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Census, spatial distribution, habitat selection and conservation of iconic avian species in a Mediterranean coastal massif: the case of El Garraf Park

Claudio Açaí Bracho Estévanez[1]

Knowledge of the population status, requirements and spatial distribution of wild species is essential when taking management decisions and undertaking appropriate conservation efforts. A census of much of El Garraf Park, combined with the use of Maxent and GIS technologies, allowed us to generate distribution models for some of this protected area's most iconic breeding birds (genera *Monticola*, *Oenanthe* and *Lanius*). Here, we explore breeding habitat selection by these species and discuss possible conservation measures and the breeding status of these species in this protected area.

Key words: *Monticola*, *Oenanthe*, *Lanius*, Species Distribution Models (SDM), habitat selection, Garraf Park.

[1]Departamento de Biología, IVAGRO, Universidad de Cádiz, Campus Río San Pedro – Puerto Real, Cádiz, Spain. E-mail: claudio.bracho@uca.es. Orcid: 0000-0003-0081-3354.

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Spatial ecology is a key discipline in biodiversity research, above all in light of the multidisciplinary and global challenges posed by natural heritage conservation (Fletcher & Fortin 2018). Tools such as species-distribution models are widely used and have important implications when targeting conservation efforts, designating critical areas and proposing habitat management measures (Gaston 1996, Rodríguez *et al.* 2007, Guisan *et al.* 2013, Fletcher & Fortin 2018). Today, many ornithological studies apply these geospatial instruments, usually in combination with geographical information system technologies and maximum entropy modelling predictions via the Maxent application (Rushton *et al.* 2004, Phillips & Dudík 2008, Moreno *et al.* 2011, Shirley *et al.* 2013, Jose & Namer 2020).

The Mediterranean basin is a world biodiversity hotspot threatened by global warming and changes in land use (Bellard *et al.* 2014, Palmero-Iniesta *et al.* 2020). At local scale, the monitoring and evaluation of species and habitats is vital for ensuring their short-term preservation. El Garraf Park, a protected area located in the western Mediterranean basin, is of great ornithological interest as home for a number of species whose European ranges are in decline. Despite this, population estimates of birds of the genus *Lanius* are lacking, while numbers of *Monticola* spp. were lasted estimated in the past century (Santaeufemia 1998). In addition, the vegetation and land cover of this protected area have greatly changed in recent decades. As occurs in related Mediterranean ecosystems in Catalonia and nearby regions, vegetation encroachment is the dominant dynamic within the studied landscape (Prodon 2020). Livestock grazing has all but disappeared in the twenty-first century. The large wildfires in 1982 and 1994 have contributed to the overall picture, as noted by Santaeufemia (1998), and along with the still-operating quarries, are the main disturbances and landscape drivers in this protected area.

The aim of this study was to carry out censuses of the breeding territories of birds of the genera *Monticola*, *Oenanthe* and *Lanius* in El

Garraf Park to develop distribution models for each species, calculate estimates of their current populations, improve knowledge of their habitat selection, assess their conservation status, and examine future perspectives within this protected area.

Material and methods

Fieldwork

The study area corresponds to El Garraf Park (12,377 ha), part of the network of protected areas set up and run by Barcelona Provincial Council. In May, June and July 2020 we carried out specific censuses aimed at locating the breeding territories of Blue Rock-thrush *Monticola solitarius*, Rufous-tailed Rock-thrush *M. saxatilis*, Black-eared Wheatear *Oenanthe hispanica*, Black Wheatear *O. leucura*, Woodchat Shrike *Lanius senator* and Iberian Grey Shrike *L. meridionalis*. The censuses were based on 35 transects, conducted along pre-existing paths, tracks and roads, that covered the largest possible number of 1x1-km grid squares within this protected area (Fig. 1). Each transect consisted of a 3.5-km walk, lasting 3–3.5 hours, started between 07.00 and 08.00h. Transects were performed twice: May 5–June 10 and June 15–July 30. The target species were searched for using 10x42 binoculars, and locations were recorded using georeferenced decimal coordinates (longitude-latitude) via the Google Maps application. The Atlas code used in the European Breeding Bird Atlas 2, which classifies evidence of breeding as either possible, probable or confirmed (Herrando *et al.* 2013), was noted for each observation. In total, 117.5 hours of fieldwork were performed in each of the two census periods (May–June and June–July).

Data processing

The territories of the target species were used as the unit of analysis and corresponded to geore-

