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Habitat associations of a raptor community in a mosaic landscape of Central Spain under urban development

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Abstract

The effects of urban sprawl and the associated road network on patterns of land use by diurnal raptors were assessed in a extent mosaic landscape of Sierra de Guadarrama subjected to exurban development (Madrid province; Central Spain), within the buffer area of a planned national park. During three consecutive years, the sightings of raptors per $0.25\,km^2$ were analyzed to identify their habitat preferences according to several vegetation types, urban cover and length of paved roads. Species richness increased with the amount of deciduous forests of Pyrenean oak *Quercus pyrenaica* and parklands of Narrow-leaved Ash *Fraxinus angustifolia* in lowland areas, while it decreased with cover of urban/suburban areas. Analyzing the three most abundant species separately, urban development had a negative influence on the Common Buzzard *Buteo buteo* and the Black Kite *Milvus migrans*, although positively affected the Booted Eagle *Hieraaetus pennatus*, probably through an increase in the availability of its potential prey within urban areas. This study did not find a negative influence of the road network, either considering total species richness or the three most abundant species separately. The current levels of urban development diminished the suitability of the study area for the raptor community overall (though particular species can be favoured), notably when residential sprawls are established over ash parklands traditionally devoted to cattle grazing.
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1. Introduction

Urbanization promotes large changes in the landscape, specially when urban sprawl affects large extensions of once continuous natural habitats, introducing intense fragmentation. This kind of human intrusion is increasingly prevalent closer to natural environments, due to the development of weekend residences of people living in large cities. Exurban development is distinct from urban development in that it occurs outside municipal limits, perforates native ecosystems, and is often situated on the periphery of protected areas (Fraterrigo and Wiens, 2005). Evaluating how increasing exurban development affects avian species with large area requirements may help to identify the proximate factors that drive these changes, in order to forecast the effects of human settlement (Marzluff et al., 2001). This

is especially important because the influence of exurban development is generally not well documented, and the results are species and environmentally specific (for a review with birds see Chace and Walsh, 2006).

The importance of birds of prey on applied conservation comes from several conceptual qualities they hold. Firstly, raptors are considered *umbrella* species with low population densities and large individual home ranges, so that by protecting these species we protect all species on which they depend or the species with similar requirements but smaller home ranges. Therefore, top predators like raptors are a key taxa in conservation planning and environmental impact assessments (Simberloff, 1998; Martínez et al., 2003). Secondly, they can act as valuable *indicator* species on changes and stresses in the urban ecosystem, as they are quite sensitive to changes in habitat structure and fragmentation and have a high susceptibility to local extinctions (Simberloff, 1988; Thiollay, 1989; Savard et al., 2000; Chace and Walsh, 2006). Thirdly, complex or expensive conservation efforts are more easily undertaken by management agencies when oriented to *flagship* species like

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raptors, because applied land-planning focused on their preservation, usually imply an improvement of effective protection for the whole region they occupy ('umbrella' effect; Simberloff, 1998; Sergio et al., 2005).

Anthropogenic landscape alterations may have different effects on raptor populations, depending either on the type and intensity of disturbance, and on the characteristics of the species involved. Deleterious impacts on raptors have been documented as a result of habitat loss and fragmentation (e.g. Thiollay and Rahman, 2002) and direct disturbance derived from human presence and associated infrastructures (e.g. White and Thurow, 1985; Brown and Stevens, 1997; Fargallo et al., 1998; Fletcher et al., 1999; Bautista et al., 2004). On the contrary, croplands, roads and other anthropogenic alterations seem not to be harmful to raptors when promoting landscape heterogeneity and/or providing new foraging or nesting opportunities (e.g. Knight and Kawashima, 1993; Zelenak and Rotella, 1997; Dykstra et al., 2000; Rottenborn, 2000; Anderson, 2001; Dean and Milton, 2003).

The north-western part of the Madrid province (Central Spain) poses a good case study to assess the effects of urbanization and the associated road network on raptor communities. This area supports breeding populations of 15 diurnal raptor species, an important figure either at the Iberian scale (60% out of 25 species; Martí and del Moral, 2003), or the European scale (38% out of 39 species; Hagemeijer and Blair, 1997). Currently, this region is undergoing an intense urban sprawl due to the huge housing demand of weekend residences, mostly by people living in the nearby large city of Madrid (3.5 million people, 40 km away). As a result, previously small villages are becoming bigger residential cities, increasing overall urban area (25% from 1992 to 2000; Comunidad Autónoma de Madrid, 2004) in parallel to the progressive abandonment of traditional farming and fragmentation of the natural areas (Alig et al., 2004; Antrop, 2004; Robinson et al., 2005). Further, this area will be included within the buffer area of the future National Park of Sierra de Guadarrama, so there is a need for knowledge as to the influence of landscape management and urban planning on raptor biodiversity.

