



Wintering raptor species distribution in a semiarid Mediterranean region: the relevance of lowlands and open habitats as stopover sites

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Abstract

As land-use cover types affect wintering birds' strategies, studying their habitat suitability for species conservation is relevant. Predictive spatial models are considered excellent tools for conservation planning and improving our understanding of species distribution. Here we build models to predict the spatial distribution of raptor species that overwinter in SE Spain. We modelled the wintering raptor species distribution based on the presence-only data obtained between 2017 and 2019 and analysed their habitat preferences based on elevation and land-use cover variables. Our results show that altitude and distance to the coastline are the most important environmental factors to affect most species' habitat suitability. Habitat type-related factors are other important predictors, and raptors subject of this study prefer lowlands and areas close to the coastline for overwintering by selecting open habitats, which include wetlands and irrigated and rainfed crops. This study highlights the importance of the habitat heterogeneity generated by wetlands and herbaceous crops within a low-altitude range as the optimal environment for wintering raptors. Such information should be considered for raptor conservation planning in human-altered landscapes.

Keywords Agricultural intensification · Land-use cover · Landscape ecology · MaxEnt · Species distribution models · Winter distribution

Introduction

How land-use changes induced by anthropogenic activities affect the requirements of many species is one of the key biodiversity conservation challenges (Chapin et al. 2000; Sala et al. 2000; Newbold et al. 2015; Powers and Jetz 2019). Many land-use changes are the consequence of an increased proportion of land used by agriculture in recent centuries, as well as a growing trend towards agricultural intensification (Meyer and Turner 1992; Foley et al. 2005). Agricultural

intensification has detrimental effects on natural systems (Stoate et al. 2001; Foley et al. 2005; Guerrero et al. 2012; Grande et al. 2018), biodiversity and key ecosystem services (Landis 2017; Sirami et al. 2019). Such changes may have, in turn, a detrimental effect on the availability of suitable habitats for many species, which leads to distribution shifts (Jetz et al. 2007; Powers and Jetz 2019) or even local population extinction (Jiménez-Franco et al. 2022).

In the case of avian species, the effects of land-use changes vary by species and the intensity of land-use change (Vickery et al. 1999; Fox 2004; Paprocki et al. 2015). This does not mean that human-made landscapes necessarily pose a threat to birdlife. Indeed, for certain species or, at least during the different periods of their life cycle, change may even provide opportunities for foraging or breeding (Cardador et al. 2011; Donazar et al. 2016; Grande et al. 2018). In line with this, cropland areas are used as a stopover habitat by bird species that can utilise a wide breadth of habitats, as well as by species with preferences for habitats with a similar structure to agricultural areas (Blount et al. 2021).

At temperate latitudes, wintering birds' survival strategies involve adaptations that range from changes in habitat

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selection to variations in diet, and they are all conditioned by the migratory displacement of which they are capable to search for favourable areas (Senar and Borrás 2004; Blount et al. 2021; Chiatante and Panuccio 2021). Considering the evidence that indicates shortened avian migration distances (e.g. Visser et al. 2009; Paprocki et al. 2014), accompanied by poleward broad-scale shifts in distributions ranges in response to rising global temperatures, there are indications that the Mediterranean Basin's climatic suitability for wintering Palearctic birds could increase (Tellería et al. 2016). However, in certain Mediterranean regions, such as the SE region of the Iberian Peninsula, the total area of natural sites and land used by extensive farming continues to fall in many landscapes because of agricultural intensification and the consequent increased agricultural landscape homogenisation (Caraveli 2000; Valera et al. 2011). The availability of suitable habitats on the regional scale has been identified as the ultimate factor that, in the short term, determines and threatens locality selection by birds during the non-breeding period (La Sorte et al. 2017). This is a gap in our knowledge. As migratory birds spend up to 85% of their total migration time at stopover sites (Blount et al. 2021), identifying important suitable areas in this stage is a priority for setting up species conservation strategies related to their wintering grounds.

Raptors are often considered good indicators of habitat quality because of their sensitivity to human disturbance and environmental contamination (Newton 1979; Sergio et al. 2005). For this group of birds, habitat transformation (i.e. agricultural intensification) can trigger two opposing effects on habitat-species relationships (Grande et al. 2018): (a) on the negative side, degradation and loss of suitable habitats, along with fewer trophic resources, because of agricultural intensification; (b) on the positive side, the provision of novel habitats and new food sources for some species (Villanúa et al. 2023).