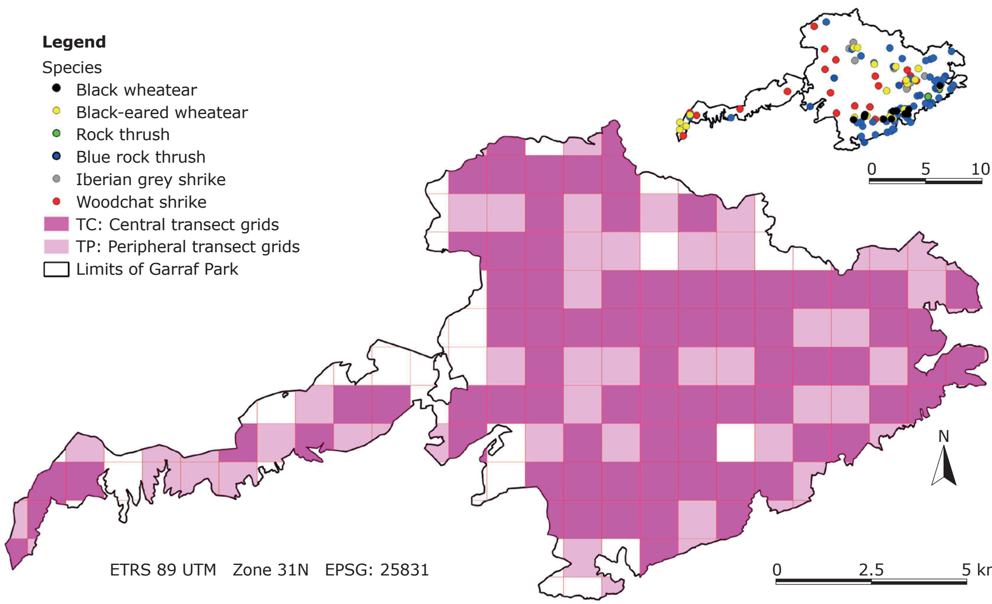


Figure 1. Boundaries of El Garraf Park and its division into 1x1 km squares. Top right: the detected territories of all studied species. The surveyed grid squares are shown in two categories according to the sampling intensity: TP and TC. TP: Peripheral transects are squares that overlap a transect or are less than 100 meters from a transect; TC: Central transects are squares whose centroid (± 100 meters) overlaps with a transect.
Límits del parc del Garraf i divisió del mateix en quadrícules 1x1 km, incloent els territoris detectats de totes les espècies estudiades. Es simbolitzen les quadrícules visitades en dues categories segons la intensitat del mostreig: TP i TC. TP: transsecte perifèric, es refereix a quadrícules que solapen un transsecte o es troben a menys de 100 metres d'un transsecte. TC: transsecte central, es refereix a quadrícules el centroide de les quals (± 100 metres) solapa amb un transsecte.

Table 1. Summary of the number of possible, probable or confirmed territories, and estimated population (territories) for the studied taxa in El Garraf Park.
Valors dels territoris possibles, probables o segurs, i de la població estimada (territoris) per als tàxons estudiats al parc del Garraf.

Species *Espècies*	**Possible territories** *Territoris possibles*	**Probable or confirmed territories** *Territoris probables o segurs*	**Estimated population** *Població estimada*
Blue Rock-thrush *Merla blava*	10	51	50 - 70
Rufous-tailed Rock-thrush *Merla roquera*	1	1	1 - 5
Black-eared Wheatear *Còlit ros*	9	11	10 - 25
Black Wheatear *Còlit negre*	4	7	6 - 12
Woodchat Shrike *Capsigrany*	7	15	15 - 30
Iberian Grey Shrike *Botxí meridional*	3	4	5 - 15

ferenced points with evidence of breeding of the studied species. We used QGIS v. 3.4.14 (QGIS Development Team 2017) and ArcGIS v. 10.7.1 (Environmental Systems Research Institute, 2019) software to incorporate georeferenced data into a geographical information system in which we overlaid various environmental layers of the study area corresponding to five quantitative variables – slope, height above sea level, vegetation vigour, aspect and solar radiation – and a land-use categorical variable. The spatial resolution per pixel was fixed at 15x15 m. Heights above sea level were downloaded from open-access databases from the Catalan Cartographic and Geological Institute (ICGC) as digital terrain models (MDT) at the above-mentioned resolution. Slope, aspect and solar radiation were obtained by performing geospatial operations with the MDT raster. The land-use variables were obtained by consulting open-access databases from the Centre for Research in Ecology and Forestry Applications (CREAF). To obtain the vegetation vigour, we calculated the Standard Difference Vegetation Index (NDVI) using the near-infrared and visible red bands (NDVI = (IRP – RV) / (IRP + RV)) in recent imagery of the study area (2019) taken by the Sentinel II satellite (part of the European Copernicus program).

We used the MaxEnt Java application v. 3.4.1 (Phillips *et al.* 2019) to run distribution models for the territories of the target species. MaxEnt is one of the most powerful tools for producing accurate spatial distribution models (Baldwin 2009, Costa *et al.* 2010, Elith *et al.* 2011). A logistic output format and ASCII output file were set with a maximum number of background points fixed at 10 000; we did not use a percentage of the data as a test. The results were generated as spatial models with distributions or appearance probabilities for territories for each species in the geographical area. The probabilities were then reclassified into two categories depending on whether the probability of occurrence of the territories was greater than 0.7 (maximum probability) or was in the range 0.7–0.5 (medium probability). R v. 3.4.0 (R Core Team, 2017) software was used to perform a Principal Component Analysis (PCA) to explore the territories of each species in a reduced dimensional space of just two principal components. Quantitative variables were considered in the analysis. The QGIS Landscape Ecology Statistics plug-in (LecoS) was used to calculate landscape metrics for Land Cover, Number of Patches, Landscape Proportion, Edge Density and the Patch Cohesion Index for the medium and maximum probabilities of occurrence of the territories in the distribution models.

Results

Censuses

The Blue Rock-thrush (61 detected territories including possible, probable or confirmed breeding sites) was the most abundant species, followed

Table 2. Summary of the spatial statistics for the obtained distribution patches in the models of the target species in El Garraf Park.
Valors de diferents estadístics espacials per a les taques de distribució obtingudes als models de les espècies objectiu al parc del Garraf.

Species *Espècies*		Blue Rock-thrush *Merla blava*	Black-eared Wheatear *Còlit ros*	Black Wheatear *Còlit negre*	Woodchat Shrike *Capsigrany*	Iberian Grey Shrike *Botxí meridional*
Land Cover (Ha) *Cobertura (Ha)*	**P>0.7**	116	94	84	332.4	99.9
	0.5<P<0.7	217	377.1	78.1	863.4	324.7
Nº of Patches *Nombre de taques*	**P>0.7**	363	631	115	1380	336
	0.5<P<0.7	1450	2021	272	4814	753
Landscape Proportion *Proporció de paisatge*	**P>0.7**	0.009	0.007	0.007	0.03	0.008
	0.5<P<0.7	0.02	0.03	0.006	0.07	0.03
Edge Density *Densitat de vores*	**P>0.7**	0.03	0.02	0.04	0.03	0.02
	0.5<P<0.7	0.09	0.08	0.05	0.09	0.07
Patch Cohesion Index *Índex de cohesió de taques*	**P>0.7**	8.9	9.3	9.6	9.6	9.6
	0.5<P<0.7	8.1	9.5	9.3	9.1	9.5

