

## Distribution of Azure-winged Magpies *Cyanopica cooki* in Spain: both local and large-scale factors considered

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**Abstract.** Although the main environmental determinants of bird distribution are contingent on the spatial scale of studies, the consistency of species distributional patterns has rarely been considered in large- and local-scale analyses. The competing roles of biotic, abiotic and landscape features in shaping the distribution of Azure-winged Magpies were assessed at two spatial scales: a large-scale analysis of 50x50 km blocks across nearly the whole of the species range (the Iberian Peninsula), and a small-scale assessment based on point counts of 50-m radius located near the northern edge of its distribution. The observed species distribution can be explained mainly by geographic and climatic features whereas the influence of landscape factors is weak. Azure-winged Magpies are more abundant near the core of its range in southwest Iberia and rarify towards the north and the east, in what seems to be a limitation of their ability to tolerate colder and drier climates, respectively. At local level, Azure-winged Magpies are habitat generalists avoiding urban sprawl whose probability of occurrence decreases with elevation, reaching zero above 1,600 m a.s.l. The species prefer wooded environments, although it tends to avoid mature, dense forests. The occurrence of potential competitors (Common Magpie *Pica pica* and Jay *Garrulus glandarius*), whose habitat preferences widely overlap with those of the Azure-winged Magpie, had no influence on either the large-scale or local distribution of Azure-winged Magpies. From a conservationist standpoint, the presence of the species in agricultural, pseudosteppe habitats with thinly forested watercourses highlights the importance of conserving gallery forests in the regions less suitable for the species.

**Key words:** Azure-winged Magpie, *Cyanopica cooki*, habitat preferences, large-scale distribution, regression and classification trees, Spain

### INTRODUCTION

Understanding the environmental determinants of abundance and distribution of species implies considering several hierarchically structured spatial scales, because the same variable may fail or succeed in predicting the species preferences depending on the spatial level considered (Wiens 1989a, Lee et al. 2002, Fischer et al. 2004, Reif et al. 2008a). Although it is widely recognized that habitat structure and landscape characteristics are the main predictors of the presence and abundance of vertebrates (Orians & Wittenberger 1991, Mazerolle & Villard 1999, Jones 2001, Blackburn & Gaston 2002), the importance of these variables

has to be jointly evaluated with that of other environmental and biotic factors such as climate or interspecific interactions. For instance, it is well known that limits to the distribution of a species may be modified by ecological interactions (such as food availability or presence of potential competitors; e.g., Davies et al. 1998, Anderson et al. 2002, Araújo & Luoto 2007, Heikkinen et al. 2007), and that biotic and abiotic variables show little redundancy in explaining species distributions (Meier et al. 2010). On the other hand, the importance of habitat features in determining patterns of distribution and abundance at fine-grained local scales usually fades when viewed at broader, regional ones (Rodewald & Yahner 2001, MacFaden

& Capen 2002). From an applied perspective, multi-scaled analyses of distribution/abundance may lead to a better understanding of the role of abiotic (e.g., geomorphology, climate), habitat and landscape (e.g., vegetation structure, habitat fragmentation) and biotic (e.g., prey availability, competitors) variables influencing the distribution of species on large-scale geographical contexts (Lawton 1993), and may help to guide conservation efforts, in particular for endemic taxa or species with isolated populations. Disentangling these factors in order to assess current postulates on global change scenarios forecasting marked disruptions on the overall dynamics of extinction/colonization is particularly relevant for Mediterranean regions.

The Azure-winged Magpie *Cyanopica cyanus* has a striking disjunct distribution consisting of two well-defined ranges with a gap of 9,000 km between both: eastern Asia (including SE Russia, China, Mongolia, Korea and Japan) and the south western quarter of the Iberian Peninsula (Spain and Portugal) (Cramp & Perrins 1994, Madge & Burn 1994). A theory suggesting that the Iberian population comes from an introduction in the 16th century by Portuguese/Spanish sailors (Dos Santos 1968, Sacarrão 1974) has been rejected after the recent discovery near Gibraltar of Azure-winged Magpie's bones dated at least 44,000 years old (Cooper 2000). Instead, it is currently widely accepted that what once was a wider and continuous distribution of the species before the Late Pleistocene was severely disrupted because of glaciation cycles, and populations of Azure-winged Magpie became extinct across the central part of its range, giving rise to the two isolated refugia currently existing. In accordance with such a marked allopatry, genetic and morphological analyses (Fok et al. 2002, Kryukov et al. 2004, Haring et al. 2007) identify consistent differences between Iberian populations and eastern ones, suggesting their taxonomic split into *Cyanopica cooki* and *Cyanopica cyanus*, respectively. Regardless of whether the endemic status of the Iberian populations applies to the species or the subspecies level, the Azure-winged Magpie is an endemic taxon of the European avifauna, occurring in a relatively restricted range in the Iberian Peninsula (approx. 168,700 km<sup>2</sup>, 28% of the total peninsular area, Martí & Del Moral 2003, Equipa Atlas 2008).

Despite being a genuine representative of the Iberian avifauna, previous studies focused on habitat selection of the Azure-winged Magpie in

Spain or Portugal are very scarce (reviewed by Cruz Solís & Valencia 2004). The typical environment inhabited by this species is the ecotonal grazing parkland of scattered holm-oaks (Cruz Solís & Valencia 2004), a land-use type particularly common in southwest Iberia, and characterized by its soft-level of anthropic management. Therefore, the identification of environmental determinants of the distribution of Azure-winged Magpie in Iberia deserves a precise assessment, to discern why its geographical range is so small when compared with the eastern one in Asia, and whether this fact entails conservation concerns. This study deals with the main environmental determinants of the species distribution in the Spanish sector of the Iberian Peninsula, considering two spatial scales: a large-scale analysis covering the whole Spanish distribution of the species (approx. 130,000 km<sup>2</sup>), where abiotic factors like climate are expected to have the larger influence, and a small-scale investigation near the northern edge of the species distribution (approx. 700 km<sup>2</sup>), where habitat structure should be the primary predictor. In an attempt to test whether interspecific competition may influence the spatial distribution of the Azure-winged Magpie we also analyze whether its distribution is influenced by the distribution patterns of Common Magpie *Pica pica* and Jay *Garrulus glandarius*, with which it shares some ecological preferences (Perrins 1998). To examine all these questions focusing in the Azure-winged Magpie may help to understand overall biogeographic patterns for many other birds also characteristic of this region, including several threatened species worldwide (e.g. Spanish Imperial Eagle *Aquila adalberti*, Black Vulture *Aegypius monachus* or European Roller *Coracias garrulus*).