Extensive farming areas represent a key ecosystem for birds wintering in Mediterranean regions (De Juana et al. 1988; Chiatante and Panuccio 2021). More recently, other authors have analysed the factors that determine the distribution and abundance of raptors wintering in different regions of Europe and North America (Kasprzykowski and Rzepala 2002; Jankowiak et al. 2015; Paprocki et al. 2015; Bobola et al. 2018). To date however, very little is known about the raptor communities that winter in the Mediterranean region (Panuccio et al. 2019). In this study, we analyse a raptor community that winters in a semiarid Mediterranean region in which interbasin water transfers have contributed to the proliferation of new intensive irrigation projects (Martínez and Esteve 2002). We relate the raptor wintering distribution to ecological features (i.e. land uses and topography). The aims of this study are to (i) model the spatial distribution of the raptor species that winter in a semiarid Mediterranean region, (ii) describe how environmental factors affect

habitat suitability for each species, and (iii) identify the main ecological requirements of the studied species to conserve the wintering areas in the study area. We hypothesise that, although the studied species may have different habitat requirements (food availability) and, consequently, different potential distributions throughout the study area, agricultural areas may be more relevant than natural areas (i.e. forests) due to more food resources. These results will allow wildlife managers to conserve ecosystems that are considered to trophic resources for winter raptor biodiversity.

Materials and methods

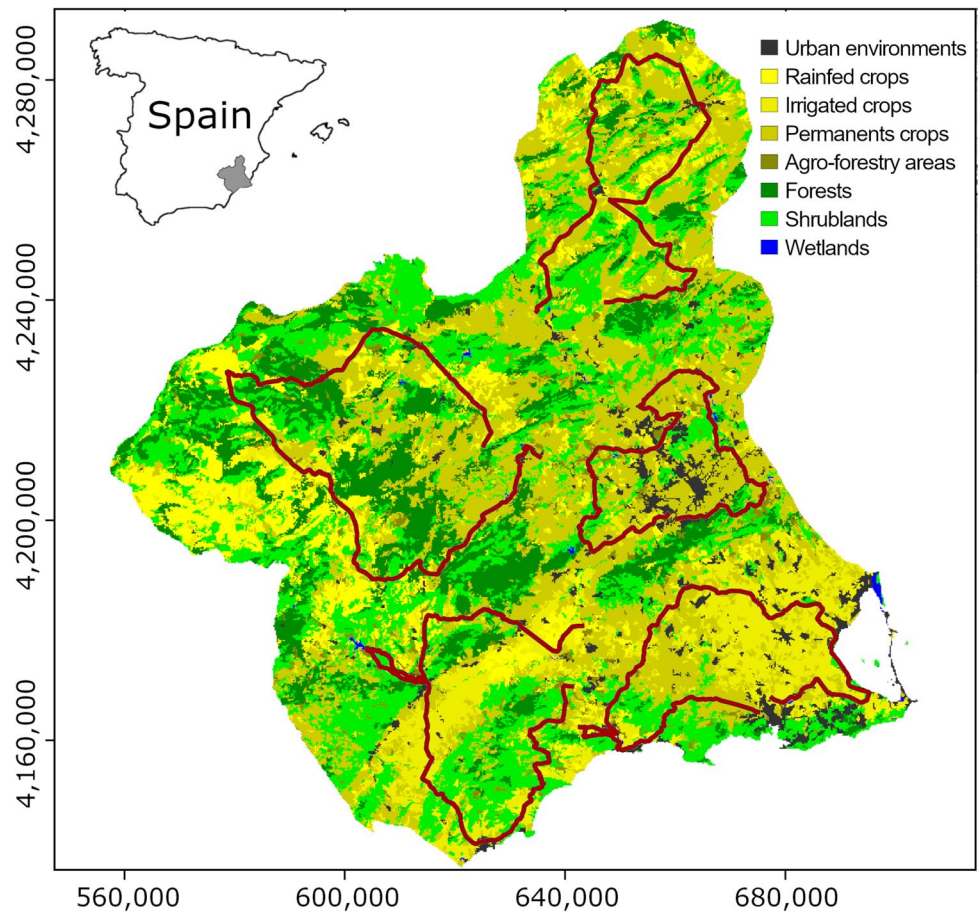
Study area

The present study was carried out between November 2017 and February 2019 in the Region of Murcia (Spain), an administrative unit located in the SE region of the Iberian Peninsula. It covers an area of 11,317 km² (Fig. 1). Due to its geographical location and other physical factors, it is dominated by a semiarid Mediterranean climate. The annual mean temperature for the five-decade 1961–2014 period is 16.7 °C, which tends to increase by 0.135 °C per decade. The annual mean precipitation is 310 mm (Garrido et al. 2015).