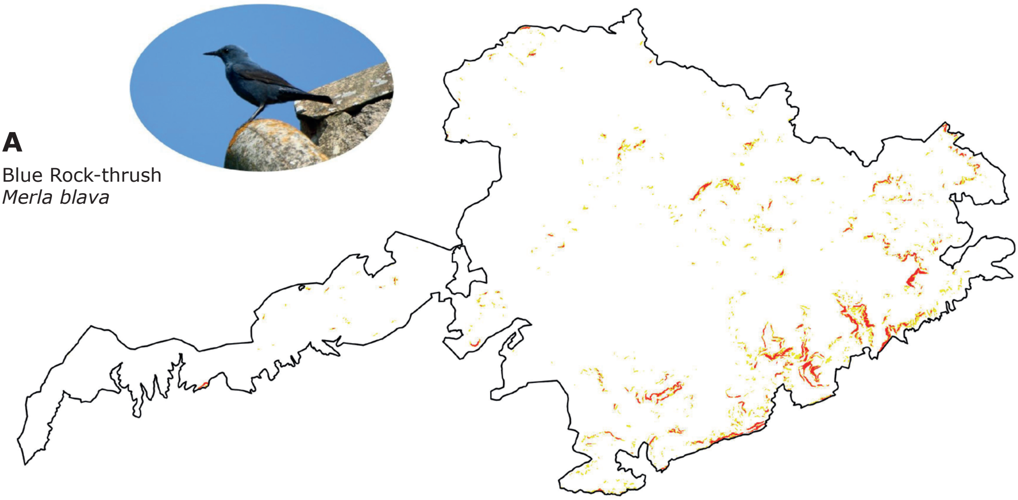
by the Woodchat Shrike (22 detected territories) and the Black-eared Wheatear (20 detected territories). We only detected 11 Black Wheatear territories, and just seven and two territories of the Iberian Grey Shrike and the Rufous-tailed Rock-thrush, respectively. Due to the small number of Rufous-tailed Rock-thrush territories, no distribution model was executed for this species. Detailed data are given in Table 1.

Spatial distribution models

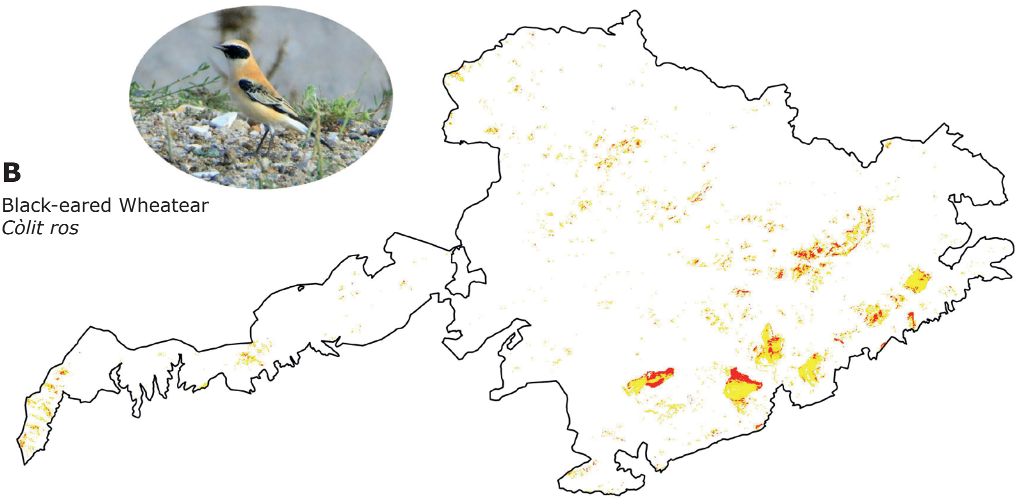
The distribution model obtained for the Blue Rock-thrush (AUC = 0.996) shows that its optimal areas are concentrated on cliffs and in quarries. This model has the lowest Patch Cohesion index and the fewest hectares (Table 2). The sea cliffs and eastern parts of the park are the best areas for this species, although some central areas such as Penyes Roges and Serra de les Conques are also relevant (Fig. 2A). The distribution model obtained for the Black-eared Wheatear (AUC = 0.991) also locates its optimal breeding patches in quarries, as well as around the Vall de Joan landfill, in La Talaia to Balcó de Vilanova area, Serra de les Conques, and in areas with limestone outcrops such as Campgràs and Vallbona (Fig. 2B). The distribution model gave the Black Wheatear (AUC = 0.997) the fewest hectares (Table 2), almost all located in active or in under restoration quarries, the exception being La Falconera, El Morro Curt and Vallcarca (all abandoned quarries, Fig. 2C). The Woodchat Shrike (AUC = 0.853) has the largest potential land cover according to the distribution model, and also the largest number of optimal habitat patches (Table 2), mostly on plateaus (both cultivated and uncultivated) such as Campgràs-La Morella, Campdàsens and La Clota, in valleys with an agroforest mosaic such as Jafre and Vallgrassa, and around agricultural areas such as Santa Susanna, Can Grau and Mas Maiol (Fig. 2D). For the Iberian Grey Shrike (AUC = 0.981), the optimal habitat patches appear on plateaus such as Pla de Querol, El Rascler and Campgràs-La Morella, although areas such as La Mola, Serra de les Conques, Pleta Xica, Mala-rases and Plans de Can Jaques also hold suitable habitat patches. A few optimal hectares are also found at La Talaia, Balcó de Vilanova and El Montgròs (Fig. 2E).