Due to the contrasting effect of landscape heterogeneity on raptors reported by available literature (see review by Chace and Walsh, 2006), the goal of this paper is to determine whether urban sprawl and/or the associated road network in this already fragmented region are limiting the availability of adequate habitat for raptors, either at the community (i.e., species richness) or the species-specific level (focusing on the most abundant raptors: Common Buzzard *Buteo buteo*, Booted Eagle *Hieraaetus pennatus* and Black Kite *Milvus migrans*).

2. Methods

2.1. Study area and sampling

The study was conducted on the southern slope of the Guadarrama Range (Madrid province, Central Spain; 40°40′N, 4°W; 900–1400 m a.s.l.). The study region has a Mediterranean-continental cold climate, with a mean temperature of 14.5 °C

and rainfall of 130 mm during spring time. The land-ownership model in this region (mostly small-holdings), the diversity of land-uses, and other environmental factors (relief, soil types, roads and tracks) have led to a marked landscape mosaic, including a high variety of habitat patches. Eight main habitats potentially relevant for foraging preferences of birds of prey were considered:

(1) coniferous forests (Scots/Cluster Pine *Pinus sylvestris/ pinaster*; mature and dense woodlands mainly in mountain slopes above 1100 m a.s.l.);
(2) oakwood forests (Pyrenean Oak *Quercus pyrenaica*; medium- to small-sized young stands in hilly areas between 900 and 1300 m a.s.l.);
(3) evergreen woods (Holm Oak *Quercus rotundifolia*; mainly composed of small trees 4–8 m high and with a dense cover of shrubs; 850–1100 m a.s.l.);
(4) parklands (Narrow-leaved Ash *Fraxinus angustifolia*; grasslands with boundary hedgerows located in valleys 800–1000 m a.s.l., where the tree layer becomes mature but scattered and is regularly managed through pruning);
(5) shrublands (mainly of genus *Cistus* and *Genista*, mostly arisen from abandonment of previously managed pastures);
(6) pasturelands (treeless pastures devoted to livestock);
(7) suburban edges (poorly vegetated areas surrounding the cities, usually covered with scattered debris);
(8) urban areas (built-up areas of five residential cities between 1.5 and 7.2 km^2 with a mixture of different urban typologies—for more details see Palomino and Carrascal, 2006).

Data on space use by raptors, 108 h of field work, were gathered by the same person (DP) during June and early July 2001, 2002 and 2003. To avoid sampling biases in raptor movements due to weather-dependent factors (Sergio, 2003), time-of-day effects (Bunn et al., 1995), or excess human disturbances on weekends (Bautista et al., 2004), birds were only monitored on windless and rainless mornings of weekdays, starting 2–3 h after sunrise and averaging 3 h of continuous monitoring. Eight vantage points covering non-overlapped areas were selected, including most of the urban area of five cities (San Lorenzo del Escorial, Cercedilla, Navacerrada, Collado Mediano and Moralzarzal), as well as diverse surrounding natural habitats. Detailed and recently published 1:25,000-scale maps were gridded on 0.5 km × 0.5 km squares, and the resulting squares of 0.25 km^2 were used as the spatial sampling units to analyze the variables considered on raptor abundances (see below). Squares larger than 0.25 km^2 should imply a lower number of sampling units, as well as a reduction in the environmental differences among squares due to the fine-grained patchy characteristics of this landscape. Overall, data for 148 squares (37 km^2) were obtained, averaging 5.8 h of surveillance per sampling square of 0.25 km^2 (it must be kept in mind that from each vantage point many sampling squares can be 'simultaneously' covered during any particular surveillance).