## MATERIAL AND METHODS

This paper is based on two sources of information at two spatial scales: the Spanish distribution in a 10x10 km grid, based on the extensive data from the last Spanish atlas of breeding birds, and the local distribution in Central Spain using field point-count censuses. Although the study is centred on the Azure-winged Magpie, data were also obtained for the Common Magpie and the Jay to test for potential effects of interspecific competition at both peninsular and local study levels.

### Distribution at a large scale (Iberian Peninsula)

Data used in this paper are those reported in the atlas of Spanish breeding birds (Martí & Del Moral 2003), a thorough survey of the recent breeding distribution of birds in 10x10 km UTM squares.

In spite of the good coverage achieved in this collective atlas work the sheer documentation of species presence/absence over so large areas (100 km<sup>2</sup>) limits its utility in biogeographical analyses. Although when a species is recorded an objective estimate of its presence is obtained (except for identification mistakes), its absence leaves unresolved whether the cause is lack of sampling effort and/or low species abundance. The binomial nature of the variable 'square occupation' (with two values, yes = 1 vs. no = 0) introduces a sizeable error term in relation to its total range of variation (error = 1 when the species is present but passes unnoticed), making difficult the estimation of statistical effects and significance testing. To minimize this error in the analyses we pooled the UTM squares of 10x10 km included within larger 50x50 km UTM squares, so that the species presence in each block of 2,500 km<sup>2</sup> indicates its frequency of recording in 26 levels (0 — no species records in 25 squares, i.e., virtually absent, by consistency in lack of observations; 25 — the species is widely distributed and its repeated recording makes 'sure' its wide distribution range). As a consequence, intermediate levels in the frequency of recording have lower relative errors in relation to the total range of variation in the dependent variable. For instance, if a species actually has a very sparse distribution (e.g. only 3 "real" presences in the 25 10x10 km squares within a 50x50 km block), and passes unnoticed in some squares where it is actually present (e.g. it is recorded in only one square), the relative error is 2 units from 26 levels. This scale of resolution has also been used in the European birds' atlas (Hagemeijer & Blair 1997). On the other hand, the pooling of smaller squares in 50x50 km blocks has the added advantage of allowing the gathering of environmental data of difficult access and simplifying statistical analyses by using a lower number of sample units. We have analysed 219 blocks of 50x50 km in the Spain's peninsular sector, excluding blocks in the periphery — coastal and bordering with France or Portugal — with less than 20 squares of 10x10 km covered by the atlas (see Fig. 1a).

For each 50x50 km block the following variables were obtained (see Table 1): 1) two spatial variables (central latitude and longitude of each

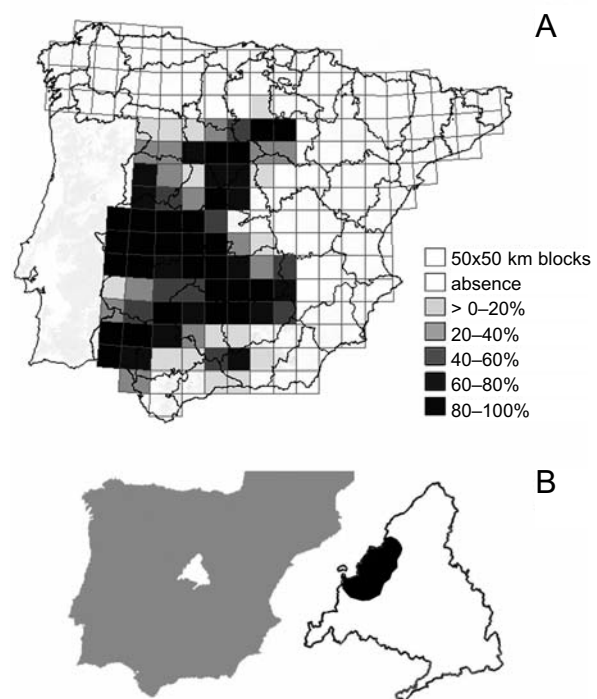


Fig. 1. Study areas: a) distribution map of Azure-winged Magpie for the grid of 50x50 km UTM squares of the study area according to the Spanish Atlas of Breeding Birds (Martí & Del Moral 2003). Frequency of occurrence measured as the number of 10x10 km UTM squares within each 50x50 km cell where the species was recorded is categorized in five percentage classes; b) location of Madrid province and the study area in the southern slope of the Guadarrama range where 427 point-count censuses were made during the breeding season (black patch).

grid cell); 2) mean elevation and altitudinal range (difference between the highest and lowest altitudes in the block); 3) length of river courses; 4) length of three kinds of motor roads (highways, national and regional-local roads); 5) area covered by twelve main habitat categories (cover was obtained using Corine Land Cover database corresponding to the years 1985–1990, to maximize the temporal overlap of environmental and ornithological data, since the field censuses for the Spain's breeding birds atlas were carried out between 1985 and 2002); and 6) six climatic variables: yearly and spring (April–June) percentage of sunny days (days with anticyclonic weather with clear skies), average yearly and spring temperature, and yearly and spring rainfall. This selection of predictor variables relates to large-scale patterns of landscape structure and defines habitat, orographic, climatic and anthropogenic gradients of great influence on the biogeographical patterns of birds in the Iberian Peninsula (Carrascal & Lobo 2003, see also Lobo et al. 2001

