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Nest site selection and the effects of land use in a multi-scale approach on the distribution of a passerine in an island arid environment

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ABSTRACT

We examine the predictive ability of habitat-species relationship models in island semi-desert environments using as model species the Canary Islands stonechat (*Saxicola dacotiae*), an endemic bird inhabiting the arid island of Fuerteventura. We investigated nest site selection and the effects of land use on its distribution in a multi-scale approach using nest positions obtained during three consecutive breeding seasons. We identified two environmental predictors, namely Tasseled cap 1 (a range value of land brightness) and slope, and three variables derived from human use (house densities, unpaved roads and fences) as the best predictors of occurrence of the species. Only slope had a positive and significant effect on stonechat occurrence; the rest being negative. Results were not restricted by the scale, indicating that design of special protection areas should be developed considering the landscape scale. Our results provide a robust prediction of the species distribution throughout Fuerteventura, demonstrating that our approach can also cope for the low vegetation signal within small arid regions such as islands. Future land use planning and management for the island should avoid the presence of negative impact elements such as opening new roads and new urbanisations in nearby habitats with the highest probabilities of species occurrence.

1. Introduction

Understanding reasons determining the presence and absence of species is a central issue in biogeography. The predictive ability of habitat-species relationship models has dramatically improved during last 20 years due to the rising use of geographic information systems (GIS). These tools enable us to extract potential predictors derived from GIS and in combination with presence/absence information it is possible to produce predictive spatial maps with wide applications in ecology, evolution and conservation. Such approaches have been abundantly carried out with species inhabiting large and diverse areas with the final aim to develop managing strategies over various scales (Marsh and Trenham, 2008; Wisz et al., 2008). However, some recent applications publishing predictive models of species with patchy and narrow range distribution are available (e.g. Nogués-Bravo and Agirre, 2006; Seoane et al., 2006). This may be partly due to the increasing number of GIS derived predictors that became available on small territories during the last years, which enables the application of predictive models on species distribution. In contrast, fewer attempts have been carried out with island organisms despite support a wide variety of endemic taxa. However, the acquisition of such information in a fine spatial resolution would enable managers to elaborate accurate development plans favouring the sustainable development in these fragile ecosystems.

The Canary Islands is an oceanic archipelago located less than 100 km from the African mainland supporting a high number of endemic taxa (Izquierdo et al., 2004) and ecosystems (Fernández-Palacios and Esquivel, 2001). However, this archipelago has been under intense human land use since the arrival of aboriginal people (≈2000 ybp), although the Europeans dramatically increased land use after the conquest during the fifteenth century. The consequences of intense human activity have led to a heterogeneous landscape structure with large extensions of original habitats highly modified or destroyed (De Nascimento et al., 2009; Fernández-Palacios and Esquivel, 2001; Machado et al., 1997). This is especially conspicuous in areas reaching from the coast up to 800 m a.s.l because these are the most suitable areas for human settlements and agricultural practices.

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Despite the fact that the Canary Islands support a high level of endemic bird taxa (Stattersfield et al., 1998), there is little information on their distributions within islands, habitat use, or factors that determine their distributional range (Carrascal et al., 1992; Illera et al., 2006; Seoane et al., 2010). Within the Palaearctic passerines the Canary Islands stonechat (*Saxicola dacotiae*) has the second most restrictive distribution range (after the Azores Bullfinch, *Pyrrhula murina*), occurring only on the island of Fuerteventura. The species colonized the Canary Islands during the Pleistocene (Illera et al., 2008). Two subspecies have also been described (one of them *S d murielae* is considered extinct). This species is an ideal model to develop habitat-species relationship models on a detailed scale due to its narrow range distribution, specific habitat requirements and strong site faithful (Illera, 2001). Ravines and slopes with high shrub cover limit its distribution both within Fuerteventura and in nearby islands (Illera et al., 2006). Human threats (both touristic and local) have increased, leading to dramatic changes of landscape scale caused by new urbanisations, extending urban areas and villages, and installation of new access roads. These actions have altered or even destroyed optimal habitats of the Canary Islands Stonechat (Illera, 2004). In addition to direct human transformation of land, grazing pressure represents an indirect threat to the species due to a reduction of the shrub layer, thus decreasing food availability and increasing soil erosion (Illera, 2001, 2004). The species is included in Annex I of the Birds Directive (79/409/CEE) and in Annex II of the Bern Convention. It has been recently classified "Endangered" in the IUCN red list due to its small population size, which is probably declining (BirdLife International, 2008). The species shows strong site fidelity (Illera and Diaz, 2008), although accurate information on its distribution throughout the island is not available, a deficit that also limits the protection of remaining habitats. Breeding biology has been previously studied and shows that annual fecundity is mainly driven by rainfall through a food-mediated process (Illera and Diaz, 2006). However, there is no information about nest site selection and factors determining its habitat selection, although suchlike data would be essential for conservation planning.