When a raptor was detected (scanned with 8 × 32 binoculars), its trajectory was mapped, timing the presence of the bird

at each $0.25\,km^2$ sampling square. The birds detected too far from the vantage points (those farther away than 2 km from the observer) were excluded from analyses, because a reliable location on maps was not possible. No attempt to distinguish among flight types was made, due to the imprecision of the possible categories, though no bird above 500 m was considered: average height above ground of flying birds was 77.6 m (S.D. = 68.5; $n = 642$ sightings, 82% of them below 100 m). Birds resting at or near the nest were not considered, because although the overall number of this casual sights was very low, their disproportionate contribution to the cumulative time of observation per sampling square biases the trends from flight data.

2.2. Data analyses

Eleven landscape descriptors were calculated. Firstly, the percentage cover in $0.25\,km^2$ sampling squares of the eight main habitats, as well as the length of roads, were measured on digitized images of published of the study region. We sampled the cover of these habitat categories and the length of roads by means of image tools in Photoshop CS (the polygon laso to count the number of pixels selected and the measurement tool for lengths). The eight habitat measurements were used to calculate an index of average structural complexity of the native vegetation per sampling square, ranging from 0 to 6 according to the following classes—0: urban; 1: pasturelands and suburban edges poorly vegetated; 2: short shrublands; 3: dense tall shrublands with small scattered trees; 4: parklands or groves with scattered trees more than 6 m high; 5: dense forests 8–12 m high; 6: the most mature forests with trees over 12 m high. The structural complexity index was obtained as the weighted average of each habitat score according to the area covered by each habitat. Overall, the 148 squares of $0.25\,km^2$ averaged 19.8% of pine forests (range: 0–100), 7.2% (0–100) of deciduous forests, 20.8% (0–100) of parklands, 2.4% (0–92) of holm-oakwoods, 5.8% (0–92) of shrublands, 20.7% (0–100) of pasturelands, 5.9% (0–76) of suburban edges, and 16% (0–100) of urban surface. Mean structural complexity was 2.9 (range: 0–6), whereas mean road length was 83 m (0–1610). Finally, the maximum altitude of each $0.25\,km^2$ was also obtained from 1:25,000 maps, averaging 1153 m a.s.l. (860–1640).

Since the probability of detecting a raptor is highly biased among sampling plots by (1) the time spent in its surveillance, and (2) its distance to the vantage point of scanning, both variables (*sampling* variables, hereafter) were controlled by including them in the statistical analyses. The effect on bird detections of spatial autocorrelation of the sampling plots was also controlled by means of polynomials (five linear and quadratic geographical variables: longitude, longitude^2, latitude, latitude^2, and longitude × latitude) of the UTM geographic coordinates at the center of each square (Legendre, 1993).

Response variables analyzed were the total number of diurnal raptor species detected, and the cumulative time of observation of the three most abundant species: Common Buzzard, Booted Eagle and Black Kite. The relationships between each of these four response variables and the independent variables (11 landscape descriptors, 2 sampling variables, and 5 geo-

graphical components; see Table 1) were analyzed by means of partial least squares regression (hereafter PLS regression), using the $0.25\,km^2$ squares as the sampling units. This statistical method is an extension of the multiple regression analysis, particularly useful in ecological analyses where the predictors (i.e., the independent variables) are many and highly collinear (e.g. Maestre, 2004; Seoane et al., 2005). PLS regression is explicitly oriented to solve the problem of lack of independence among the predictors, since they become grouped in one – or several, but orthogonal – lineal gradient/s of covariation, while meeting the condition of maximizing the explanation of the response variable. In other words, in PLS regression a few multivariate factors extracted according to the underlying relationships existing among the original independent variables are 'forced' to maximize the explained variance in the dependent variable. Significance of the relationships between predictor variables and PLS factors was tested using factor loadings. The relative contribution of each variable to the derived factors was calculated by means of the square of predictor weights. For more details on this statistical exploratory technique, see Statsoft (2001) and Tobias (2003).

3. Results

Overall, 15 species were found: Eurasian Griffon *Gyps fulvus*, Cinereous Vulture *Aegypius monachus*, Eurasian Sparrowhawk *Accipiter nisus*, Northern Goshawk *Accipiter gentilis*, Golden Eagle *Aquila chrysaetos*, Spanish Imperial Eagle *Aquila adalberti*, Common Buzzard, Short-toed Snake-Eagle *Circaetus gallicus*, Peregrine Falcon *Falco peregrinus*, Eurasian Hobby *Falco subbuteo*, Common Kestrel *Falco tinnunculus*, Booted Eagle, Black Kite, Red Kite *Milvus milvus* and European Honey-Buzzard *Pernis apivorus*. The two species of vultures in the study region were not considered in the analysis of species richness because they do not use the study area as regular foraging locations, and they usually flew very high over the ground, while crossing the area.