Table 1. Environmental features characterizing Iberian distribution of Azure-winged Magpie considering UTM blocks of 50 x 50 km. \*\*\*\* —  $p < 0.0001$ ; \*\*\* —  $p < 0.001$ ; \* —  $p < 0.05$ ; ‡ — significant differences after sequential Bonferroni correction.

|                                      | Absence |       | Presence |       | Student<br>t-test |        |
|--------------------------------------|---------|-------|----------|-------|-------------------|--------|
|                                      | mean    | sd    | mean     | sd    |                   |        |
| <b>TOPOGRAPHY</b>                    |         |       |          |       |                   |        |
| Mean elevation (m)                   | 680.8   | 390.2 | 606.6    | 297.7 | 1.61              |        |
| Elevational range (m)                | 1233.9  | 617.3 | 805.1    | 432.5 | 6.10              | **** ‡ |
| <b>CLIMATE</b>                       |         |       |          |       |                   |        |
| Mean yearly rainfall (mm) — RAINFALL | 801.1   | 383.4 | 614.3    | 164.9 | 4.97              | **** ‡ |
| Mean spring rainfall (mm)            | 188.8   | 72.4  | 149.5    | 38.3  | 5.25              | **** ‡ |
| Mean yearly temperature (°C)         | 13.5    | 2.5   | 14.2     | 1.8   | 2.45              | *      |
| Mean spring temperature (°C)         | 15.1    | 2.3   | 16.1     | 1.7   | 3.45              | *** ‡  |
| % yearly sunny days                  | 54.5    | 6.4   | 60.6     | 3.2   | 9.47              | **** ‡ |
| % spring sunny days                  | 57.5    | 6.0   | 64.7     | 3.3   | 11.33             | **** ‡ |
| <b>LAND USES</b>                     |         |       |          |       |                   |        |
| % urban/industrial cover             | 1.2     | 2.3   | 0.7      | 1.5   | 1.87              |        |
| % dry farming cover                  | 12.4    | 15.4  | 16.1     | 15.4  | 1.80              |        |
| % irrigated farming cover            | 4.0     | 6.7   | 3.3      | 4.4   | 0.93              |        |
| % olive groves cover                 | 0.7     | 2.2   | 4.0      | 8.0   | 3.81              | *** ‡  |
| % fruit groves cover                 | 16.7    | 11.4  | 17.2     | 10.5  | 0.34              |        |
| % agricultural areas — %AGRICUL      | 34.3    | 21.3  | 37.7     | 19.1  | 1.24              |        |
| % grassland cover                    | 3.2     | 4.1   | 8.0      | 5.8   | 6.79              | **** ‡ |
| % shrubland cover                    | 10.3    | 6.4   | 9.8      | 5.6   | 0.61              |        |
| % young forest–tall shrubland cover  | 5.3     | 3.7   | 4.9      | 3.6   | 0.75              |        |
| % broad-leaved cover                 | 4.5     | 5.4   | 5.6      | 4.4   | 1.69              |        |
| % coniferous cover                   | 7.3     | 6.1   | 3.9      | 4.6   | 4.73              | **** ‡ |
| % forest cover                       | 14.2    | 8.7   | 9.8      | 6.2   | 4.39              | **** ‡ |
| <b>LINEAL ELEMENTS</b>               |         |       |          |       |                   |        |
| Km highways                          | 30.0    | 41.3  | 23.1     | 42.7  | 1.19              |        |
| Km 1 <sup>st</sup> order roads       | 72.7    | 42.6  | 61.3     | 43.0  | 1.96              |        |
| Km 2 <sup>nd</sup> order roads       | 631.6   | 323.6 | 559.0    | 261.1 | 1.85              |        |
| Km powerlines                        | 128.1   | 112.6 | 95.7     | 99.2  | 2.26              | *      |
| Km watercourses — KM RIVERS          | 409.8   | 228.7 | 468.3    | 243.4 | 1.81              |        |

for more details on data recording and treatment using Geographic Information Systems).

#### Distribution at a local scale (Central Spain)

Data were gathered on the southern slope of the Guadarrama Range (Madrid province, Central Spain), spanning over 700 km<sup>2</sup> of piedmont and mountain areas (40°35′–40°48′ N; 3°45′–4°10′ W; 850 to 2,265 m a.s.l.; Fig. 1b). This is an area located at the north-eastern border of the Iberian distribution of the Azure-winged Magpie (Martí & Del Moral 2003), where the species has recently spread its distribution and increased in abundance (Díaz et al. 1993). The study region has a Mediterranean-continental cold climate, with a mean temperature of 14.5°C and mean rainfall of 130 mm cumulated during springtime. The environmental heterogeneity of this study area (see later) is much larger than in the core of the species range (huge flat valleys, uniformly covered by parklands), allowing the description of fine-

grained responses to habitat structure by the Azure-winged Magpie. Besides, by being an area recently colonized by the species, it also offers a good opportunity to test the interspecific relationships of Azure-winged Magpie with other corvids already present.

We assessed breeding bird occurrence of the study species through 427 single-visit point counts, lasting 20 min, and recording the species within a 50-m radius (0.8 ha). All censuses were carried out by the same person (DP) on windless and rainless days, during May and early June in four consecutive years (2001–2004), and between sunrise and 1100 h GMT in the morning, or between 1800 h GMT and sunset in the late evening. Corvids are easily detectable species (especially *Cyanopica* and *Pica*), so the possible influence of a detectability decrease in the evening, postulated for some songbird species, is considerably ameliorated in our study. Moreover, residuals of the classification tree (see below) do

not differ when comparing morning vs evening plots. Censuses were spanned throughout the four years of study, avoiding censusing certain habitats in only one particular year. Sampling points were located as to include only one homogeneous habitat and were set at least 200 m apart from each other (in many instances at more than 400 m). They were georeferenced with a Garmin 12 GPS (precision of 1 m by means of the average location function).