The aim of this study was to characterize the nest site selection in the Canary Islands stonechat in a hierarchical habitat modelling approach with two broad objectives: 1) to understand factors limiting the nest site distribution and 2) to model the species habitat use based on spatially explicit predictors, namely GIS layers of human habitat changes (e.g. roads, houses, terraces and fences), digital elevation data (altitude, aspect, slope) and Landsat transformations such as Normalized Difference Vegetation Index (NDVI) and Tasseled cap. As the Canary Islands stonechats are strictly sedentary on their territories all year round (Illera and Diaz, 2008), we used the nest coordinates as points of habitat use in a landscape modelling approach. Use of satellite data for avian habitat modelling has become well established within the last few decades (Gottschalk et al., 2005). Landsat is also a standard sensor for suchlike applications (Cohen and Goward, 2004; Leimgruber et al., 2005). Since specific predictors may differ due to their scale, and habitat use may vary along different scales, it is especially relevant to carry out multi-scale approaches in habitat use studies (Graf et al., 2005; Martinez et al., 2003; Mateo-Tomás and Olea, 2009; Ortego and Diaz, 2004; Seoane et al., 2006). In order to evaluate the effect of scale we examined the habitat use and the effects of land use on the Canary Islands stonechat distribution in a four-tiered habitat approach, namely nest position, microhabitat, territory and landscape. Our specific objectives were: (1) to identify the best predictors of the Canary Islands Stonechat in order to model its distribution in Fuerteventura, (2) to evaluate the importance of scale on the habitat preference, and (3) to evaluate the human impact based on standard GIS data.

2. Methods

2.1. The island of Fuerteventura

With a size of 1660 km^2, Fuerteventura is the second largest island within the Canary archipelago, and was formed some 22 million years ago by volcanic activity (Carracedo and Day, 2002). Of all Macaronesian islands it is the closest to the African continent (<100 km). Fuerteventura has a mainly flat topography with low altitudes (the highest peak is 807 m above sea level). Despite its arid climate (<150 mm/year on average) Fuerteventura hillsides were terraced in order to create a system of extensive agriculture allowing crop production without irrigation (Jensen, 1934). Most formerly used areas, however, are nowadays left open. Livestock widely dominates the current rural land use. Goat numbers severely increased during the last few decades, populations of which are now a matter of concern for island biodiversity conservation (Carrete et al., 2009; Gangoso et al., 2005). The scarce annual precipitation supports a typical semiarid habitat dominated by shrubby Euphorbiacea and Chenopodiaceae vegetation (Rodríguez et al., 2000).

2.2. Nest data

Nesting positions of the Canary Islands Stonechat were sampled in the field during three consecutive breeding seasons (2001–2003). We conducted nest searching within the whole distribution range of the species in Fuerteventura. In order to avoid any bias in the habitat selection patterns, nest searching was carried out at 12 study sites (see Fig. 1, in Illera and Diaz, 2006)

