation measures is strongly recommended.

Figure 57. Elements to consider in the habitat of the boreal owl. In the illustration, a grove of mountain pines with rhododendron and European blueberry shrubs. Healthy trees, decaying trees and large stumps that provide substrate for the nests of the black woodpecker, the European green woodpecker and the great spotted woodpecker, thanks to which there are occasionally old cavities with multiple holes. There is also downed deadwood of different sizes, small groups of regenerated pine trees, along with blueberry, rhododendron and raspberry bushes, herbaceous plants, rocks and screes, ecotones with pastureland, common junipers and Pyrenean broom. These ecotones are all microhabitats for small mammals, such as the wood mouse, the yellow-necked mouse, the European snow vole and the field vole. Natural or high-cut stumps, used as hunting perches. The same habitat is shared by ungulates, the western capercaillie and predators-competitors of the boreal owl, such as the pine marten and the tawny owl. Drawing: Toni Llobet.

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