The censuses were spread out throughout all main habitats and altitudinal belts present in the study region, comprising: i) Alpine shrublands of *Cistus purgans* and *Juniperus nana* above the tree line (1,900–2,300 m a.s.l.); ii) Pine forests (*Pinus sylvestris/pinaster*) spread out between 1,050 and 1,900 m a.s.l. They are the most mature woodlands in the region, in spite of being managed for logging; iii) Open and dense oak forests (*Quercus pyrenaica*), mainly young stands 20–50 years old, predominantly located at 950–1,350 m a.s.l.; iv) Montane shrublands of *Cistus ladanifer*, *Cistus laurifolius* and *Genista* spp. (1,000–1,600 m a.s.l.); v) Open parklands of Holm-oak (*Quercus ilex rotundifolia*) devoted to cattle grazing (800–1,000 m a.s.l.), a traditional landscape in rural Iberia, named ‘dehesas’ and ‘montados’, in Spanish and Portuguese respectively; vi) Dense Ash-groves (*Fraxinus angustifolia*) on valley-fields (850–1,100 m a.s.l.) providing both pasture and shade for grazing cattle. The tree layer is managed through continuous clearance and pruning; vii) Riparian forests (*Populus alba*, *Fraxinus angustifolia*, *Alnus glutinosa*, *Salix* sp.) on streams crossing valley-fields (850–1,100 m a.s.l.); viii) Open habitats (mainly pasturelands), devoted to cattle grazing, with very low density (< 2 trees/ha) of small trees (< 6 m height), and shrub cover (< 10%; hedgerows of brambles, hawthorns and rock-roses *Rubus* sp, *Rosa* spp., *Prunus* spp., *Crataegus* sp.). They are located on valleys (850–1,100 m a.s.l.); ix) Towns and cities, ranging between 0.5 and 15 km<sup>2</sup> (mean = 3.3 km<sup>2</sup>; n = 16) and typically comprising a densely built-up commercial core, surrounded by residential areas of block buildings, terraced-houses or gardened detached houses (at 850–1,200 m a.s.l.).

Habitat structure of each census plot was sampled within a radius of 25-m centred in the plot, and was carried out immediately before bird counts began. We estimated by eye, after training, some habitat structural features within a radius of 25 m: percentage cover of herbaceous, shrub

and tree layers, average height of the shrub and tree layers, number of trunks 5–10, 10–30 and > 30 cm in diameter at breast height (dbh), and total numbers of coniferous, evergreen, or deciduous trees. Additional variables were also recorded in urban plots: percentage cover of buildings, average height of buildings, and number of vehicles parked or in movement (as a raw measure of intensity of human transit).

### Statistical analyses

A first step in data analysis was comparing the environmental features of areas where the Azure-winged Magpie was present with those where the species was not observed (at both the scale of 50x50 km blocks in the peninsular distribution analysis, and of 0.8 ha census plots in the study of local habitat preferences). These comparisons were carried out by means of t-tests. To control for type I errors, we followed suggestions by Chandler (1995) to increase the power of individual tests while maintaining fixed experiment-wise error rates. In each of the two batteries of t-tests, the sequential Bonferroni adjustment (Rice 1989) with an experiment-wise error rate of 0.05 was used.

Next, regression trees were used to analyse the large scale relationships of the frequency of appearance of the Azure-winged Magpie in 10x10 km squares within 50x50 km blocks (see Fig. 1) with environmental variables in 50x50 km blocks; additionally, classification trees were used to analyse the local effects of altitude and habitat structure on bird species occurrence in the sample of 427 census plots of 0.8 ha. Regression and classification tree analyses allow interpretation of datasets where there are complex nonlinear relationships between response and predictor variables, and/or high-order interactions among predictor variables (Breiman et al. 1984, De'ath & Fabricius 2000). The stopping rules in tree growth applied in our data analyses were (1) groups including at least 20 cases, (2) significant reductions in residual deviance (a measure of group heterogeneity) attained by a splitting criteria (according to a  $\chi^2$  test) and (3) pruned after a 10-fold crossvalidation procedure using the minimum crossvalidation cost.

Finally, a discriminant function analysis (Chatfield & Collins 1995) was carried out to test the extent of differences in local habitat preferences of the Azure-winged Magpie, the Common Magpie and the Jay. We used a forward stepwise discriminant function analysis.

Statistical analyses were carried out using SPSS 2000 (MathSoft 1998) and Statistica 6.0 (StatSoft 2001).

## RESULTS

### Distribution at the regional scale (Iberian Peninsula)

In comparison with unoccupied areas, 50x50 km blocks with Azure-winged Magpies were less mountainous, had less spring and annual rainfall, were warmer, had a higher proportion of sunny days (both in spring and throughout the year), were less covered by woodlands (mainly lacking coniferous forests), and had more surface of olive tree plantations and pasturelands (Table 1).

Ten geographic and climatic variables explained 69.1% of the original variation in the frequency of occurrence of the Azure-winged Magpie in 50x50 km blocks ( $\chi^2 = 9.86$ , d.f. = 7,  $p << 0.001$ ; Fig. 2A). The most important variables affecting the species distribution were the percentage of sunny days in springtime (positively) and the west-east position within the Iberian Peninsula (longitude; the species was less frequent in the eastern sectors of Spain). Annual rainfall had opposite contrasting influences on the species occurrence, depending on the geographic location considered. In the less sunny areas (% of spring sunny days < 63.5), located west of the meridian 2°42' W, and south of latitude 42°00' N, the Azure-winged Magpie was more frequent in the less rainy sectors (less than 757 mm of annual rainfall), whereas in the more sunny areas (% of spring sunny days > 63.5) located west of meridian 2°26' W and north of latitude 37°15' N, annual rainfall positively influenced the species distribution (see Fig. 2A).

