Multiscale analysis of habitat selection by Bonelli´s eagle (*Aquila fasciata*) in NE Spain.

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Abstract:

The habitat selection of 14 individual breeding Bonelli´s eagles equipped with satellite tracking devices was evaluated using a multiscale approach during different periods of the annual cycle over eight years. We studied whether habitat structure and prey availability influence habitat use through the use of vegetation templates and censuses of potential prey. The results showed heterogeneous selection of wooded, rocky and scrub areas alternating with agricultural areas at a regional scale. At the home range scale, forests and scrubland were mainly selected over the entire year, except during the breeding season, when, surprisingly, humanized areas were selected. Although Bonelli's eagle is considered a forest raptor, during the breeding season they select other types of habitat (i.e. urban areas and dense scrub). This may be related to the high prey availability (especially pigeons) in these areas. Because habitat selection differs at different scales, understanding the effects of this plasticity may be necessary to establish protected areas including urban areas and implement habitat management actions.

Keywords: GPS Satellite telemetry; multiscale approach; habitat selection; Compositional analysis; prey availability.

1. Introduction

Spatial and temporal scales in ecology have been included in scientific research for decades (Wiens 1989; Levin 1992). In the field of conservation biology, and more specifically in habitat selection studies, the selection of an appropriate scale is very important. Ecological patterns that determine habitat selection may act differently depending on both the spatial scale and temporal scale (Wiens 1989; Levin 1992; Rico et al. 2001). Moreover, multiscale approaches may reveal patterns that are not perceived at a single scale (Levin 1992) and may be determinant in species conservation (Ontiveros et al. 2004).

The use of new tools allows a non-arbitrary scale selection based on biological criteria for the species. The implementation of Geographic Information Systems (GIS), GPS-tracking data and ecological data have been selected in these types of multiscale habitat selection studies, especially land cover databases (Balbontín 2005). One of the most popular land cover databases in Europe is CORINE. Despite the fact that CORINE is a systematically constructed land cover database covering a large area, it has been shown that this type of land cover data may be insufficient at a detailed scale (Heikkinen et al. 2014). For this reason, it is important to explore particular habitat structures, especially at a local scale where these features may change more rapidly (Wiens 1989). In addition, comparisons should be made with the available digital land cover information.

Similar to habitat structure, climate and resource availability can influence habitat selection as well (Ontiveros and Pleguezuelos 2000; Ontiveros et al. 2005; López-López et al. 2006). Territorial species establish their home range based on resource availability, for example, the availability of nesting areas (López-López et al. 2006) and prey (Ontiveros and Pleguezuelos 2000). However, this resource availability may vary over the years or over particular periods in a single season. Recording food availability and its distribution throughout the home range can help to understand occurrence patterns of individuals at a particular place (regional scale) or the establishment of their territories (home range scale), but also their particular use of resources within the home range (local scale).

This is the case of Bonelli´s eagle (*Aquila fasciata*), a territorial raptor that is distributed throughout the western Palearctic, but mainly restricted to the Mediterranean region (Hagemaijer and Blair 1997; Ontiveros 2014). In the last several years, it has suffered a general decline in its populations (Birdlife International 2015), but most severely in the Western area of the Iberian Peninsula (Ontiveros 2014). Changes in land use by humans and a decrease in potential prey availability have played an important role in their decline (Ontiveros 2014).

Studies about habitat selection by Bonelli´s eagle are key to gaining knowledge about the spatial ecology of this species. Muñoz et al. (2005) and Carrascal and Seoane (2009) indicated the factors affecting the distribution of this species at a large-scale using geographic, climatic, landscape and human variables. On the other hand, Carrete et al. (2002) and López-López et al. (2006), explored habitat preference factors at a local scale also using these types of variables. Balbontín (2005) used the same approach to study juvenile dispersal. To our knowledge, this is the first study that uses precisely-defined home ranges (Martínez- Miranzo et. al. 2016) of 14 adult individuals of different sexes at different spatial and temporal scales.

The aim of this study is to evaluate habitat selection by Bonelli´s eagle at different spatial and temporal scales and whether factors like habitat structure and prey availability determine long-term habitat selection. According with that, the results of this study may have important repercussions in the knowledge about the spatial ecology of this eagle, helping to establish appropriate conservation policies.