The average monthly temperature values in winters vary from 12.2 °C in November to 8.5 °C in January. The monthly average precipitation in winter varies from 35 to 24 mm (AEMET 2011). The wide gradient between coastal and inland areas reflects the drop in temperature and the increase in precipitation when moving more inland in winter (AEMET 2011). In the coldest sector of the Region of Murcia (NW), there are relatively few days with snow, which has evolved from around 20 days in 1960 to about 10 days in 2014. This tendency is related to climate change (Garrido et al. 2015). Moreover, this geographical gradient from coastal areas to inland (from SE to NW) also shows a general pattern of a lowering turnover rate in forest bird species associated with climate and land-use change (Jiménez-Franco et al. 2024).

A complex orographic lies system in the study region, in which mountainous units alternate with flatter depressions to generate an altitudinal range from sea level to 2014 m asl. Combined with the wide climatic gradient, this contributes to generate a wide diversity of habitats that can be encompassed in three main ecosystem types: semidesert areas, Mediterranean scrub and coniferous forest (Esteve et al. 2015). From 1965 to 2000, the creation of 50,000 ha of human-modified habitat has significantly reduced the amount of natural area in this region (Calvo et al. 2017), where the agricultural landscape is dominated mainly by irrigated and dry land crops that total > 600,000 ha and represent more than half the land surface (Calvo et al. 2017).

Fig. 1 Map of the study area (Region of Murcia, SE Spain) with the distribution of road surveys (red transects), including the land-use cover types used in the species distribution models. Coordinates are indicated as UTM 30S (metres)



Data collection

Bird occurrence data were collected for two winters from November 1 to February 28 (2017–2018 and 2018–2019) by two complementary methodologies: (a) professional fieldwork, based on road-based vehicle surveys conducted by trained professionals; (b) volunteers' survey, based on bird record collection by means of volunteer collaborators. The simultaneous use of different methodologies is frequent in avian distribution studies (e.g. Moyer-Horner et al. 2012; Fletcher et al. 2019) because it avoids the detectability problems of certain less conspicuous species and can provide more records of more detailed data of all the species present (Zuberogoitia et al. 2020) that enhance the predictive accuracy of species distribution models (Tehrani et al. 2022). It is for this reason that this complementary methodology can be used successfully to build species distribution models (Broman et al. 2014; Flesch and Belt 2017).

Professional fieldwork. We surveyed five road transects during the 2018–2019 season (Fig. 1), each covering one of the agrarian districts making up the study region (Fernández 2012). Routes had an average length of 163 ± 11 km and an overall length of 817 km in the study area. Sampling journeys were repeated 3 times every ~40 days, and the total

covered length was 2451 km. Following the usual methodological recommendations (e.g. Fuller and Mosher 1987; Sunyer and Viñuela 1996; Panuccio et al. 2019), routes were driven at low speed (20–40 km/h) to ensure increased likelihood of bird detection. Whenever a raptor was sighted, the car stopped long enough to allow field optics (binoculars 10×42 and telescope 20–60×) to be used for identification and data collection purposes. Routes were designed to cover the different landscape structures present in the study area, and to include, to the greatest possible extent, raptor activity hours by starting censuses at 2 h after sunrise at the most and finishing 1 h before sunset (Fuller and Mosher 1987; Bibby et al. 2000). Itineraries were not followed when adverse weather conditions (strong winds, fog or precipitation) affected censuses' visibility or bird mobility.

Volunteers' survey scheme. Volunteers' data collection was carried out throughout the study period (2017–2018 and 2018–2019 winter periods). A total of 87 cooperating birdwatchers were provided with a survey sheet and an application for smartphones developed specifically for this study (Teacher et al. 2013). Volunteers' monitoring schemes have been proven suitable for collecting large quantities of data on birds (Sunyer and Viñuela 1990; Bonney et al. 2009; Teacher et al. 2013; Sullivan et al. 2014) at different spatial scales (Hernández-Navarro et al.

2023). We did not consider active citizen monitoring schemes (such as eBird) since the presence data provided was much less accurate for the spatial scale considered in our study. Therefore, to obtain the raptor presence data in the most precise way possible, a given record was considered correct when the collaborator completed all the required fields: date, time of day, location (UTM 30S coordinates), identified species, number of counted individuals and, optionally, any observations that were considered relevant to the sighting.