The addition of 12 variables describing the structure of the landscape and human impacts to the previous model, produced only a subtle, near negligible, increase in the deviance explained (72.7%;  $\chi^2 = 10.37$ , d.f. = 7,  $p << 0.001$ ; Fig. 2B). Landscape variables mainly related to the species distribution were the percentage cover of terrain devoted to agricultural activities (negatively) and the length of rivers and streams (positively; Fig. 2B).

In summary, the localities where the species was more frequent are those with a percentage of sunny days in springtime higher than 63.5%, located west of 2°26' W and north of 37°42' N, and with less than 56% of the area devoted to

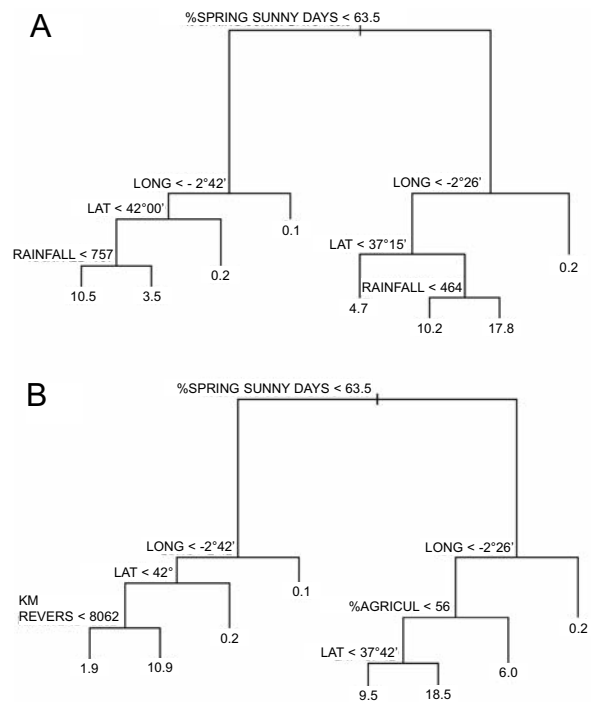


Fig. 2. Regression tree models for the occurrence of Azure-winged Magpie in the Spanish sector of the Iberian Peninsula. Values at the tips of branches show the frequency of occurrence of the species in squares of 10x10 km within blocks of 50x50 km. Length of the branches is proportional to deviance explained by each split. The splitting variables and threshold values selected refer to left branches of the tree so that right branches met opposite conditions. a) regression tree using ten geographic and climatic variables; b) regression tree using 12 variables describing the structure of the landscape and human impacts in addition to ten geographic and climatic variables. LONG/LAT: geographic coordinates (longitude/latitude), in degrees and minutes. For other acronyms see Table 1.

agricultural activities (occupation of 74% of 50x50 km blocks area, or an average of 18.5 out of 25 10x10 km squares).

The residuals of this regression model were not significantly related to either the frequency of occurrence of the Common Magpie or the Jay (0.2% of the variance explained by a linear regression model including the frequencies of occurrence of these species in 50x50 km blocks; regression coefficients are 0.013 for the Common Magpie,  $p = 0.088$  and -0.008 for the Jay,  $p = 0.772$ ).

### Habitat distribution at the local scale (Central Spain)

Occupied sites (0.8 ha census plots) were at lower altitudes and had less human impact (measured by several variables describing cover and height of buildings and number of vehicles) than unoccu-

Table 2. Habitat features characterizing local distribution of Azure-winged Magpie in northern Madrid province (Central Spain) in 0.8 ha census plots. \*\*\*\* —  $p < 0.0001$ ; \*\* —  $p < 0.01$ ; \* —  $p < 0.05$ ; ‡ — significant differences after sequential Bonferroni correction.

|                                  | Absence |       | Presence |       | Student t-test |        |
|----------------------------------|---------|-------|----------|-------|----------------|--------|
|                                  | mean    | sd    | mean     | sd    |                |        |
| Altitude                         | 1231.5  | 317.9 | 1126.0   | 193.3 | 3.05           | ** ‡   |
| Presence of watercourses         | 0.1     | 0.2   | 0.2      | 0.3   | 2.06           | *      |
| % built-up cover — %BUILDINGS    | 6.3     | 17.3  | 0.0      | 0.0   | 7.16           | **** ‡ |
| Height of the buildings          | 1.3     | 3.3   | 0.0      | 0.0   | 7.75           | **** ‡ |
| # motor vehicles                 | 1.4     | 6.9   | 0.0      | 0.2   | 3.98           | **** ‡ |
| % rock cover — %ROCK             | 4.6     | 9.7   | 2.4      | 3.7   | 2.88           | **     |
| % herbaceous cover               | 50.2    | 31.0  | 59.1     | 29.6  | 1.80           |        |
| % shrub cover — %SHRUBS          | 18.4    | 22.6  | 16.2     | 17.6  | 0.73           |        |
| Height of the shrub layer        | 1.0     | 0.7   | 1.2      | 0.6   | 1.97           | *      |
| % tree canopy cover              | 32.0    | 26.7  | 33.7     | 23.4  | 0.43           |        |
| Height of the tree layer         | 9.8     | 5.2   | 10.5     | 3.9   | 1.04           |        |
| # coniferous trees               | 53.7    | 87.7  | 33.6     | 69.1  | 1.70           |        |
| # holm-oak trees                 | 3.2     | 11.1  | 3.3      | 12.8  | 0.05           |        |
| # deciduous trees                | 42.3    | 89.1  | 79.0     | 120.7 | 1.87           |        |
| # trees 5–10 cm dbh.             | 27.4    | 61.5  | 30.6     | 41.5  | 0.44           |        |
| # trees 10–30 cm dbh.            | 55.4    | 65.8  | 73.4     | 86.6  | 1.28           |        |
| # trees >30 cm dbh. — #TRUNKS+30 | 16.4    | 24.8  | 12.0     | 13.5  | 1.77           |        |

pied sites (Table 2). They were also located in areas with watercourses and sparse rocky cover (marginally significant after sequential Bonferroni correction).