2. Methods

2.1. Study area

The study was conducted in the Aragon Region, Northeast Spain. The altitude in the area ranges from 130 to 1200 m above sea level. Land cover consists mainly of coniferous forests and large areas of Mediterranean scrub filled with cultivation areas, mostly of dry cereals, fruit trees and Mediterranean crops (olive trees and vineyards). Crags, cliffs and other unproductive areas like steppes are also present in this area (Sampietro et al. 1998).

2.2. Data collection

From 2004 to 2013, 14 adult breeders of Bonelli's Eagles (8 males, 6 females) were trapped in Aragón using radio-controlled bow-net traps. All individuals were ringed with a metal ring and were equipped with a 45-g Argos/GPS PTTs device (Microwave Telemetry, MD, USA). Transmitters were powered with solar panels and fixed to birds as backpacks with a Teflon harness with a central ventral rupture point (Garcelon 1985). The weight of the transmitters only represents 2.25% of total body weight (Kenward 2001). PTTs were programmed to work between 6:00 h. and 21:00 h. and collect one location per hour. To avoid bias towards roosting areas, consecutively repeated locations in the early morning and late evening of inactive eagles were excluded because they were considered to be non-independent (Swihard and Slade 1985; Seaman and Powell 1996; Kenward 2001). A total number of 59 482 locations from the fourteen individuals were obtained.

2.3. Multi-scale and temporal habitat selection

The size and shape of the home range between years is maintained by Bonelli's eagles in this area, but there are variations in the use within the home range depending on the period of year (Martínez-Miranzo et al. 2016). The analysis of habitat selection was conducted at three different temporal scales and spatial levels of detail according to Johnson (1980) (Regional Scale, included all Aragon Geographical Region; Study Area scale, included all space with valid location obtained by GPS; and Home Range scale, within each territory calculating from GPS data ; RS, SA, HR, hereafter).

For the temporal variations in habitat selection we divided the year into three periods related to the biological cycle of the species (Arroyo et al. 1995). Period 1 was defined as the non-breeding season (NBr), from September 1 to February 14, when breeding individuals are less tied to their nesting area and made distant movements (Ontiveros 2014). In period 2, or the breeding season

(Br) (from February 15 to June 14), both parents invest in clutches but females spend most of the time at the nest, and in general parents' movements are restricted (Ontiveros 2014). During period 3, or post-fledging dependence period (Pfd), between June 15 to August 31, parents continue to feed fledglings near nesting areas until the juveniles leave the territories where they were born and disperse (Real et al. 1998).

The different habitat types were extracted following habitat structure criteria from previous Bonelli’s eagle preferences (Ontiveros 2014) from categories in CORINE Land Cover (European Environment Agency 2007) depending on the scale used for the analysis (CLC 2006 for regional and study area scale and CLC 2000 for home range scale). We were unable to use the same CLC data for all the analysis because the detail level of CLC 2006 is lower than later versions of CLC 2000 (Table 1). In order to stablish more precise habitat structure preferences at a home range scale the 3 highly selected categories for study area scales (Forest, Scrub and Grassland) were redefined more precisely into 9 new categories following CLC 2000 (i.e study area: scrub was redefined at a home range scale into dense scrub, open scrub, coniferous scrub and hardwood scrub) (Table 1). The number of categories were restricted according to data analysis used (Aebischer et al. 2003).

To test for random habitat selection by breeders at a RS we performed Chi square analysis in Statistica 8.0 software (StatSoft, 2007). Using Random Point Generation in ArcGis 9.3 software (ESRI 1999-2009), we generated the same number of random points as GPS locations in all Aragon Region area and tested the frequency difference between the two data sets. ANOVA analysis in Statistica 8.0 software was selected to test the temporal variation at this scale.

To perform habitat selection analysis at the SA level, we built **a** Minimum convex polygon (MCP 100%) defined as the maximum area used by individuals (Kenward 2001). MCP was calculated with all valid locations including outermost locations. Individual home range was estimated using Hawth’s tools (Beyer 2004) and Fixed Kernel methods, 95% isopleths (Worton 1989) with a default smoothing factor=1 (Fernández et al. 2009; Bosch et al. 2009; Martínez-

Miranzo et al. 2016) in ArcGIS 9.3 software. Home range sizes were constructed using only diurnal locations.

Compositional Analysis described by Aebischer et al. (2003) was selected to study habitat selection at SA and HR levels. This analysis utilizes a MANOVA test to compare the proportion of habitat available to habitat used and shows a rank of habitat types in order of use. In the cases where the habitat value is zero (not available or no use), we used the value 0.01 as recommended in Aebischer et al. (2003).