Environmental variables and processing

Ecological predictors were chosen according to previous descriptions of diurnal raptor communities (e.g. Bustamante and Seoane 2004; Jankowiak et al. 2015; Panuccio et al. 2019). Two different types of ecological variables to describe species-habitat relationships were selected (Seoane et al. 2004):

- a) Land uses. Corine Land Cover variables (Büttner and Kosztra 2017) were grouped into eight categories (CORINE Land Cover map 2018) (<http://centrodedescargas.cnig.es>; Fig. 1): *urban environments* (including human infrastructures and industrial areas), *rainfed crops* (extensive herbaceous agriculture), *irrigated crops* (intensive herbaceous agriculture), *permanent crops* (almonds, olive groves, vineyards, other arboreous crops), *agro-forestry areas*, *forests*, *shrublands* and *wetlands*. The frequency of each variable was estimated using a 1000-metre radius mobile-window to include species' habitat requirements on the landscape scale (Abellán et al. 2011).
- b) Topographical. Two continuous quantitative variables were recorded: *altitude*, obtained from a digital elevation model map (DEM; <http://centrodedescargas.cnig.es>); the estimated *distance to the coastline* (km), due to its influence on climatic factors (Davies et al. 2007; Paprocki et al. 2014; Kawamura et al. 2019; Zhang et al. 2019). We took these variables as a proxy of climatic variables given the high correlation between them (Freeman et al. 2018). Moreover, the distance to the coastline in the study area showed a general pattern of a lowering turnover rate in forest bird species associated with climate and land-use change (Jiménez-Franco et al. 2024).

All these layers were used with a grid size of 100×100 m. To ensure a set of independent descriptors, linear correlation tests were performed to eliminate closely correlated variables ($r > 0.70$; Zuur et al. 2009; Dormann et al. 2013).

Species distribution models

We modelled species distribution using the statistical approximation of maximum entropy implemented in *MaxEnt* (version 3.4.1; Phillips et al. 2006). This machine-learning technique is

particularly appropriate for working with a presence-only dataset, and its predictive performance has been demonstrated to be more efficient than other presence-only and presence-absence methods, especially for relatively small sample sizes (Elith et al. 2011).

For modelling purposes, the observations obtained by professional fieldwork and volunteers' monitoring scheme were used after eliminating those referring to the same date in the same 1×1 km cell to prevent possible duplication and over-sampling problems in certain locations (Radosavljevic and Anderson 2014). The MaxEnt models were constructed for each species with a sample size composed of more than 15 observations to avoid the uncertainties related to an excessively small sample size (Pearson et al. 2007; Wisz et al. 2008). MaxEnt was run with default settings (regularisation multiplier $b = 1$; auto-features; convergence threshold = 0.00001) by employing the human footprint layer (HFP) as a bias grid (10,000 background points with a likelihood of presence proportional to HFP; Venter et al. 2016; Fandos and Tellería 2018; Tellería et al. 2019). This bias layer aims to correct the possible effect of areas with greater human presence on the sampling effort (Merow et al. 2013; Sullivan et al. 2014; Tellería et al. 2019). The model was replicated 30 times with 70% of the occurrences used as training data and the remaining 30% for model testing to assess variability in the model (Franklin and Miller 2010; Zeng et al. 2015). The percent contributions of jackknife tests were utilised to analyse the contribution rate and the importance of variables. Model discrimination performance was assessed by the mean area under the curve (AUC) of the receiver operating characteristics (ROC). The AUC is a threshold-independent measure of model evaluation that ranges from 0 to 1. An AUC value between 0.5 and 0.7 indicates poor model performance, while 0.7–0.9 denotes good model performance and > 0.9 very good performance (Swets 1988; Peterson et al. 2011). Only the models with AUC values > 0.75 were retained because these values are considered suitable for conservation planning (Zeng et al. 2015).

Habitat suitability maps were generated with the *clo-glog* output (Phillips et al. 2017), where values range from a minimum probability value of 0 to a maximum value of 1. To facilitate the interpretation of suitability maps, they were transformed and represented using the QGIS software (version 3.4.4; Team QGIS Development 2018) with discrete 5-level categorisation based on the continuous models obtained with MaxEnt: 0–0.2, unsuitable; 0.2–0.4, low suitability; 0.4–0.6, moderate suitability; 0.6–0.8, high suitability; 0.8–1.0, very high suitability (Zhang et al. 2019).

Results

In this study, 2106 observations were recorded by considering both professional fieldwork and volunteers' survey schemes, recording a total of 15 raptor species (Table 1).