There were complex, non-linear habitat preferences of the Azure-winged Magpie in Central Spain (Fig. 3). The tree model explained a low amount of the original deviance in the species occurrence in 427 census plots (29.4%; AUC = 0.841;  $\chi^2 = 78.1$ , d.f. = 8,  $p < 0.001$ ). Altitude played a prominent role in defining the species presence, and the mere presence of buildings (area covered by buildings > 3.8%) was responsible for its absence. The first three split criteria of the classification tree, including twice the variable altitude and once the cover of buildings, explained nearly one half of the total explained deviance (14.7%). Overall, the probability of occurrence of Azure-winged Magpies was lower at higher altitudes as the species was not found in any habitat above 1,567 m a.s.l., while it was present in 39% of the census plots below 924 m a.s.l. The lower frequency of occurrence between 924 and 1,006 than above 1,006 m may be explained by considering that this narrow altitudinal belt is the most altered by human infrastructures within the study area (i.e., where villages and other forms of urbanization are settled).

In the mountain areas between 1,006 and 1,567 m a.s.l., the probability of occurrence of the species diminished with increases in shrub cover (see the splitting criterion %SHRUBS in Fig. 3),

maturity of woodlands (#TRUNK+30), and rock cover (%ROCK). The highest probability of the species occurrence (presence in 22% of sampling points) was found in habitats with a shrub cover lower than 39%, with fewer than 219 mature trees (diameter at breast height larger than 30 cm) per hectare and with rock cover under 10%. Within habitats attaining these attributes in the mountainous gradient, the species was considerably more frequent (probability of occurrence = 43%) below 1,050 m a.s.l. than above this altitude.

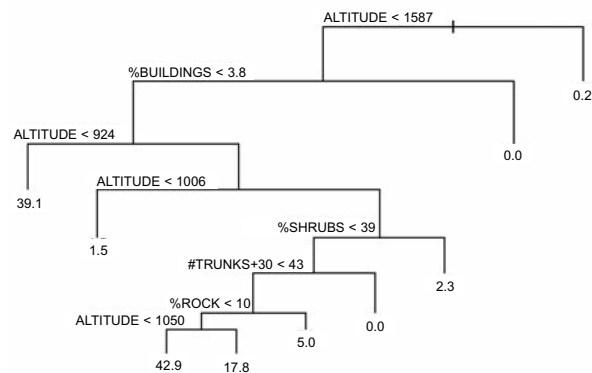


Fig. 3. Classification tree modelling the presence in 0.8 ha census plots (i.e. 50 m in diameter) by the Azure-winged Magpie in northern Madrid province (Central Spain). Splitting criteria indicate the conditions for the left branches. Length of the branches is proportional to deviance explained by each split. Numbers at terminal tips are probabilities of occurrence expressed in percentages. For acronyms see Table 2.

The residuals of the habitat model in Fig. 3 were unrelated to the presence-absence of the Common Magpie ( $p = 0.743$ ) or Jay ( $p = 0.112$ ) (one-way ANOVAs comparing the residuals of the Azure-winged Magpie probabilities of occurrence in the samples with the presence or absence of the other two corvid species).

The segregation at the local scale of the Azure-winged Magpie, Common Magpie and Jay was assessed with discriminant function analysis. The analysis significantly separated the three species (Wilks' lambda = 0.43;  $F_{10,400} = 21.32$ ,  $p << 0.001$ ; Fig. 4). The first discriminant component (canonical  $r = 0.73$ ,  $\chi^2 = 172.6$ , d.f. = 10,  $p << 0.001$ ) was positively and significantly correlated with altitude ( $r = 0.84$ ,  $p << 0.001$ ), cover of the tree layer ( $r = 0.65$ ,  $p << 0.001$ ) and density of coniferous trees ( $r = 0.59$ ,  $p << 0.001$ ). The second component (canonical  $r = 0.30$ ,  $\chi^2 = 19.5$ , d.f. = 4,  $p = 0.001$ ) opposed census plots with tall buildings (correlation with height of buildings =  $-0.68$ ,  $p << 0.001$ ) to those with a high density of tree trunks (correlation with the number of trees 10–30 cm in diameter at breast height =  $0.55$ ,  $p << 0.001$ ). The percentage of correct classification of census plots occupied by the three species is 73.4%. The Azure-winged Magpie was the species worst classified by the model, with only 20% of the occupied census plots classified correctly (65% of occupied plots are classified as

belonging to Common Magpie and 15% as belonging to the Jay). Conversely, the percentage of correct matches was higher for the Magpie (92%) and Jay (69%). Therefore, while the Jay and Common Magpie were clearly segregated (only 4.7% of the plots occupied by each one of these two species are classified as belonging to the other species), the habitat preferences of the Azure-winged Magpie widely overlap with those of the other two corvid species.

## DISCUSSION

We have shown that the distribution of Azure-winged Magpies in Spain can be mainly understood by geographic and climatic factors, with little influence of variation related to landscape features at a large (2,500 km<sup>2</sup>) spatial-scale. Azure-winged Magpies are more abundant near the core of its range in southwest Iberia and rarify towards the north and the east, in what seems to be a limitation of their ability to tolerate colder and drier climates in the northern and eastern, respectively, borders of their distribution rather than due to constraints in landscape-habitat preferences. Similarly, Luoto et al. (2007) found that climatic variables were large-scale determinants of land bird species distribution in Finland, while land cover variables were mainly important at finer spatial resolutions. On the other hand, Storch et al. (2003) and Reif et al. (2008B) have found that central European birds are more affected by habitat composition than by climate, suggesting stronger climatic limitations in the dry Mediterranean than in more temperate, central regions.