We conducted vegetation templates within the study area to find differences in habitat structure at an HR scale between CLC 2000 and actual composition. Following the method described by Prodon and Lebreton (1981), we recorded the vegetation structure along 140 randomly selected transect (2.5Km approx. each). In total, 1033 vegetation templates were made at the beginning and end of each itinerary and each time there was contact with any potential prey. Line transects were performed on foot during two consecutive years during the three annual periods previously described. We visually estimated grass cover (the percent of vegetation below 0.5m in height), scrub cover (the percent of vegetation between 0.5m and 2m in height) and tree cover (the percent of vegetation above 2m in height).

Only scrub cover was selected for the analysis because scrubland has a positive effect on the frequency of species occurrence (Carrascal and Seoane 2009) and is one of the most selected habitat types at this scale. With the percent of vegetation structure calculated in each transect, we created two categories in relation to the principal type of scrub cover in CLC 2000. Values between 0% and 40% were selected because they best fit the values recorded by CLC 2000. Open scrub was assigned to percent between 0%-40% and dense scrub to percent between 40% and 100%. We compared whether there were differences between scrub cover in CLC 2000 and the actual scrub cover. In addition, we checked for the possible difference between periods and years.

2.5 Prey availability

To record prey availability at different habitat types, we selected the main prey groups for this species in Aragon. Pigeons (including *Columba* sp. and *Streptopelia* sp.) (27 %), Lagomorphs (including *Oryctolagus cuniculus* and *Lepus europaeus*) (22%), partridges (*Alectoris rufa*) (11%) and corvids (*Corvus sp.*) (7%) (Alcántara et al. 2003) represent up to 67 % of Bonelli´s eagle diet in Aragon. Direct censuses on foot were performed (Tellería 1986). A total of 140 random transect (2.5 Km aprox. each) were performed during two consecutive years in the three annual periods described above in the study area. A total of 1,050 km were censused and 753 contacts of prey were obtained. The very low presence of rabbit and partridge in the study area was insufficient for analysis. For each itinerary, the total number of available prey was recorded and corrected by the total length of each transect obtaining an index of prey/length unit (KAI, kilometric abundance index) (Tellería 1986).

We compared prey availability with scrub habitat type. This type of habitat may influence the presence and detectability of prey by the eagles. To overcome the large number of no prey presence in the transect Generalized Linear Models (GLZ) analysis in Statistica 8.3 software with Poisson distribution and logit transformation was performed. Prey type was used as a dependent variable and the presence of clear and dense scrub were the categorical explanatory variables. For all statistical tests, probability values less than 0.05 were considered significant.

3. Results

3.1. Habitat selection.

At the regional scale, habitat selection by Bonelli´s Eagle showed a strong tendency towards scrub and forest, which represent 76.5 % of the total habitat selection. Results differed significantly from random (χ^2_3 = 68874.42, p < 0.001). No differences between periods were found at this scale.

Compositional analysis at the study area scale showed that eagles do not use the habitat randomly. We found significant differences in habitat-use among three periods of the year (see Table 2). According to the ranking matrix, forest and scrub habitat were the most used while agricultural areas like fruit trees and crops were less selected. Nevertheless, we detected differences in selection order between periods (Table 2). Forest was selected more than scrub outside of the breeding season while during the breeding season scrub and rock were the most chosen habitats. In addition, urban areas were significantly more preferred during the breeding season.

We also found significant values at a home range scale (Table 2). Compositional analysis showed that coniferous forest and dense scrub were the most selected and evergreen and riparian forests were the least preferred habitats. Differences in use between periods were also found. Dense scrub is more selected during the breeding season and post-fledging dependence period while coniferous forest was the most preferred during the non-breeding season.

We found significant differences between scrub cover in different periods ($F_{(2,631)} = 7.6649$; $p < 0.001$). The scrub cover values were higher during the breeding season and lower during the nonbreeding season. No differences were found between actual scrub cover categories and CORINE categories ($F_{(1,631)} = 0.00063$; $p = 0.979$). The scrub cover values did not change between years.

3.2 Prey availability

GLZ models showed significant differences between pigeon abundance and habitat structure. Higher abundances of pigeons were found in dense scrub (Wald X^2 (1) = 17.563, $p < 0.001$). On the other hand, when we compared corvids abundance and habitat structure, they showed higher abundances in clear scrub (Wald X^2 (1) = 5.6962, $p = 0.017$).