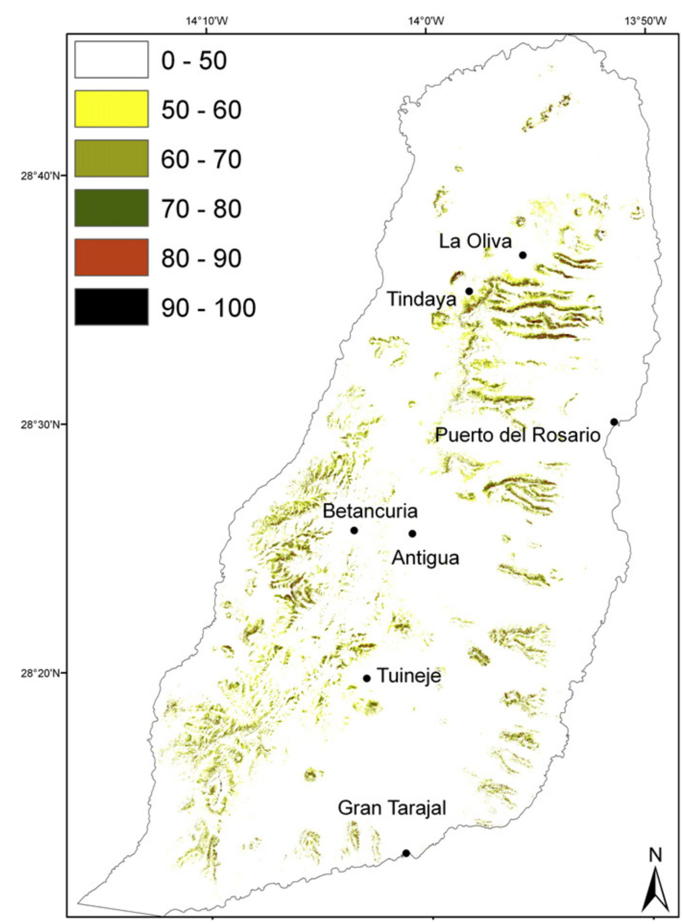

Fig. 1. Predictive map of the Canary Islands Stonechat distribution based on the Maxent model. Strength of prediction of each map pixel is showed in colours.

including both optimal and suboptimal areas for the species. Nests were found during the building, incubation and nestling stages from December until April. Nesting geographic positions were taken by GPS. Analyses were solely performed on nests used by birds, but we excluded those nests found in the south of Fuerteventura (see below). In order to test nest habitat preferences we compared use (actual nesting positions) and availability (pseudo-absence points). We created pseudo-absence (i.e. random) points within the study sites selected to enable a comparison of the actual nesting positions with the average habitat characteristics of the area searched (Kaczensky et al., 2008; Zaniewski et al., 2002).

2.3. GIS and remote sensing data

Nest sites and pseudo-absence points were buffered by 100, 500 and 1000 m intervals, thus all predictors were extracted for the actual nesting position as well as the three surrounding buffers, for which the mean values of each predictor were calculated. The range of Landsat derived predictors (Table 1) was extracted as a surrogate for habitat heterogeneity on a landscape scale. All spatial data were processed at a resolution of 30 × 30 m. Data extraction was performed using the Hawth Tool Plug-in within Arc Map. In order to assess the habitat of the nesting sites and their buffers, Landsat transformations were processed. These included NDVI, an index directly related to the photosynthetic capacity, which is used to estimate primary productivity and often equalled to vegetation cover (e.g. Campbell, 1996). Since the Landsat scene does not cover the southern part of the island (named Jandía peninsula) we decided to exclude this area (≈9% of Fuerteventura) from further analysis. In order to compensate for the relatively dry habitat of the study area, which generally infers a high noise due to soil signals, Tasseled cap transformations were derived. Tasseled cap algorithm is suggested to cope with the low vegetation signals in arid environments (Karnieli et al., 2008; Von Wehrden et al., 2006). The Tasseled cap transformations represent calculations of the terrain brightness (channel 1), vegetation greenness (channel 2) and terrain wetness (channel 3) (Todd et al., 1998). Thus the first channel gives information on the soil/stone characteristics of the terrain; the second can be interpreted as an indicator of vegetation productivity; and the third indicated water content. Altitude, aspect and slope of the study area were derived from Shuttle radar topographical mission (SRTM) data (Jarvis et al., 2006). Since aspect represents a circular data structure, the sines and cosines were calculated as surrogates of the northern and western exposure. Vector data were digitized from topographic maps, and included houses, fences and secondary roads. These datasets were recalculated to give density (in km^2) with a resolution of 30 m. Preliminary analyses revealed no significant trends regarding other vector data (e.g. ravines and terraces). We used Arc-Map (Ver. 9.2) to perform GIS analyses.

2.4. Statistical analysis

Nesting sites and buffers were analysed by individual binomial generalized linear models (GLM) that included scaled predictor data in order to enable a comparison of the model estimates. For each spatial scale a single model was created. Redundant predictors were initially eliminated by calculating the variance inflation factors (threshold gt; 10). Afterwards we subsequently removed non-significant predictors in a backward fashion. Autocorrelation patterns are known to infer biases or even reversed patterns within ecological models (Kuhn, 2007). We checked residual autocorrelations of each model by correlograms, which indicated Moran's I against distance classes (Fortin and Dale, 2005). No significant autocorrelation, however, was detected by this process indicating a representative sampling.