Climate has a strong influence in determining the nowadays patterns of occupation of Azure-winged Magpie, as shown by the importance of high levels of solar radiation (i.e., the proportion of sunny, anticyclonic days, per year). Rainfall, on the contrary, has opposing roles depending on "basal" levels of water income, the effect being negative in the wetter locations and positive in the drier areas. Valencia et al. (2002) provide more detailed information on rainfall and temperature as limiting factors for Azure-winged Magpie in relation to their breeding ecology, which is also highly influenced by altitude, another important variable determining distributional patterns at the regional level (see Table 2 and Fig. 3). On the other hand, both latitude and longitude appear as additional, important factors affecting Azure-winged

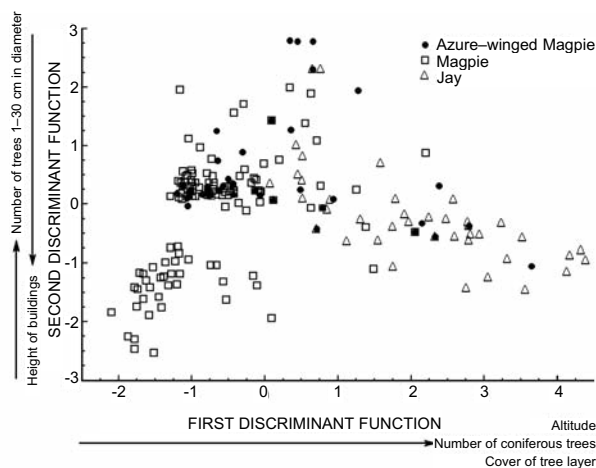


Fig. 4. Discriminant function analysis showing habitat segregation of Azure-winged Magpie, Common Magpie and Jay at the local scale. The first discriminant function is positively ( $p < 0.001$ ) correlated with altitude and cover of the tree layer (mainly coniferous trees). The second component opposes census plots with tall buildings (negative values) to those with a high density of tree trunks 10–30 cm in diameter at breast height (positive values).



Magpie distribution. This concurs with results of Storch et al. (2003), who pointed out the importance of the geographical position, besides those of topography and climate, in shaping species distributions and composition of local bird assemblages in central Europe. As theirs, our results probably imply a role for spatial dynamics and history in determining distributional patterns of Azure-winged Magpies. During the Late Pleistocene, southwest Iberia most probably was the last major glacial refuge for the Azure-winged Magpie, as also proposed for many other European bird species (Blondel 1990, Covas & Blondel 1997, Blondel & Mourer-Chauviré 1998). Their relatively narrow climatic tolerance probably prevented Azure-winged Magpies from a widespread post-glacial recolonization, highlighting the interaction of spatial dynamics and history on current patterns of distribution.

Almost none of the wide landscape categories we considered at large geographical scale were important in explaining the Azure-winged Magpie distribution except landscape devoted to agriculture, with a negative influence for the species reflected in its absence of vast, suitable in climatic terms, deforested Mediterranean-type areas. Another significant influence, in this case of positive sign, was provided by the presence of watercourses, most likely due to the tree cover remaining in their margins. In fact, presence of water also entered marginally in the habitat preference test of northern Madrid province (Table 2). Riparian woodlands represent a refuge for this species in landscape dominated by extensive croplands, allowing the species to be present in large deforested areas (e.g., cerealist pseudosteppes in central and southern Spain). From a conservationist standpoint, the presence of Azure-winged Magpies in agricultural, pseudosteppe habitats crossed by thinly forested watercourses speaks of the importance of conserving gallery forests in regions less appropriate for the species.

The study at a local level refined some of the patterns emerged when viewing the present distribution at a larger geographical extent. In Central Spain, Azure-winged Magpie tended to avoid populated areas, and thus it is an urban-avoider species heavily affected by urban sprawl (Palomino & Carrascal 2006). There was also an important negative effect of very dense scrubland, a fact that may be explained by the ground foraging habits of this species (probably constrained by limitations in access and increased

predation risk; Perrins 1998). Overall, different approaches gave complementary, consistent, views for the explanation of the present species range of Azure-winged Magpies, reinforcing the evidence for using multi-scale approaches to deepen into factors modelling distribution/abundance of bird species (Mazerolle & Villard 1999, Jones 2001, Luoto et al. 2007).

The Azure-winged Magpie may be a fine instance of the biogeographical implications of habitat alteration caused by humans in the Mediterranean region (Gil-Tena et al. 2009). Deforestation of land for agricultural purposes in the past probably had a negative impact on the species by enforcing range contractions. These are nowadays visible in the isolation of the Azure-winged Magpies of Sierra Nevada (SE Spain) and adjacent mountains from other Andalusian populations located at the Guadalquivir basin, or other populations at southern Extremadura and central Castilla-La Mancha which are isolated by large extensions of cereal and vineyard crops (Martí & Del Moral 2003). On the other hand, there is quantitative evidence for a progressive increase of the species in Spain: the Azure-winged Magpie has shown a yearly rate of population growth between 1998 and 2009 of 4.9% (95% confidence intervals: 3.0%–6.8%; SEO/BirdLife 2010). The same pattern has been documented at the regional level during the last decade in the same area of northern Madrid province than the one here studied (Palomino et al. 2006; 1996–2005 yearly population growth rate of 9.8% with a 95% confidence interval level of 3.4–15.2%)

A primary cause of the northern expansion of the species could be the overall land-uses changes in the Iberian Peninsula towards natural and human-induced afforestation (Santos et al. 2006, Sirami et al. 2008, Gil-Tena et al. 2009). Currently, the socio-economical crisis of rural activities in Spain is favouring subtle changes in land-uses, leading to field abandonment and a subsequent increase in forest development due to natural succession of poorly vegetated locations. If so, the 'cornered' refuge of the species in Iberia will necessarily expand northwards due to the mere availability of forest surface there (see Sirami et al. 2007, 2008 for birds in NE Spain).