Habitat selection

Blue Rock-thrush territories were found on rocky areas with steep slopes and cliffs at heights above sea level ranging from a few meters to the highest regions of the massif, and with highly variable values of solar radiation and vegetation vigour. Both Black-eared and Black Wheatears selected areas with less steep slopes. The Black-eared Wheatear is found from the highest limestone plateaus to the coastal quarries, with a notable preference for areas with greater solar radiation and lower NDVI values than the Blue Rock-thrush or the two shrike species. The Black Wheatear's distribution is very dependent on the vegetation vigour, being the taxon with the



A
Blue Rock-thrush
Merla blava



B
Black-eared Wheatear
Còlit ros

C
Black Wheatear
Còlit negre

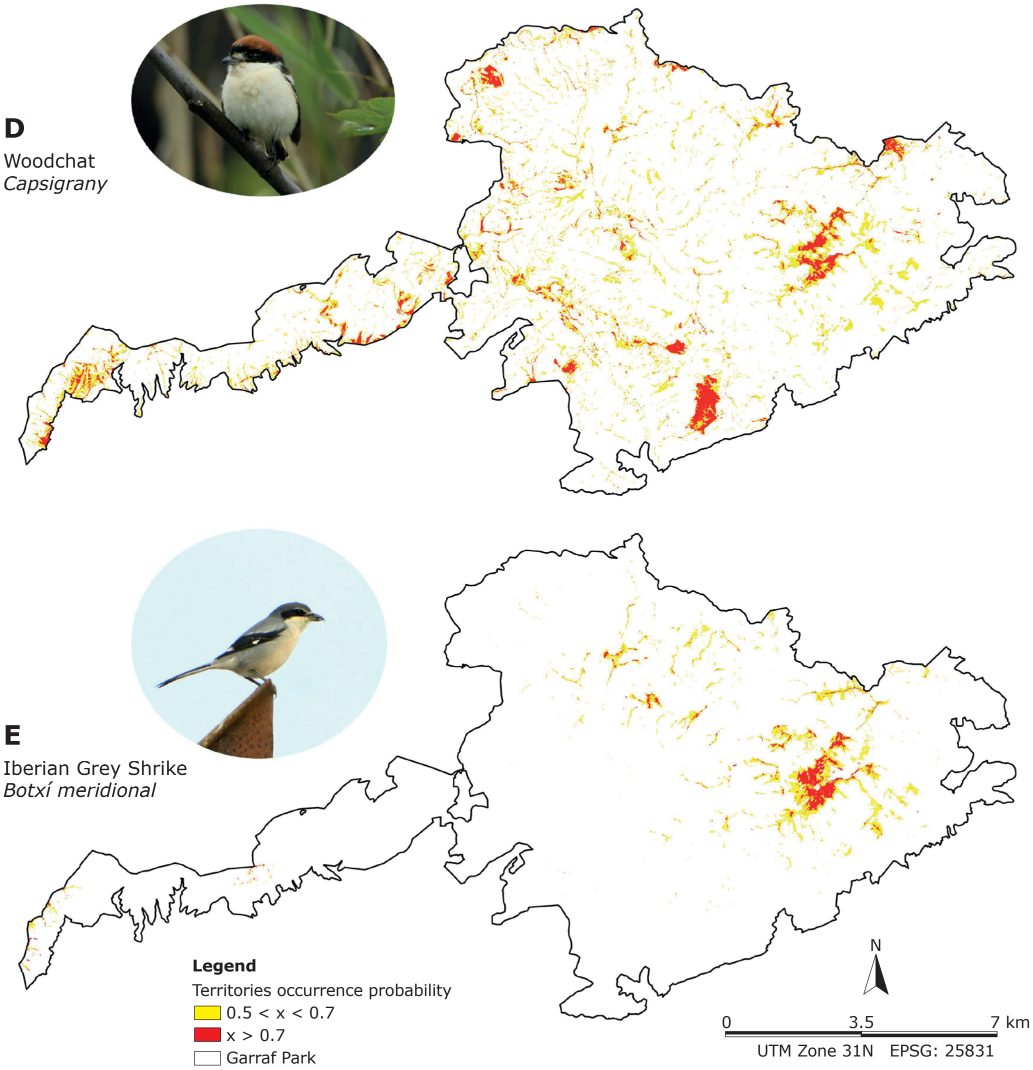


Figure 2. Distribution models of the Blue Rock-thrush (A), Black-eared Wheatear (B), Black Wheatear (C), Woodchat (D) and Iberian Grey Shrike (E) in El Garraf Park.
Models de distribució de la merla blava (A), el còlit ros (B), el còlit negre (C), el capsigrany (D) i el botxí meridional (E) al Parc del Garraf.

lowest NDVI values in the detected territories. It is found at a lower average height than the other species and its range in the park is highly dependent on the coastal quarries. The territories of the shrikes were found in areas with gentle slopes and great solar radiation (particularly the Iberian Grey Shrike). The average height above sea level was lower for the Woodchat Shrike and it is found both on the high plateaus and in the lowland areas of the park. The Iberian Grey Shrike, on the other hand, is concentrated above all in the highest regions of the park and has the highest average height above sea level of the six studied species. Of these species, the Woodchat Shrike had the highest NDVI values (Table 3).

The Principal Component Analysis (Fig. 3) gives an Eigenvalue of 1.8679 for the first principal component and 1.2725 for the second principal component, with an explained proportion of 0.3736 and 0.2550, and a cumulative proportion of 0.3736 and 0.6286, respectively. The variables that most contribute to the first principal component were solar radiation (value = -1.98), slope (value = 1.94) and height (value = -1.19), with NDVI (value = 0.252) and aspect (value = 0.02) being less important. The variables that most contribute to the second main component were NDVI (value = -1.58), height (value = -1.39) and aspect (value = 1.27), followed by solar radiation (value = 0.43) and slope (value = -0.23). There is a close relationship between the Blue Rock-thrush's distribution and the first principal component, this species having a positive selection for slope. The Black Wheatear is clearly related to the second principal component and has a negative NDVI selection. The Black-eared Wheatear is favoured by solar radiation, while neither the Woodchat nor the Iberian Grey Shrikes are favoured by slope.

Discussion

Blue Rock-thrush

The strong Blue Rock-thrush population in El Garraf depends on the availability in the long-term of areas with vertical or steep slopes. Its population trend is stable having increased from 50–60 pairs in 1998 (Santaeufemia 1998) to 50–70 estimated territories in 2020. Despite having more territories than any other of the studied species, the models give the Blue Rock-thrush fewer optimal habitat hectares (Table 2). This is explained by its clear selection of very steep slopes (Table 3), a variable explicitly included in our models that ensured great accuracy for the distribution of this species. Along with the Black Wheatear, the Blue Rock-thrush had the highest AUC values, a parameter positively related to the model accuracy (Fielding & Bell 1997).