Table 1 Wintering raptor species observed in the study area, total number of presences recorded during the study (Records), divided by the type of census in professional fieldwork (PF) or volunteers' survey scheme (VSS); and number of presences considered to build models (Modelling). The mean areas under the curve (AUC) with standard deviation (in brackets) are indicated for the modelled species

Species	Common name	Acronym	PF	VSS	Records	Modelling	AUC (SD)
<i>Accipiter gentilis</i>	Northern goshawk	<i>Accgen</i>	1	7	8	–	
<i>Accipiter nisus</i>	Eurasian sparrowhawk	<i>Accnis</i>	14	180	184	182	0.763 (0.032)
<i>Buteo buteo</i>	Common buzzard	<i>Butbut</i>	25	215	240	236	0.829 (0.021)
<i>Circaetus gallicus</i>	Short-toed snake eagle	<i>Cirgal</i>	0	7	7	–	
<i>Circus aeruginosus</i>	Western marsh harrier	<i>Ciraer</i>	24	193	217	209	0.957 (0.011)
<i>Circus cyaneus</i>	Hen harrier	<i>Circya</i>	3	36	39	38	0.929 (0.035)
<i>Elanus caeruleus</i>	Black-winged kite	<i>Elacae</i>	0	14	14	–	
<i>Falco columbarius</i>	Merlin	<i>Falcol</i>	2	29	31	31	0.771 (0.066)
<i>Falco naumanni</i>	Lesser kestrel	<i>Falnau</i>	0	4	4	–	
<i>Falco peregrinus</i>	Peregrine falcon	<i>Falper</i>	6	46	52	52	0.670 (0.066)
<i>Falco tinnunculus</i>	Common kestrel	<i>Faltin</i>	261	786	1047	1004	0.852 (0.009)
<i>Hieraaetus pennatus</i>	Booted eagle	<i>Hiepen</i>	12	233	245	225	0.952 (0.008)
<i>Milvus migrans</i>	Black kite	<i>Milmig</i>	0	4	4	–	
<i>Milvus milvus</i>	Red kite	<i>Milmil</i>	0	12	12	–	
<i>Pandion haliaetus</i>	Osprey	<i>Panhal</i>	0	2	2	–	
Total			348	1768	2106	1977	

The species distribution models were constructed for the eight species ($n = 1977$ observations) that had a minimum number of records ($n > 15$) using all the environmental predictors of the starting set given the absence of correlation (Table S1). According to the values extracted from the evaluation of model performance for these eight modelled species (mean AUC, Table 1), prediction performance was generally high, and values were only poor (< 0.75) for the *Falco peregrinus*, whose predictions were not considered.

The environmental predictors that referred to elevation and distance to the coastline contributed the most to predict habitat suitability for most species by surpassing the land-use descriptors (Fig. S1). Elevation was the best predictor for *Buteo buteo*, *Circus aeruginosus*, *Falco tinnunculus* and *Hieraaetus pennatus*. In some cases, the high gain obtained in the jackknife test, such as for *F. tinnunculus* and *H. pennatus*, indicated that their distribution was strongly influenced by this factor. Distance to the coastline was also one of the main predictors of species distributions, but for none of the species was this factor the main explanatory variable.

Habitat type was the best predictor for *Circus cyaneus* and *Falco columbarius* (Fig. S1d, e). Of the anthropic land uses, rainfed crops made a notable contribution for *C. cyaneus*, irrigated crops for *H. pennatus* and *F. tinnunculus*, agro-forestry areas for *F. columbarius* and urban environments for *A. nisus*. With natural environments, wetlands were the most relevant predictor and featured among the main variables for *C. aeruginosus*, *C. cyaneus* and *F. columbarius*. Forests made a greater contribution as an explanatory variable for *F. columbarius* and *F. tinnunculus* and shrublands did so for *C. cyaneus*.

Increase in elevation led to a sharp drop in habitat suitability for all the species affected by this factor (Fig. S2). In

contrast, distance from the coastline was associated with increased habitat suitability for intermediate distances. The optimum distance in this respect varied from around 40 km for *H. pennatus*, *F. tinnunculus* and *C. aeruginosus* to approximately 80 km for *A. nisus* and *B. buteo*.