4. Discussion

This study shows the importance of a multiscale approach to identify habitat selection by Bonelli´s eagle. Our results show that while, at a regional scale, individuals select heterogeneous habitat with crops areas, scrub areas and coniferous forest, at a smaller scale habitat structure within the home range plays a key role in habitat selection. Increased use of scrubland and coniferous forest, as with other areas with human presence, has been detected. Selection seems to be conditioned by the presence of potential prey and personal experience of each individual. Such selection varies depending on the season and the needs of individuals at each particular moment of the season.

The integration of modern tracking tools and classical census methods provides large amounts of high quality data. This allowed us to implement the method described by Aebischer et al. (2003), avoiding its main problems (i.e., inappropriate level of sampling and sample size, non-independence of proportions and arbitrary definition of habitat availability). It also allowed us to establish sampling periods synchronized with the biological cycle of the species.

Similarly, studies involving comparisons over time can reveal differences in habitat use related to the needs of each species at a particular time during the annual cycle (e.g. breeding season in raptors). For this reason it is important to consider seasonal variability in the use of space and should be linked to the availability of resources and the importance of a heterogeneous and changing habitat within a study area. Therefore, long-term studies of endangered species are also important because conservation policy implementation in large areas is often based on very short-term studies (Wiens 1989).

At a regional scale, we found a non-random selection of habitat types. In line with other studies (Carrascal and Seoane 2009, Ontiveros 2014), Bonelli´s eagle in the Aragon region selected heterogeneous landscapes with scrub and forest, dotted with cliffs (important for nest site selection by this raptor) (López-López et al. 2003). Prey detectability seems to be the main factor driving the selection of this type of habitat (Ontiveros et al. 2005). Nevertheless, crops and other fruit fields were not selected by individuals (Carrete et al. 2002). Despite the fact that this species can tolerate human presence (Muñoz et al. 2005), high-intensity human activities such as agricultural practices or heavy vehicle traffic in the area may exceed the eagles tolerance threshold, regardless of higher prey abundance (pigeons, partridges and rabbits in fruit crops and edge habitats) (authors' unpublished data). Furthermore, no temporal variation was found at this scale. This variation is difficult to detect at a large scale and even at others levels.

At the study area scale, eagles showed a differing habitat selection among seasonal periods. Rocks were selected by individuals during the breeding season. The Bonelli´s eagle is a Mediterranean raptor that nests in cliffs at moderate altitudes, and therefore a positive selection for this habitat is expected during this period. Scrub was also more selected during this period. The presence of chicks during the breeding season demands provision of high amounts of food by the breeders. Scrub is the preferred habitat for the main prey species of Bonelli´s eagle (rabbits and partridges) (Gil-Sánchez et al. 2000; Carrete et al. 2002). Therefore, individuals spend more time in these areas hunting. Forests (principally coniferous forests) are more selected during the rest of the periods. Although they do not visit the nest area frequently, they spend a lot of time in forest habitat during the rest of the year, primarily for roosting and defending their home range.

Urban areas (small rural villages and open industrial areas) were primarily selected during the breeding season over other habitats. The scarce abundance of prey for these eagles (rabbits and partridges) in their original habitats and the plasticity of this species to adjust their diet can condition such selection (Ontiveros and Pleguezuelos 2000). Under conditions of prey shortage, Bonelli´s eagles can hunt rock pigeons (*Columbia livia*) and common woodpigeons (*Columba palumbus*). Pigeons concentrate mainly in urban habitats (Palma et al. 2006) and therefore eagles use these high-density areas to hunt more efficiently. In fact, there is an important percent of this type of prey in the Bonelli´s eagle diet in Aragon (Alcántara et al. 2003).

Individuals’ experience, especially in raptors with large home ranges, is important to optimize resource exploitation. At the home range scale, we found that dense scrub is more selected than open scrub. In contrast to other studies (Balbontín 2005; López-López et al. 2006) breeders in Aragon preferred this type of scrub although prey detectability is lower. In spite of the fact that the main prey such as rabbits and partridges are very common in areas with clear Mediterranean scrub, alternative prey such as pigeons (which makes up 26.7 %

of the diet in Aragon (Alcántara et al. 2003)) are also associated with coniferous forest and transition areas with dense scrub. The shortage of main prey in the study area along with the personal experience of the individuals and the knowledge of their home range can lead individuals to spend more time looking for alternative prey such as pigeons in these areas of dense scrub despite their lower detectability.