A PLS regression identified one significant ($p < 0.001$) factor of covariation among the 18 descriptor variables explaining 36.8% of original variance in the number of raptor species per $0.25\,km^2$ square (Table 1). Spatial autocorrelation and geographical effects only accounted for 1.1% of the original variance in species richness. An important amount of the explained variance (17.9%) was related to surveillance variables: species richness was positively related to the time devoted to surveillance of each square, and negatively with the distance to the vantage point of scanning. The variability in species richness directly attributable to landscape predictors was 17.8%. The number of species per $0.25\,km^2$ square increased with the structural complexity of the vegetation and cover of oakwood forests and ash parklands, but decreased with the surface covered by urban/suburban areas and pasturelands (Fig. 1). There was also a tendency towards more species richness in lowlands than at higher altitudes in the Guadarrama mountains (see coeficient weight for altitude in Table 1). Therefore, the maximum species richness of raptors was observed in wooded lowland areas with a very low cover of urban and suburban ground.

Table 1
Predictor weights of the partial least squares regressions

| | Resulting multivariate factors on | | | |
	Species richness	Common Buzzard	Booted Eagle	Black Kite
Landscape variables				
Maximum altitude	−0.183*			−0.379***
%Coniferous forest			−0.299***	
%Oakwood forest	0.347***	0.541***		
%Ash parklands	0.322***			0.400***
%Holm-oakwoods				
%Shrublands		−0.299***		
%Pastures	−0.217***		−0.195*	−0.200*
%Urban	−0.272***	−0.249**	0.407***	−0.207*
%Suburban	−0.224**		0.202*	−0.185*
Road length		0.314***		
Vegetation structural complexity	0.388***	0.389***	−0.271***	0.236**
Sampling biases				
Surveillance time	0.495***	0.413***	0.575***	0.200*
Distance to vantage point	−0.307***	−0.286***	−0.493***	
Geographical effects and spatial autocorrelation				
Longitude	−0.251**		−0.214**	−0.347***
Latitude	−0.310***			−0.435***
Longitude × longitude	−0.234**		−0.233**	−0.326***
Latitude × latitude	−0.281***			−0.419***
Longitude × latitude	−0.301***			−0.443***
R^2 by the whole factor	36.8	31.6	25.0	25.7
Contributions by categories of variables (R^2)				
Landscape variables	17.8	22.7	6.6	20.2
Sampling biases	17.9	8.9	17.9	1.3
Geographical effects	1.1	0.0	0.5	4.2

One multivariate factor (a linear combination of the 18 original predictors) is showed per response variable: the number of raptor species and the cumulative time of observation of the three most abundant species in each 0.25 km^2 sampling square. The four PLS regression analyses are highly significant ($p < 0.001$). Only significant relationships between individual variables and factors (*<0.05; **<0.01; ***<0.001) are shown. R^2: percentages of original variance accounted for. For the sake of clarity, the predictor variables have been grouped by three main categories (see text).
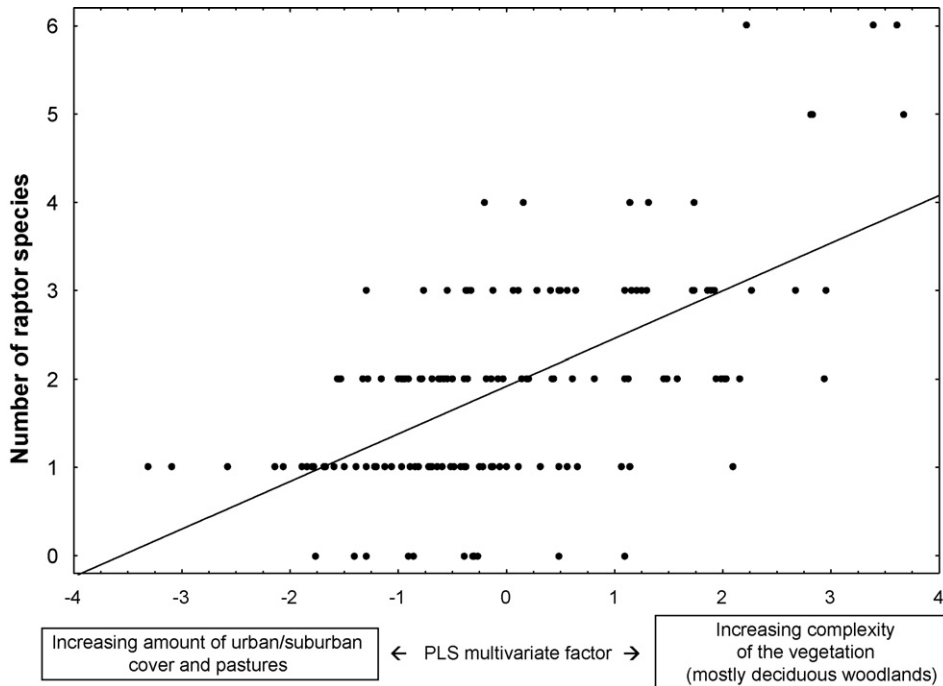