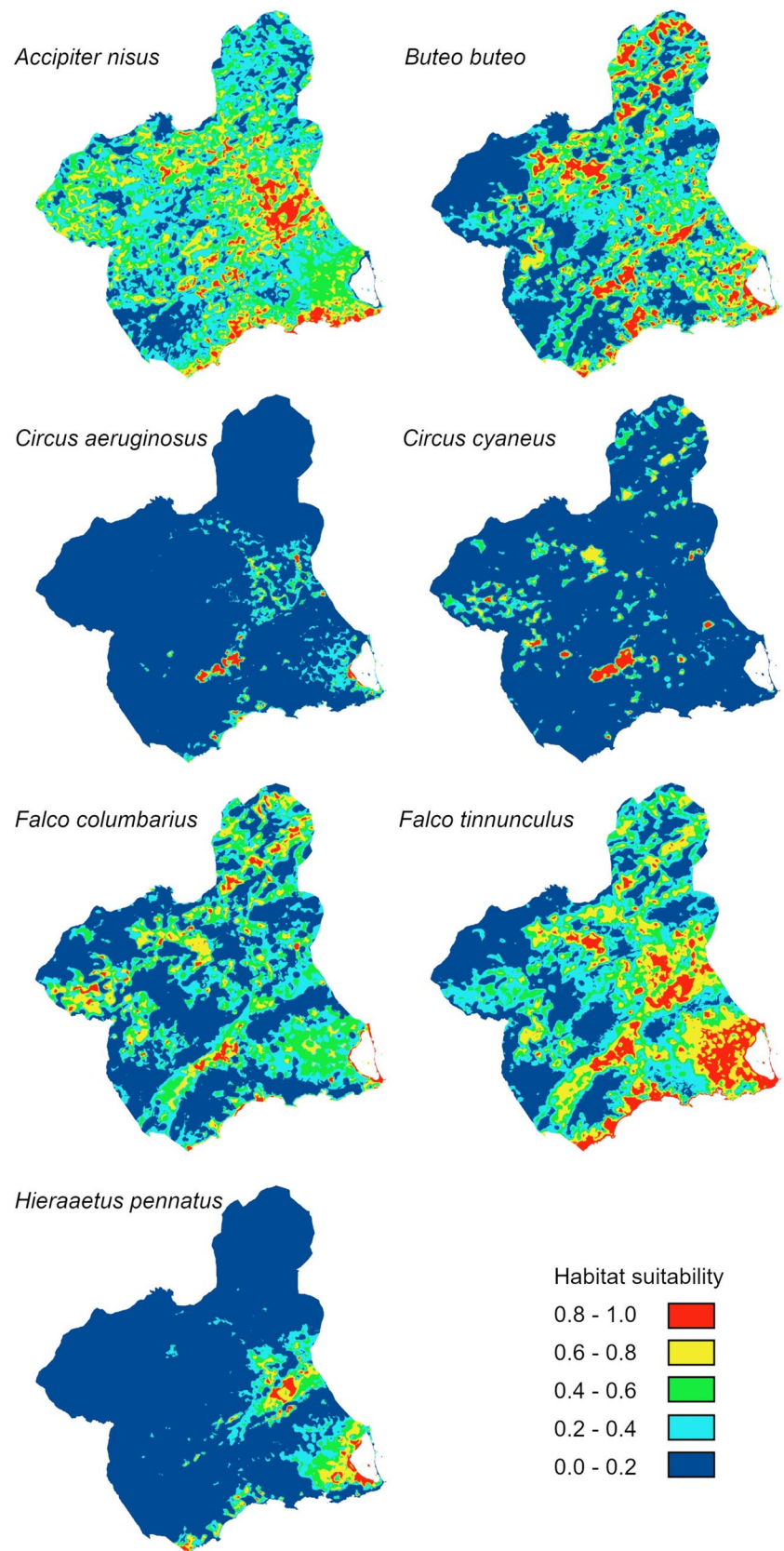
The areas dominated by tree species, related to agro-forestry landscapes, decreased habitat suitability for *F. columbarius* and *F. tinnunculus*. Absence or a low proportion of shrublands, accompanied by a moderate proportion of rainfed crops and wetlands on the landscape scale, was optimal for *C. cyaneus*. A higher proportion of wetlands was preferred by *C. aeruginosus*, whose presence substantially increased when such habitats occupied around 60% of the landscape (Fig. S2d).

According to the suitability distribution maps and the proportion of highly suitable habitats (habitat suitability > 0.6) of the modelled raptor species (Fig. 2), it was possible to differentiate between two general distribution patterns for the (a) species that had a wide distribution pattern and a high proportion of suitable habitat, such as *B. buteo*, *A. nisus* or *F. tinnunculus* and (b) species with a more restricted distribution pattern, such as *C. aeruginosus*, *C. cyaneus*, *F. columbarius* or *H. pennatus*. For some species (*B. buteo*, *F. columbarius*, *F. tinnunculus* and *H. pennatus*), coastal areas had a high habitat suitability (Fig. 2).