Occupied Blue Rock-thrush territories had a great variety of different vegetation types, which makes this species particularly able to persist under future scenarios. Ongoing landscape changes such as the decline in traditional cattle rising, afforestation and scrub encroachment should not lead to the local extinction of this species. At Les Agulles, Eramprunyà, Penyes de Can Marcer and Vall de Sant Joan some territories occupy rocks located in a dense maquis (*Querco-Lentiscetum* A. et O. Bolós 1950) or forest matrix, with few open areas, or in patches of Aleppo pine *Pinus halepensis* and holm oak *Quercus ilex* (*Quercetum ilicis* Br.-Bl. 1915) woodland. As well, a great number of territories are found in both active and abandoned quarries, where there is a completely different landscape matrix and large open areas. Thus, the highest concentrations of Blue Rock-thrush territories are found in Serra de Coma Roja, Serra de les Esglesietes and Les Pedrisses, where quarries, vertical walls and steep rocky slopes abound. Depending on how the quarries are restored, some currently available cliffs will disappear, which could have a considerable impact on this and other rock-loving species (Castillo *et al.* 2008). However, the general abundance of cliffs and rocky slopes in El Garraf

Table 3. Mean and standard deviation for slope, height, solar radiation (WH/m2) and NDVI in the detected territories for each species in El Garraf Park. Also included are the mean and standard deviation of the variables for the whole park.
Mitjana i desviació estàndard per als valors de pendent, alçada, radiació solar (WH/m2) i NDVI dels territoris detectats de cada espècie al parc del Garraf. També incloem la mitjana i la desviació estàndard de les variables tractades per l'àrea del parc.

Species *Espècies*	**Slope** *Pendent*	**Height** *Alçada*	**Solar radiation** *Radiació solar*	**NDVI** *NDVI*
Blue Rock-thrush *Merla blava*	53 (± 11.4)	237 (± 138)	337131 (± 108991)	0.47 (± 0.23)
Black-eared Wheatear *Còlit ros*	22 (± 9.2)	323 (± 142)	482603 (± 38587)	0.27 (± 0.11)
Black Wheatear *Còlit negre*	30.7 (± 15)	166 (± 55.2)	414606 (± 74612)	0.07 (± 0.02)
Woodchat Shrike *Capsigrany*	7.6 (± 4.2)	284 (± 143)	463887 (± 19250)	0.57 (± 0.13)
Iberian Grey Shrike *Botxí meridional*	7.8 (± 3.5)	469 (± 68)	481999 (± 11880)	0.48 (± 0.12)
El Garraf Park * *Parc del Garraf**	18.7 (± 9.1)	275 (± 119)	440781 (± 51883)	0.65 (± 0.14)

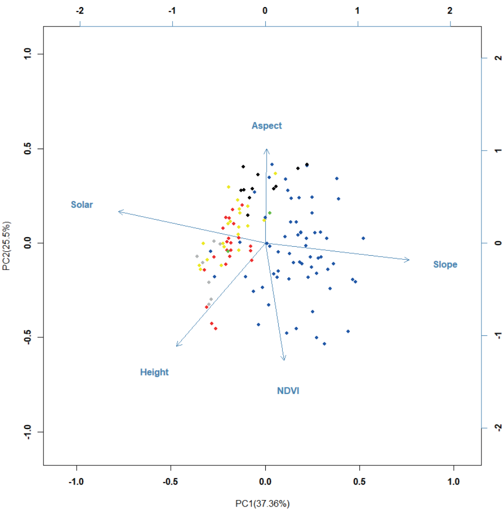


Figure 3. Principal component analysis considering NDVI, aspect, height, solar radiation and slope. Each point corresponds to a territory of a studied species. Blue points represent Blue Rock-thrush (N = 61), green points Rufous-tailed Rock-thrush (N = 2), yellow points Black-eared Wheatear (N = 20), black points Black Wheatear (N = 11), red points Woodchat Shrike (N = 22), and grey points Iberian Grey Shrike (N = 7). *Anàlisi de components principals considerant NDVI, orientació, alçada, radiació solar i pendent. Cada punt correspon a un territori de les espècies estudiades. Els punts blaus representen la merla blava (N = 61), els punts verds la merla roquera (N = 2), els punts grocs el còlit ros (N = 20), els punts negres el còlit negre (N = 11), els punts vermells el capsigrany (N = 22) i els punts grisos el botxí meridional (N = 7).*

Park is enough to sustain suitable habitat for the Blue Rock-thrush (over 70% of optimal hectares in our model are outside quarries).

Two nests were found in abandoned farmhouses and Blue Rock-thrushes were also observed resting or feeding on buildings (e.g. in the village of El Garraf, and in El Poal in Castelldefels) or other anthropogenic structures (sections of the C-32 motorway and quarry infrastructure) several times, which highlights this species' ability to explore and benefit from urbanized environments (Gaggi & Paci 2010). As Santaeufemia notes (1998), this species hunts arthropods in flight above trees. Most observations of hunting took place on cliffs or on isolated rocks, where they search for arthropods and small lizards around rock outcrops, irregularities and edges, capturing prey directly on the ground, after chases, by entering small cracks or after short flights. If available, they will also visit rocky meadows and screes, sometimes in Black-eared Wheatear territories. They also patrol flat or slightly sloping areas of quarries where they coexist with the Black Wheatear.

Rufous-tailed Rock-thrush

The Rufous-tailed Rock-thrush has an altitudinal limit preference in Catalonia, being commonest in the Pyrenees and pre-Pyrenees and only occasionally found in coastal mountain ranges. It presence is thus almost testimonial in El Garraf (Estrada *et al.* 2004). The potential population of this species in the park is small due to the loss of traditional cattle rising and vegetation encroachment in various areas, as has been observed also at greater elevations where land abandonment and the loss of upland grazing have negatively affected this species' populations (Sanchez 1994, Rolando *et al.* 2006).