Fig. 1. Relationship between the richness of raptors per 0.25 km^2 and the multivariate gradient obtained in the partial least regression analysis (see Table 1).

For each of the three most abundant species in the study region, the respective PLS regressions identified the significant ($p < 0.001$) factor of covariation among the 18 descriptor variables, explaining the variability among squares in the cumulative time of observation for the Common Buzzard (31.6%), the Booted Eagle (25.0%) and the Black Kite (25.7%; Table 1). The geographical and spatial autocorrelation effects explained a very low amount of variance (<5%) in the three species (markedly low in the Common Buzzard and the Booted Eagle). Sampling bias derived from differences among squares in surveillance time and distance to vantage points had an important influence in the Common Buzzard and the Booted Eagle.

After controlling for geographical effects and sampling bias, 22.7% of the variance in the Common Buzzard distribution among 0.25 km^2 squares was explained by landscape predictors. This species was more frequently observed at squares with higher vegetation structural complexity, covered with a high proportion of oakwood forests, and a low extent of shrublands. It was also positively influenced by the length of paved roads, but it avoided urban areas.

For the Booted Eagle, once geographical effects and sampling bias were removed, only 6.6% of the observed variability in the cumulative time of observation in 0.25 km^2 squares was significantly related to habitat descriptors. This species was positively influenced by urban/suburban cover, and negatively by the extent of mature coniferous forests and pasturelands.

Finally, 20.2% of the variability in the Black Kite distribution among 0.25 km^2 squares was accounted for by habitat descriptors. This species selected locations at lower altitudes on the valleys, mainly covered by deciduous parklands of ash trees, and it was negatively affected by urban/suburban areas and pasturelands.

4. Discussion

Our results show the importance of deciduous woodlands of Pyrenean Oak and parklands of Narrow-leaved Ash for maintaining a highly diverse community of diurnal birds of prey in this increasingly urbanized area on the piedmont of the Guadarrama range. Conversely, treeless open-country (mainly extensive pasturelands) diminishes the species richness of diurnal raptors. Extensive grazing cows has historically prevailed in this area over intensive croplands or more damaging stockbreeding such as goat herds, allowing the persistence of wooded patches that have favoured a well established and diverse raptor community. Forestry management in the public areas of Guadarrama mountains should favour the preservation of deciduous woodlands and ash parklands, as they constitute the most important native habitats in lowland areas where cities and developments have been established, and because they are very important for the conservation of this diverse raptor community. In addition, this type of forested habitat also enhances landscape quality from a human perspective (Gómez-limón and De Lucio, 1999). Gulinck et al. (2001) shows an example based on the whole Madrid province on current advances in comparative landscape analyses useful in integrating avifaunal priorities with land cover data. This recommendation needs to be highlighted considering that the study area is included within the buffer area of the planned National Park of Sierra de Guadarrama.