We used a Maxent approach to model the nesting habitat (Jaynes, 1957). The model uses presence only data and estimates the distribution of a species by identifying the probability distribution of maximum entropy across the whole study region (Dudík et al., 2007; Phillips et al., 2006). This methodology has been suggested to outperform other presence based model procedures (Gibson et al., 2007; Ward, 2007). We used the Maxent software to derive the distribution model (http://www.cs.princeton.edu/~schapire/maxent). The model was evaluated with a jacknife procedure, which calculates the explaining power of the different predictors within the model. The area under the curve (AUC) statistic was used for model evaluation, where values larger than 0.7 indicate a valid model performance. All statistical analyses were done with the R software (R Development Core Team., 2008; Ver. 2.8).

3. Results

Based on the 119 nest sites used in the analyses, several predictors derived from Landsat explained nest site selection in the Canary Islands Stonechat (Table 2). The generalized linear models contained Tasseled Cap transformations indicating a negative preference regarding the habitat. The Tasseled Cap Channel 1 was the most important predictor, being significant at all scales with

Table 1
List of predictors used in this study. Gavia: small agricultural area.

Predictor	Source
Northern exposure	Sinus transformed SRTM data
Western exposure	Cosinus transformed SRTM data
Slope (mean value)	SRTM data
Altitude	SRTM data
Tasseled cap 1 (range value)	Landsat data (GLCF)
Tasseled cap 1 (mean value)	Landsat data (GLCF)
Tasseled cap 2 (range value)	Landsat data (GLCF)
Tasseled cap 2 (mean value)	Landsat data (GLCF)
Tasseled cap 3 (range value)	Landsat data (GLCF)
Tasseled cap 3 (mean value)	Landsat data (GLCF)
Ravines (mean value)	Digitized
Fences (mean value)	Digitized
Gavia (mean value)	Digitized
Houses (mean value)	Digitized
Mainroads (mean value)	Digitized
Secondary roads (mean value)	Digitized

Table 2
Estimate of the multiple regression models, performed for each buffer individually ($n = 119$). Only significant values are showed. Significant relationships are marked with asterisks. ***: $p < 0.001$; **: $p < 0.01$; *: $p < 0.05$.

	0	100	500	1000
western exposure				
northern exposure				
altitude				
Tasseled cap 1 range				
Tasseled cap 1 mean	−1.15***	−0.94***	−0.55**	−0.60***
Tasseled cap 2 range				
Tasseled cap 2 mean				
Tasseled cap 3 range				0.36*
Tasseled cap 3 mean				
NDVI mean				
NDVI range				
Fences mean	−0.44*	−0.47**		−0.40*
Houses density	−6.79***	−6.26***	−2.21***	−2.49***
roads mean	−1.33***	−1.19***	−1.14***	−0.99***
Slope mean	0.58***	0.49*		
Slope range		0.42**	0.95***	0.36**

a rather decreasing effect on size and larger buffers. Tasseled Cap Channel 3 was significant at the landscape scale. Other Tasseled Cap transformations and NDVI (range and mean) were not significant.

Birds showed significant preferences for nesting in regions with a higher slope; however at buffer ranges of 500 and 1000 m the mean slope became redundant with the slope range and was thus replaced by this predictor (see Table 2).

Predictors representing human impact showed a significant and negative effect on nest site selection. Density of secondary roads, fences and houses appeared to have a negative effect on habitat use (Table 2). Density of houses and secondary roads decreased with increasing buffer size. Finally, density of terraces and ravines was non-significant on nest selection.

The AUC of the maxent model was relatively high (0.93), indicating a valid model performance. Spatial variation in prediction accuracy was low. Predictor Jackknife validation revealed that the predictors altitude (41.3%) and slope (22.6%) have the highest explaining power followed by TC1 (15.9%), TC2 (7.5%) and TC3 (7.1%). Predictive power of NDVI (3.5%) and northern exposure (2.1%) were instead negligible. Altitude showed an unimodal pattern, with a maximum of about 300–400 m above see level. Slope showed an increasing pattern, with most suitable habitats at values gt; 13°. Tasseled Cap 1 indicated a negative linear pattern, with highest probability of occurrence at lower values. All other predictors provided extreme unimodal patterns. Based on a threshold of 0.5 (= less than 10 percentile training data present), less than 1% of the examined area would be suitable for nesting habitats (see Fig. 1).