During fieldwork this species was observed on natural rocky slopes, in dry Mediterranean meadows and on cliffs in quarries. Rufous-tailed Rock-thrushes held territories in places such as Les Agulles until the past decade (F.X. Santaeufemia pers. comm.). However, some of these areas are currently covered by vigorous vegetation with a predominance of dense maquis, and the lack of open areas has probably led to the disappearance of this species' territories here. The recovery of traditional grazing or the after-effects of disturbances such as wildfires, with a consequent decrease in wooded areas and an increase in open spaces, could potentially favour this species in the higher parts of the park (Pons & Prodon 1996, Kati *et al.* 2009, Nikolov 2010, Bazzi *et al.* 2015).

Black-eared Wheatear

The conservation perspectives of the Black-eared Wheatear deserve special attention. Although optimal hectares are found in most areas of the park (Fig. 2B), the population of this species is very scattered and landscape changes in the short term could decrease the suitability of some currently occupied slopes. There has been a significant decrease in the Black-eared Wheatear population in El Garraf in recent decades, a decline from an estimated 70–80 pairs in 1998 (Santaeufemia, 1998) to only 10–25 territories in 2020 being noted in a context of generalized range reductions in the Iberian Peninsula dating back to the second half of the twentieth century (Mestre *et al.* 1987). Screes and rocky slopes with an abundance of dry grassland (*Phlomido-Brachypodietum retusi* Br. – Bl. 1924) and south-facing slopes are the key habitat for this bird in El Garraf, as is the case in related species (Santaeufemia 1998). Our results for this species' habitat selection coincide with previous studies in which south-east-facing slopes and sparse vegetation are highlighted as key for the presence of this species (Brambilla *et al.* 2013). Vegetation encroachment could threaten current Black-eared Wheatear territories. However, some territories are located on screes and rocky slopes that have not been disturbed (essentially by wildfires) for over 20 years and the vegetation in these areas has not yet become too vigorous to prevent occupation by Black-eared Wheatears. Steep slopes, high solar radiation and the stoniness of certain areas lead to a low soil fixation capacity that perpetuates thin soils on which Mediterranean dry grassland communities dominated by grasses such as *Brachypodium retusum* thrive (Kutiel 1992).

Disturbance by wildfires and traditional grazing are linked to decreases in vegetation vigour, as well as the penetration and expansion of dry grassland communities dominated by grasses such as *Brachypodium retusum* (Herrando *et al.* 2003, de Luis *et al.* 2004, Eugenio & Lloret 2006, Lasanta *et al.* 2018). Consequently, one of the most notable concentrations of Black-eared Wheatear territories in El Garraf (in the area from La Talaia to Balcó de Vilanova) corresponds to an area affected by a recent wildfire (2012), which has temporarily increased the amount of optimal habitat for this wheatear. Although in the mid-term the vegetation of certain sunny, stony and arid slopes is unlikely to become too vigorous for the Black-eared Wheatear, most slopes and plateau will suffer oscillations in Black-eared Wheatear occurrence driven by the intensity and recurrence of wildfires and/or grazing disturbance (Prodon 1987, Pons & Lay 2005, Zozaya *et al.* 2012).

The presence of quarries is another disturbance that is positive exploited by the Black-eared Wheatear. Although not as dependent on quarries as the Black Wheatear, 35% of detected Black-eared Wheatear territories are in or near quarries. This bird usually patrols the outer limits of quarries with areas of sparse vegetation. These areas offer optimal vegetation vigour for nesting and feeding, above all in and around false yellowhead *Inula viscosa* bushes (*Inulo-Oryzopsietum miliaceae* O. Bolòs 1957), another habitat that should be considered when restoring the quarries in El Garraf in the future.

Black Wheatear

The small population of Black Wheatear described in 2014 depends on a scarce resource: almost semi-desert habitats strictly linked to quarries. Under current bioclimatic conditions, the vegetation would become intolerably vigorous if the extractive disturbances did not exist (Noguera *et al.* 2014). In 2020, all Black Wheatear territories were in quarries (active or under restoration), although there were occasional observations in natural habitats close to quarries. Outside quarries, disturbances such as recurrent fires or intense livestock grazing could generate optimal or suboptimal habitat for this species (Real 2000, Pérez-Granados *et al.* 2013, Josa & Bertolero 2018).

The distribution model for the Black Wheatear shows four areas beyond the quarries this species currently occupies that have suitable hectares: La Falconera, El Morro Curt, Vallcarca and Cantera Roca (Fig. 2C). Three of these areas correspond to abandoned quarries, while Cantera Roca is a still active quarry. Black Wheatear territories were documented at La Falconera until 2011 (Noguera, Aute & Santaeufemia, 2014). During future quarry restoration activities, management efforts should favour the colonization or recolonization by this endangered species. Human disturbance was the probable cause of its disappearance from La Falconera and so we suggest that access limitations and habitat adequation actions be contemplated at this site. At El Morro Curt and Vallcarca, similar actions could be implemented and periodic monitoring should be conducted to detect any possible colonization by this species. Recurrent wildfires on south-facing slopes in the Park could provide temporarily optimal hectares for the Black Wheatear. An example of this phenomenon occurred in the Muntanya de Montserrat Natural Park, where a burned area was briefly colonized by this species, which disappeared once the vegetation become too vigorous (Real 2000). Accordingly, prescribed fires could be used as a possible management tool for strengthening the Black Wheatear population in El Garraf (Noguera *et al.* 2014). Further study is required of the metapopulation context of this species in its El Garraf and now-extinct Montserrat populations (Real 2000). More knowledge is needed regarding nearby source populations (Josa & Bertolero 2018) to help evaluate colonization-extinction regimes, the importance of local extinctions, and the effect that phenomena such as global warming could have in both the short and mid-terms (Harrison 1991).