An important cause of woodland loss in the valleys and piedmont of this region is urban sprawl, threatening naturally regenerating oak stands and old ash groves near city limits. Social and economic pressures incessantly claim more building area on public or private rural lands. Though the first residential developments (ca. 1970) were predominantly spread single-detached houses, with big gardens that have become mature after 20–40 years, the current residential models prevailing are scarcely gardened and densely built-up (e.g. small detached houses). As in the case of the songbird community (Palomino and Carrascal, 2006), the species richness of raptors in this region is negatively affected by the urban developments. Less diverse raptor communities have been described at landscapes progressively more anthropogenic (Brandl et al., 1985; Sorley and Andersen, 1994; Jullien and Thiollay, 1996; Herremans and Herremans-Tonnoeyr, 2000; Sánchez-Zapata et al., 2003). Although it is expected that specialist species depending on extensive native habitats or on particular prey items mostly avoid human-altered landscapes, moderate levels of landscape alteration also can allow the occurrence of many species, mostly due to edge effects (Vannini, 1989; Ellis et al., 1990; Donázar et al., 1993; Rodríguez-Estrella et al., 1998; Reynaud and Thioulouse, 2000; Anderson, 2001). Thus, moderate urbanization may favour raptors with more opportunistic requirements (e.g. Bird et al., 1996; Bosakowski and Smith, 1997; Berry et al., 1998). Nevertheless, the present degree of urbanization in the study area is already globally adverse for its raptor community. So, we predict that the undergoing urban sprawl of scarcely gardened and densely built-up developments over deciduous parklands in Guadarrama valleys will negatively affect the rich community of birds of prey.

The habitat preferences obtained for the Common Buzzard agrees with the general distribution patterns previously described in the Iberian Peninsula (Sánchez-Zapata and Calvo, 1999; Bustamante and Seoane, 2004). But in addition, our analysis also shows that the regular foraging movements of the Common Buzzard are negatively affected by urban cover (see similar conclusions with regard to nest site selection: Burak, 2002; Krüger, 2002; Kruszyk and Zbronski, 2004). Nevertheless, the Common Buzzard was positively affected by the presence of paved roads in Guadarrama valleys. The selective use of road verges has been already cited for this species (Meunier et al., 2000; Lõhmus, 2001; Bautista et al., 2004). This pattern is probably due to the availability of perches (mostly telephone poles) and/or road-kills near ditches, although it could involve an important risk of mortality from traffic (e.g. Hell et al., 2005), or electrocutions from electricity pylons (Ferrer et al., 1991; Mañosa, 2001).

The Booted Eagle was the most frequently observed raptor in the study area, appearing in 54.7% of the squares surveiled. The Booted Eagle avoided areas covered either by pasturelands or dense mature coniferous forests, and preferred the 0.25 km^2 squares with the presence of urban/suburban areas (it is a species regularly seen in old urban developments with wooded gardens and small detached houses; pers. obs.). These results reinforce

the idea of a marked resilience of the Booted Eagle to human disturbances (Carlton, 1996; Suárez et al., 2000). Furthermore, species that meet their food requirements within the cities should show positive responses to the urban area (Chace and Walsh, 2006). The importance in Spain of anthropophilic birds as regular prey of the Booted Eagle (pigeons, magpies, jackdaws and starlings), instead of other wild species (rabbits or lizards; Veiga, 1986; Martín and López, 1996) could be directly related to the frequent use of urban developments.

Foraging areas preferred by the Black Kite were located in lowlands, particularly the ash parklands. This species avoided areas highly altered by human uses, such as cities, suburban sites, or treeless pasturelands. This pattern observed in the piedmont of Guadarrama mountains markedly contrasts with other works showing that the Black Kite is positively influenced by moderate levels of human impacts, mainly due to its scavenging habits and hunting opportunism (Brandl et al., 1985; Sorley and Andersen, 1994; Herremans and Herremans-Tonnoeyr, 2000; Meunier et al., 2000; Dean and Milton, 2003; Sánchez-Zapata et al., 2003; Bustamante and Seoane, 2004). Nevertheless, the use of anthopogenic areas by the Black Kite are only occasional, and linked to profitable human wastes, but otherwise avoided when more natural habitats and food resources are available (Blanco, 1997; Sergio et al., 2003). Thus, favourable habitats for the species in Guadarrama valleys are spread over large areas (i.e., extensive ash groves devoted to cattle grazing and breeding of bulls for bullfights) and remain free from important human disturbances, thereby minimizing the need to exploit residential urban habitats which provide scarce feeding opportunities.

In conclusion, this paper did not find a deletereous influence of the road network, either considering total species richness or each one of the three most abundant species. On the contrary, the increasing urbanization of the landscape is affecting negatively the habitat suitability of the study area for the raptor community. The influence of urban sprawl is particularly negative when buildings are densely established over deciduous oakwoods or parklands of ash trees traditionally devoted to cattle grazing. The Booted Eagle is the least affected species by urban developments with wooded gardens and small detached houses.

Acknowledgements

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