In conclusion, long-term multiscale habitat selection studies can reveal aspects that are undetected at a single scale or that might need some time to be revealed due to changes during the year mainly driven by differential resource availability. In addition, the use of new tracking technology can show more precise results in certain areas and can address more precise conservation concerns. In our study area, we confirmed that in spite of the fact that individuals follow a general pattern for establishing home range, prey availability is very important to determining that home range. The home range use by individuals is closely related to the period of the year. Therefore, it is very important to implement conservation measures not only at a large scale but also at a short time scale, keeping in mind variation throughout the year. Habitat structure and the adaptation of the species to habitat changes should be considered. For example, the use of urban areas by Bonelli´s eagles during the breeding season is not usually included in conservation programs. In the same way, conservation policies addressing temporal variation could be considered, for example, regulating climbing activities during the breeding season and managing forest areas during the non-breeding season.

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Table 1. Habitat type composition (H. Type). Percentage of diferent habitat categories extracted from CLC depend on the scale : CLC 2006 (Regional scale and Study area scale) and CLC 2000 (Home range scale).

H. TYPE	CLC 2006	%	CLC 2000	%
Scrub			Coniferous scrub	5.13
	Transitional woodland shrub	3.67	Dense scrub	19.32
	Sclerophyllous vegetation	12.15	Open scrub	35.62
			Mixed scrub	0.07
			Hardwood Scrub	1.04
Forest	Broad-leaved forest	2.47	Evergreen forest	3.19
	Coniferous forest	7.44	Coniferus forest	33.65
	Mixed forest	0.29	Riparian forest	0.74
Grassland	Natural grassland	0.99	Natural grassland	1.24
Crops	Non-irrigated arable land	40.97	Non-considered	
	Permanently irrigated land	9.34	Non-considered	
	Rice fields	0.52	Non-considered	
	Annual crops	0.00	Non-considered	
	Complex cultivation	7.63	Non-considered	
	Crops and natural vegetation	8.01	Non-considered	
Fruit Crops	Vineyards	1.37	Non-considered	
	Fruit trees	1.05	Non-considered	
	Olive groves	1.09	Non-considered	
Urban	Urban Continuos	0.31	Non-considered	
	Urban Discontinuous	0.14	Non-considered	
	Industrial area	0.25	Non-considered	
	Human networks	0.04	Non-considered	
	Mineral extraction	0.12	Non-considered	
	Dump sites	0.02	Non-considered	
	Construction sites	0.15	Non-considered	
	Ocio area	0.02	Non-considered	
Water	Inland waters	0.29	Non-considered	
	Water bodies	0.37	Non-considered	
Bare rock	Bare rock	0.09	Non-considered	
Unproductive	Sparsely vegetated areas	1.13	Non-considered	
	Burnt areas	0.03	Non-considered	
	Dunes and sand plains	0.05	Non-considered	

Table 2. Ranked matrix of habitat type selection for all individuals (n = 14). For Study Area scale (SA) habitat types, Forest (FOR), Scrub (SCR), Bare rock (ROC), Grassland (GRA), Water (WAT), Urban (URB), Unprotuctive (UNP), Crop fruit (FRU) and Crops (CRO). For Home range scale (HR) habitat types, Coniferous forest (CON.F), Coniferous scrub (CON. S), Grassland (GRA), Dense scrub (DEN. S), Open scrub (OPE.S), Mixed scrub (MIX.S), Hardwood Scrub (HAR. S), Riparian forest (RIP.F) and Evergreen forest (EVE.F)

Scale	**Period**	**Wilk´s λ**	**P**	**Ranked habitat types**
SA	NBr	0.1046	0.0090	FOR>**SCR**>ROC>GRA>WAT>**URB**>UNP>FRU>CRO
	Br	0.0937	0.0020	SCR> ROC>FOR>URB>GRA>WAT>UNP>FRU>CRO
	Pfd	0.0547	0.0010	FOR>SCR>WAT>ROC>GRA>URB>UNP>FRU>CRO
HR	NBr	0.3324	0.0355	CON.F>CON.S>GRA>DEN.S>OPE.S>MIX.S>HAR.S>RIP.F>EVE.F
	Br	0.2893	0.0171	DEN.S>GRA>CON.F>MIX.S>CON.S>OPE.S>RIP.F>EVE.F>HAR.S
	Pfd	0.2857	0.0160	DEN.S>MIX.S>CON.S>GRA>CON.F>OPE.S>HAR.S>RIP.F>EVE.F