Woodchat Shrike

The Woodchat Shrike is a well-established bird in some regions within El Garraf Park (Fig. 2D). A remarkable number of territories are found in the agricultural mosaics at Jafre and Vallgrassa, around Mas Maiol, Can Planes and Can Grau, and on cultivated plateaus such as Campdàsens. It also occurs in flat uncultivated areas with garrigue, ruderal vegetation, dry grassland and scattered maquis or trees. It is absent from uniform landscapes, preferring ecotones between garrigues and maquis, meadows and forests, cultivated fields, ruderal vegetation, and small patches of scrub and woodland. These preferences coincide with previous studies that indicate its choice of semi-open, heterogeneous landscapes, as well as its selection of open Mediterranean forests and certain regression stages, and traditional agricultural mosaics (Hernández 1994, Brambilla 2017).

Management practices favouring landscape heterogeneity, transition habitats and the recovery of agricultural or ruderal areas, all currently occupied by large areas of dense pine forest and maquis, could increase Woodchat Shrike numbers in the park (Isenmann & Fradet 1998, Bergmeier *et al.* 2010). Thus, we believe that management strategies should focus part of their conservation efforts on the wooded parts of the protected area and opt for the restoration of open spaces, which in turn would help reduce the risk of wildfires by promoting forest discontinuity and fuel fragmentation (Fernandes *et al.* 2016). Additionally, the encouragement of livestock-related activity could favour the appearance of grasslands of great interest for this and other taxa by favouring heterogeneity in what is otherwise a largely homogeneous landscape (Isenmann & Fradet 1998, Bergmeier *et al.* 2010, Lasanta *et al.* 2018).

Iberian Grey Shrike

The Iberian Grey Shrike has a marked preference for the plateaus in the Garraf massif that are covered by thin garrigue scrubland (*Quercetum cocciferae* Br.-Bl. 1924), dry grassland or patches of maquis with good-sized shrubs in which to nest and hunt from. Key areas for this species' conservation are found on a few slopes and plateaus in the centre and highest part of the park (Fig. 2E). According to our model, Campgràs-La Morella, El Rascler, La Pleta Xica, El Pla de Querol, Mala-Rases, La Mola and Els Plans de Jaques are essential areas as they are near to a great number of favourable hectares. Our model also reveals optimal areas at La Talaia, Balcó de Vilanova and Montgròs (at the western limit of the park), far from the previously described core area. Although no breeding territory was detected in this western area during the fieldwork, successful breeding has been reported in more recent years (R. González de Lucas, pers. comm.). The Iberian Grey Shrike is associated with different regression stages of Mediterranean woodlands, including sparse garrigues with isolated, prominent shrubs and slopes with scattered oak woodland and bushes; nevertheless, it is also associated with dry croplands with scattered trees (Hernández & Infante 2004, Carrascal *et al.* 2005, Campos & Martín 2010). Data from the SACRE bird-monitoring program reveals a sharp decline in this shrike's numbers in the Iberian Peninsula, in sharp contrast to the stability of Blue Rock-thrush numbers and the only moderate declines of Rufous-tailed Rock-thrush, and Black and Black-eared Wheatears populations (Escandell 2013). This decline has also been reported to be intense throughout Catalonia and Occitania (ICO 2021).

The absence of Iberian Grey Shrike breeding territories in the park's agricultural landscapes is significant. During autumn and winter this shrike significantly expands its territory into non-breeding areas (Hernández & Infante 2004, Campos & Martín 2010). Thus, observations during the non-breeding season in peripheral croplands should not be considered breeding territories. As with the Black-eared Wheatear,

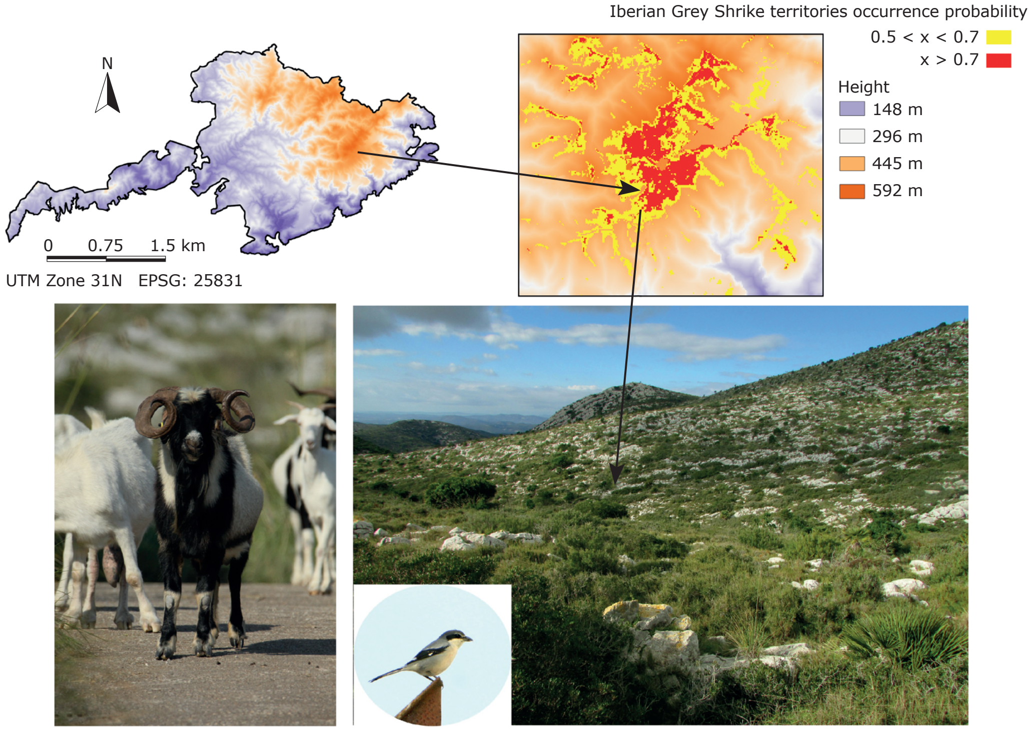


Figure 4. Typical landscape, potentially optimal for the establishment of the Iberian Grey Shrike in the study area. In several parts of the core area occupied by this species including Campgràs, livestock grazing is still a relevant driver of the vegetation structure.
Paisatge típic potencialment òptim per a l'establiment de territoris del botxí meridional a l'àrea d'estudi. A diverses regions de la "core area" ocupada per l'espècie, com al Campgràs, la ramaderia extensiva és encara un factor rellevant pel que fa a l'estructura de la vegetació.