Different species within an avian family tend to share many life-history traits, making difficult a clear distinction of their particular ecological characteristics, and allowing hypothesizing that interspecific competition may influence their spatial

distributions (Connor & Bowers 1987, Wiens 1989b, Sanderson et al. 2009, Gotelli et al. 2010). Nevertheless, our approach does not reveal any influence of the similar-sized Common Magpie and Jay on the distribution of Azure-winged Magpie at either large or local scales. The breeding distribution of the Azure-winged Magpie would be linked in a parsimonious manner to the availability of preferred landscapes and to variables describing habitat structure at both scales of analyses, independently of the presence of the other two potential competitors. Therefore, there is no evidence that species interactions may have a significant influence in mediating the spatial segregation of these three similar-sized related species in the Iberian Peninsula.

In conclusion, Azure-winged Magpies can be defined as a Mediterranean-type generalists that avoid the urban sprawl and whose probability of occurrence decrease with elevation, being absent above 1,600 m a.s.l. Although they prefer wooded environments, they tend to avoid dense, mature forests. Absence of a very dense shrub layer and scarcity of rock outcrops are key habitat requirements maximizing their occurrence. There was little influence of landscape structure variables on the large-scale distribution pattern in Spain, while geographic and climatic factors played a prominent role. The occurrence of potential competitors (Common Magpie and Jay) did not influence either the large-scale or the local-scale distribution of Azure-winged Magpie. The species most probably suffered the negative influence of severe anthropic transformations in Andalusia, Extremadura and Castilla-La Mancha during the later centuries, when dry cereal cultivations and vineyards accompanied extensive deforestation and urban sprawl.

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## STRESZCZENIE

**[Czynniki wpływające na występowanie sroki błękitnej w Hiszpanii]**

W pracy określono rolę czynników biotycznych, klimatycznych i krajobrazowych w kształtowaniu rozmieszczenia sroki błękitnej. Analizy prowadzono w dwóch skalach przestrzennych: makro — obejmującej całą zasięg gatunku w Hiszpanii, który jednocześnie stanowi większość zasięgu europejskiego, oraz lokalnej — obejmującej zasięg w środkowej Hiszpanii, gdzie obserwowana jest ekspansja tego gatunku, a, a jego liczebność wzrasta (Fig 1). Czynniki związane z występowaniem gatunku w skali makro określano na podstawie występowania ptaków w polach 50 × 50 km UTM. Dane zaczerpnięto z opracowania atlasowego ptaków lęgowych Hiszpanii, w którym obecność gatunku przedstawiano w kwadratach 10 × 10 km UTM. Następnie, dla lepszego oszacowania potencjalnego błędu obserwacji łączono dane z 25 kwadratów 10 × 10 km i dla takiej skali do dalszych analiz brano pod uwagę: długość i szerokość geograficzną, średnią wysokość n.p.m., jak i różnice w wysokości bezwzględnej, długość rzek i strumieni, długość dróg, wielkość powierzchni pokrytej jednym z 12 typów siedlisk (na podstawie bazy Corine), oraz dane klimatyczne (Tab. 1).

W ten sposób wzięto pod uwagę zróżnicowanie czynników środowiskowych, klimatycznych, rzeźby terenu i zmian antropogenicznych, które mogą wpływać na występowanie ptaków w makroskali. Dane takie zanalizowano dla 219 pól  $50 \times 50$  km.

Dane dotyczące występowania w skali lokalnej zbierano na obszarze ok. 700 km<sup>2</sup>, położonym w środkowej Hiszpanii, na podstawie pojedynczych liczeń punktowych. Liczenia trwały 20 min, zapisywano ptaki widziane i słyszane w promieniu do 50 m. Łącznie liczenia prowadzono w 427 punktach w maju i czerwcu w latach 2001–2004. Punkty rozmieszczone były w głównych typach siedlisk na tym terenie. Opis siedliska w punktach liczeń ptaków (w promieniu 25 m) obejmował oszacowanie: udziału roślinności zielnej, krzewów i drzew, wysokości krzewów i drzew, liczby drzew w 3 skalach wielkości, z podziałem na liściaste, iglaste i zimozielone. Na terenach zurbanizowanych dodatkowo opisywano udział budynków, wysokość budynków i liczbę samochodów.

Zarówno w skali lokalnej, jak i makro opisywano także występowanie sroki i sójki jako potencjalnych konkurentów sroki błękitnej. W makroskali (pola  $50 \times 50$  km) występowanie sroki błękitnej było najlepiej wyjaśniane przez czynniki geograficzne i klimatyczne (Fig 2A),

natomiast dołączenie do analiz zmiennych krajo-brazowych nie wpłynęło znacząco na uzyskane wyniki (Fig 2B). Stwierdzono, że sroki błękitne występowały na terenach mniej górzystych, z mniejszą ilością opadów, większą liczbą dni słonecznych oraz większym udziałem upraw oliwek i pastwisk (Tab. 1).

W skali lokalnej gatunek ten unika terenów zurbanizowanych, a prawdopodobieństwo jego występowania zmniejsza się wraz z wysokością (nie jest obserwowana powyżej 1600 m n.p.m.), preferuje tereny zadrzewione, ale unika gęstych starych lasów (Tab. 2, Fig. 3).

Nie stwierdzono, aby obecność potencjalnych konkurentów — sroki i sójki, wpływało na występowanie sroki błękitnej zarówno w skali makro, jak i lokalnej. Stwierdzono, że preferencje siedliskowe badanego gatunku pokrywają się z tymi obserwowanymi dla sójki i sroki, ale dwa ostatnie gatunki ptaków krukowatych mają dość odrębne nisze (Fig. 4).

Z punktu widzenia ochrony sroki błękitnej, uzyskane wyniki wskazujące na występowanie tego gatunku na terenach rolniczych, z niewielkimi ciekami wodnymi o brzegach porośniętych drzewami, podkreślają konieczność ochrony lasów galeriowych na terenach mniej odpowiednich dla tego gatunku.