Discussion

Our results showed that altitude and distance to the coastline were the best predictors to affect habitat suitability, probably due to their close association with climatic factors (Freeman et al. 2018). Altitude and climate are two closely

Fig. 2 Habitat suitability maps for seven raptor species wintering in the Region of Murcia (SE Spain)



related environmental factors that can play a determinant role in species distribution and the composition of local assemblages of birds and other taxa (Storch et al. 2003). Moreover, these variables may drive raptor species distributions on the macro-scale (Zhang et al. 2019). Altitude range does not impose limitations per se to the distribution patterns of wintering raptors but can strongly affect food availability (Zhang et al. 2019), which is often the main constraint for birds in winter in Mediterranean environments (Leal et al. 2019). Previous studies have found that higher altitudes increase environmental thermal stress and adversely affect animal thermoregulation by negatively influencing fitness and survival for wintering contingents. Food resources also decrease as altitude increases (Carrascal et al. 2002; 2012; Senar and Borrás 2004). At the same time, the closer to the sea, the milder the winter temperature. This scenario favours winter residence and the survival of bird feeding on open lowlands, an environment in which many prey raptor species are especially abundant in winter (Herbers et al. 2004; Senar and Borrás 2004). Therefore, in our case, altitude and distance to the coastline play an indirect role in determining the species distribution of local assemblages of raptors. This pattern has also been observed for forest species richness associated with heterogeneous areas of human-habitat influence, where low areas near the coast have high species richness and species turnover rates associated to the combined effects of climate and land-use changes for the last decades (Jiménez-Franco et al. 2019; 2024).

Altitude and distance to the coastline are also related to land uses in the study area. Forested areas tend to be situated at mid- and high-elevation mountain ranges and are mainly composed of pine (*Pinus halepensis*, *Pinus pinaster* and *Pinus nigra*). Forested landscapes, mostly situated at mid- and high elevation mountain ranges, are avoided by these species of wintering raptors probably due to the scarcity of their favoured foraging habitats (Carrascal and Palomino 2012). Other tree-dominated land cover types that are usually located at lower elevations, such as agro-forestry systems and permanent crops, also failed to contribute significantly towards habitat suitability for any of the modelled species. For this reason, it seems more likely that the presence of a dense tree cover influences foraging behaviour because of reduced prey detectability and accessibility (Bechard 1982; Butler and Gillings 2004; Ontiveros et al. 2005; Bobola et al. 2018).

Despite causing irreversible alterations to landscapes, urban environments can offer new abundant and stable food sources mainly for birds and particularly small- and medium-sized raptors (Donázar et al. 2016; Solaro 2018; Kettel et al. 2019), which can benefit from more hunting success and lower flight activity than those possible in non-urban settings (Rutz 2006). In our case, there was a negative

relationship between species distribution and urbanised areas, except for *A. nisus*. It would seem that this species can successfully exploit urban habitats, a novel environment that may provide a valuable foraging habitat and high food availability for bird-eating raptors (McGrady 1991; Papp 2011; Jankowiak et al. 2015; Schütz and Schulze 2018).

Open habitats, such as wetlands and herbaceous crops, were important in the species distribution models, which suggests the importance of these natural and artificial habitat types in shaping raptor distribution. It is interesting to highlight the effect of wetlands on raptor distribution, which showed similar patterns for *C. aeruginosus*, *C. cyaneus* and *F. columbarius*. It is known that wetlands are critical habitats for the resting and feeding of many avian species in winter (Bobola et al. 2018). In recent decades, a matrix of fields used for intensive agriculture and urbanised areas now surround these wetlands in SE Spain, which generates a high diversity of natural and anthropogenic habitats (Sebastián-González et al. 2010). These represent favourable foraging grounds for certain raptors, such as *F. columbarius*, *C. aeruginosus* and *C. cyaneus* (Carrascal and Palomino 2012; Alves et al. 2014), by offering conditions that lead to the detection and capture of a variety of prey, including passerines, water birds, and small- and medium-sized mammals (Sunyer and Viñuela 1990; Clarke et al. 1993; Bobola et al. 2018).