the literature indicates that the Iberian Grey Shrike habitually breeds in agricultural areas in the Mediterranean basin (especially in almond and olive groves) (Campos *et al.* 2006, Campos & Martín 2010, Campos *et al.* 2010). Nevertheless, it is likely that the small area covered by these crops in the park (less than 5% of the protected area) is of little relevance to this shrike, even though they are typically used by the Woodchat Shrike. It should also be noted that the Woodchat Shrike has the highest NDVI average of all the studied species in the detected territories, almost one unit higher than the Iberian Grey Shrike (Table 3; Lefranc 1993). It has been reported a segregation between Iberian Grey and Woodchat Shrikes based on vegetation type, the latter selecting environments with greater tree cover (Hernández 1994).

The recovery of extensive livestock on certain plateaus or slopes (Fig. 4), as well as further management actions favouring herbaceous vegetation and a garrigue-scrubland mosaic to the detriment of homogeneous forest and maquis habitats should increase the suitability of certain areas for this shrike species (Lepley *et al.* 2004). This type of management would be particularly adequate on plateaus and in areas such as Pla de Bassa Llacuna and Pla de Puigmoltó, two sites where we failed to detect territories of this species that appear to be dominated by vegetation that is too vigorous for this shrike.

Final considerations

In recent decades, the study area, as well as vast other regions of the northern Mediterranean basin, have undergone processes of vegetation encroachment associated with changes in traditional land uses (Preiss *et al.* 1997, Strijker 2004, Álvarez *et al.* 2012, Otero *et al.* 2015, Cervera *et* *al.* 2016, Palmero-Iniesta *et al.* 2020). All six studied species benefit from perturbations that limit vegetation encroachment and enhance landscape heterogeneity. The recovery of agricultural mosaics and extensive grazing, together with the implementation of programs of prescribed burning in certain areas, could strengthen the populations of the studied taxa, and could foment scarce habitats and contribute to reducing the risk and impact of future wildfires (Etienne 1996, Perevolotsky & Seligman 1998, Boer *et al.* 2009). We consider that the risk from wildfires will continue to increase in the Mediterranean basin in coming decades (Moriondo *et al.* 2006, Morán-Ordóñez *et al.* 2020) and so actions designed to reduce fuel continuity and vegetation encroachment – which also benefit threatened species – are appropriate management measures in terms of both fire prevention and biodiversity conservation (Castellnou *et al.* 2010).

Favouring habitats such as scattered garrigues and dry Mediterranean grassland benefits bird species linked to open spaces (Prodon 1987, Pons & Prodon 1996, Herrando *et al.* 2003, Zozaya *et al.* 2011). Nevertheless, individual species' particular ecological requirements mean that not all management measures will generate optimal habitat hectares for all taxa: for example, although the Black Wheatear requires high-intensity disturbances to guarantee appropriate vegetation vigour, the Black-eared Wheatear does not require such severe management actions (Table 3). Likewise, the two shrikes take full advantage of tall scattered scrubs, so any management action should prioritize preserving this type of vegetation as hunting and nesting habitat for these species. To reconcile different coexisting management and wildlife conservation objectives, we believe that it is feasible to implement measures such as prescribed fires on certain coastal slopes and in abandoned quarries, although the possible negative effects on other priority species should always be taken into account. This would be particularly beneficial for the park's Black and Black-eared Wheatear populations. In addition, special sensitivity in the restoration of the park's quarries will be required to prevent the future local extinction of the peripheral Black Wheatear population (Channell 2004, Noguera *et al.* 2014). The promotion of extensive livestock grazing is a key management tool on most of the plateaus in the park given that it foments heterogeneous landscapes in areas where low and high vegetation vigours coexist (Perevolotsky & Seligman 1998, Bermejo & Lauenroth 2012, Erin 2014), and will potentially benefit species such as the Rufous-tailed Rock-thrush, Black-eared Wheatear and Iberian Grey and Woodchat Shrikes, amongst other animal species.

Finally, it is clear that past and current socioeconomic constraints are an important limitation on the development of the measures we outline here. Local and regional solutions should be sought to encourage the effective and sustainable recovery of traditional management techniques such as livestock grazing, to promote the potential benefits of prescribed fires, and to foment the key role played by landscape heterogeneity in Mediterranean biodiversity.

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Resum

Cens, distribució espacial, selecció d'hàbitat i conservació d'espècies d'ocells emblemàtiques en un massís litoral mediterrani: el cas del Parc del Garraf

El coneixement de l'estat poblacional, requeriments i distribució espacial de la fauna és primordial per encetar mesures de gestió i conservació adequades. La realització d'un cens que abasta les principals regions del parc del Garraf, combinat amb la utilització de l'aplicació Maxent i tecnologies SIG, ha permès obtenir models de distribució d'alguns ocells emblemàtics de l'espai natural: les espècies nidificants dels gèneres *Monticola*, *Oenanthe* i *Lanius*. A més, s'aprofundeix en la selecció d'hàbitat que fa cada ocell per nidificar i es discuteixen possibles actuacions, així com el seu estat de conservació a l'espai protegit.

Resumen

Censo, distribución espacial, selección de hábitat y conservación de especies de aves emblemáticas en un macizo litoral mediterráneo: el caso del Parque del Garraf

El conocimiento del estado poblacional, requerimientos y distribución espacial de la fauna es primordial para ejecutar medidas de gestión y conservación adecuadas. La realización de un censo abarcando las principales regiones del parque del Garraf, combinado con la utilización de la aplicación Maxent y tecnologías SIG, ha permitido obtener modelos de distribución de algunas aves emblemáticas del espacio natural: las especies nidificantes de los géneros *Monticola*, *Oenanthe* y *Lanius*. Además, se profundiza en la selección de hábitat que realiza cada ave para nidificar y se discuten posibles actuaciones, así como su estado de conservación en el espacio protegido.

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