4. Discussion

Our multi-scale habitat modelling approach provided significant predictive information on factors determining the nest site selection and human impacts affecting the Canary Islands Stonechat, despite its narrow range distribution and specific habitat use. Using nesting positions we were able to identify two environmental predictors, namely Tasseled cap 1 and slope, and three variables derived from human land use as the best predictors of occurrence of the bird in Fuerteventura. Tasseled cap 1 reflected the arid habitat conditions on Fuerteventura, where plant cover was generally sparse and therefore NDVI did not detect valid differences. The first Tasseled cap channel generally demarcates terrain brightness, which is a proxy for the reflectance characteristics of the examined region (Crist and Cicone, 1984). Within our analyses a higher probability of species presence was found at lower TC1 values, indicating that the birds preferred habitats with a lower reflectance. The island is characterised by a pronounced difference between rather flat habitats that typically have a higher reflectance and more open vegetation, whilst the slopes with a higher angle are typically covered by more shrubby vegetation.

We also confirmed a positive and significant preference of slopes by the Canary Islands stonechat, which is related to food availability (Illera, 2001). Interestingly, our model identified negative effects of land use, which have limited the chat distribution in Fuerteventura. Specifically, house densities, unpaved roads and fences were the predictors that had a negative effect on habitat use. These anthropogenic disturbances show the negative effects of ongoing human occupation on the Canary Islands stonechat territories. The most obvious consequence is the loss of optimal nesting areas. However, this land use can also increase the presence of introduced predators such as rats and cats, having negative effects on the annual fecundity of closer territories (Illera and Diaz, 2006).

We obtained similar results in our multi-scale approach, with a general decreasing effect size as buffers became larger. These results showed that the negative impacts produced by land use are not restricted to only small scale factors such as nest position, as higher scales such as territory and landscape have important implications for the species conservation (Illera, 2001). Design of special protection areas should be developed considering not only the bird territorial areas but also the landscape scale. Since we detected no spatial autocorrelation within our models, we are confident that no sampling bias flaws our analyses.

The Maxent model, used to model the distribution of the species, obtained a good predictive accuracy (AUC = 0.93). Regardless of obtaining accurate and robust prediction with this technique, final results need to be considered with caution as we were not able to directly use shrub cover in the model. Shrub cover has previously been identified as an important element in the habitat selection of the species (Illera, 2001). Tasseled Cap 1, however, might be indirectly reflecting this parameter as this predictor indicates the principal vegetation gradient found on the island. Slope and altitude (regardless of shrub cover) were emphasized in the model, while other predictors such as NDVI and Tasseled Cap 2 and 3, appeared negligible. This fact would explain the conspicuous bias represented in the map, which assigns the highest prediction strength of the Canary Islands Stonechat to be the western slopes (Fig. 1) despite the low presence of shrub cover (J.C. Illera, pers. obs.). Similar bias has been found using individual birds as independent points (Bibby and Hill, 1987; Illera and Tella, 2005). Nevertheless, the results obtained in this study provide a robust prediction of the species distribution throughout much of Fuerteventura, demonstrating that our approach is also appropriate for arid areas with a low vegetation signal. Our analyses may therefore enable managers to prevent significant land cover changes near areas with the highest probabilities of occurrence of the stonechat, and the general procedure can readily be applied in other drylands and other species.

Overall, we have identified positive, but also more importantly, negative predictors of the distribution of the Canary Islands Stonechat in Fuerteventura. Future land use planning and management on the island should consider the negative effects of new roads, new urban developments or expansion of existing developments on habitats that have the highest probability of species occurrence. The distribution map based on nesting positions should be considered as a first step in achieving an accurate abundance model. The future models on abundance should identify the best suitable areas found to have the highest number of pairs of the Canary Islands Stonechat in order to include them within the special protected area network. The specific foraging and nesting habitat requirements (Illera, 2001; this study) and the strong site fidelity (Illera and Diaz, 2008) show that the strict protection of these areas is the most effective way of guarantee its survival.

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