Our models showed that the two predominant types of herbaceous crops (irrigated and rainfed) had the strongest influence on habitat suitability for raptors. This response is probably influenced by high food availability and the open structure of these environments that generate heterogeneous landscapes (Blount et al. 2021), which may offer increased food accessibility to open-space foragers (Leal et al. 2019). Hence, this pattern would explain why the distribution of the generalist *B. buteo*, a species that usually occupies open areas of sparse vegetation and scattered trees in winter, is optimal in landscapes made up of 80% irrigated crops (Wuczyński 2005; Baltag et al. 2013; Jankowiak et al. 2015) after having rapidly adapted to habitats that provide natural perches for hunting (Butet et al. 2010; Baltag et al. 2013). The case of *H. pennatus* is similar because its preference for irrigated crops also suggests that open-field agriculture offers many food resources, particularly when they are close to other habitat types like urban environments, forests, and especially wetlands (Palomino and Molina 2012; Vidal-Mateo and Urios 2017). In contrast to irrigated crops, whose presence seems to increase food availability for more generalist raptors (Cardador et al. 2012; Ferrer-Sánchez 2015; Grande et al. 2018), rainfed crops are used by specialist raptors like *C. cyaneus* (Carrascal and Palomino 2012; Clarke et al. 1993; Bobola et al. 2018). Therefore, in our case, the greater habitat heterogeneity generated by the closeness of herbaceous crops, wetlands and natural

habitats may provide new foraging habitats to open-space raptors (Grande et al. 2018), as suggested by the greater complexity of the raptor communities observed in open spaces in winter (Panuccio et al. 2019). These results corroborate the importance of complex habitats to host biodiversity (Robledano et al. 2010), where it is necessary to enhance and value the multifunctionality of farms and landscapes, and to actively manage these landscapes for production, biodiversity and human well-being (Estrada-Carmona et al. 2022).

Previous studies have shown that traditional agricultural systems ensure a high biodiversity level (Pimentel et al. 1992). Nonetheless, the current model of agricultural intensification has resulted in generally declining bird populations that inhabit crop fields (Rahmann 2011; Bretagnolle et al. 2019). This negative effect of intensive agriculture on bird populations has been linked with loss of ecological heterogeneity and the lower quality of certain habitats (Guerrero et al. 2012). Several studies also suggest a negative impact of this process on raptor communities (Sánchez-Zapata et al. 2003; Carrete et al. 2009). However, as demonstrated herein and by previous studies (Cardador et al. 2011; Bobola et al. 2018), intensive crops and the agricultural infrastructure associated with them can provide new opportunities by, for example, providing new or more abundant trophic resources (Grande et al. 2018), which could be a determining factor for winter survival. Raptors might, therefore, select them to reduce interspecific competition and to facilitate co-existence with species that have similar trophic requirements (Sergio et al. 2007; 2008; Jankowiak et al. 2015; Paprocki et al. 2015; Bobola et al. 2018). In contrast, depending on the differences in each raptor species' habitat preference, and in line with the conclusions of other studies (see Jankowiak et al. 2015; Bobola et al. 2018; Grande et al. 2018), we suggest that the expansion and intensification of agriculture to the detriment of natural land uses marginalise those species less suited to such changes which need more stable environments. For instance, it may affect the presence and abundance of steppe birds, particularly species of high conservation priority (De Frutos et al. 2015). This means that these habitat-dependent species would be replaced with species that are favoured by such transformations in their wintering grounds to further contribute to biotic homogenisation processes (Le Viol et al. 2012). Therefore, it is relevant to develop field works along years to study the population dynamic and the effects of dynamic landscapes on wintering raptors (Paprocki et al. 2015; McClure et al. 2021). Our results show the importance of agricultural areas as migration stopover sites, for which management actions should be set up to preserve high-quality habitats. Moreover, long-term studies are needed to quantify how land-use changes can affect the occurrence, diversity and abundance of species during the non-breeding period.

Conclusion

Overall, our study compiled information from two data sources (professional fieldwork and volunteers' survey scheme) by using maximum entropy models to obtain the potential distribution and habitat association of wintering raptor species in a semiarid Mediterranean region. Our approach improves the efficiency of designing biological surveys when time and costs are limited (Robinson et al. 2020) because most survey efforts usually focus on raptors' breeding period (Jiménez-Franco et al. 2020). Our results underline that some species have a wide distribution pattern, but others are distributed in specific areas that are mostly associated with wetlands where the food availability is high in winter periods. This study highlights the importance of the habitat heterogeneity generated by wetlands and herbaceous crops within a low-altitude range as the optimal environment for wintering raptors. We also consider that these results are useful for improving habitat management in the human-influenced portions of species' wintering areas (Limiñana et al. 2015).

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10344-024-01784-5>.

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Author contribution MA and JFC conceived the ideas and designed the methodology; MA, JEM and MLO collected the data; MA, MVJF and JFC analysed the data; MA and MVJF led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethical approval This is not applicable. This is an observational study.

Competing interests The authors declare no competing interests.

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