



Evaluating landscape connectivity in fragmented habitats: Cantabrian capercaillie (*Tetrao urogallus cantabricus*) in northern Spain



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ABSTRACT

Cantabrian capercaillie (*Tetrao urogallus cantabricus*) is listed as endangered according to IUCN criteria. The high degree of fragmentation and anthropogenic disturbances in capercaillie habitat suggests that habitat patterns may be related to decline of capercaillie populations in northern Spain. The objectives of this study are: (1) determining critical territories for the maintenance of capercaillie connectivity; and (2) evaluating the importance of public forests and their appropriate management to maintain the habitat connectivity for this species. This study is focused on northern Spain, where forest areas are critical for the maintenance of capercaillie. We applied connectivity methodologies based on morphological spatial pattern analysis (MSPA) and the probability of connectivity (PC). The results of the MSPA were incorporated into a standard GIS and compared with the spatial distribution of the public forest. Most of the valuable areas for connectivity were inside the public forests. Moreover, these public forests mainly form continuous features. Therefore, forest planning and management, mainly in public forest, should approach this problem including connectivity considerations and, more specifically, identifying the most critical forest sites for the maintenance of capercaillie habitat.

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1. Introduction

Capercaillie (*Tetrao urogallus*) populations have declined throughout most of the species range, especially in central and southern Europe (Storch, 2000). This trend has been observed in the Black Forest in southwestern Germany, which holds the largest capercaillie population in central Europe outside the Alps (Braunisch and Suchant, 2007) or in other colonies such as the southern remnant population in the Rhodope Mountains in Bulgaria (Graf, 2006). At a national level, 14 of the 18 grouse species are red-listed in at least one country (Storch, 2007b). Populations at the southern edge of a species' range and in densely populated regions are most often red-listed; habitat degradation, loss and fragmentation due to human land use activities are the major threats to viability of capercaillie populations, availability of habitat due to climate change, land use fragmentation (Klaus, 1994; Storch, 2007a). On local and regional scales, many populations of capercaillie are declining and threatened with extinction (Storch, 2007b).

The Cantabrian subspecies of capercaillie (*Tetrao urogallus cantabricus*) is listed as endangered according to IUCN criteria (Storch et al., 2006). At the beginning of the 2000s it was estimated that there were about 600 Cantabrian capercaillies present in an area of 1700 km² in the Cantabrian Mountains of northern Spain (Martí and Moral, 2003; Storch, 2007b). The population had a female: male sex ratio of 1:1.6 (Morán-Luis et al., 2014). Compared to a historic range of 3500 km², the area of occupancy has declined by >50% in the last 20–30 years (Martí and Moral, 2003; Quevedo et al., 2006b).

Capercaillie requires large tracts of mature forest, and are thus sensitive to landscape-level habitat alteration (Storch, 1995). Therefore, integrating forestry practices and capercaillie habitat preservation is a major conservation challenge (Storch, 2007b). The high degree of fragmentation and anthropogenic disturbances in the habitat of Cantabrian capercaillie suggests that changes in habitat patterns may be related to the population decline (Gómez-Manzanedo et al., 2009; Quevedo et al., 2006b). Moreover, improving connectivity between patches and populations is one of the main measures proposed for conservation of the subspecies (Espinosa et al., 2004; Storch, 2007b). This implies that forest planning and management should approach this problem by explicitly including connectivity considerations and, more specifically, by

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identifying the most critical forest sites for the maintenance of capercaillie habitat connectivity (Pascual-Hortal and Saura, 2008).

In the Cantabrian Mountains, most of the capercaillie habitats are located in public forests. This legal status guarantees protection and maintenance of the forests and their fauna (Espinosa et al., 2004; García et al., 2005) that may lead to an improved conservation status of this species by connecting its populations, facilitating dispersal of individuals and minimizing mortality risk. In this context, it is essential to identify which areas are critical habitats for connectivity since loss of forest habitat would probably lead to exponential increases in isolation of the remaining fragments (García et al., 2005). This situation could be particularly important for the isolated populations of endangered forest vertebrates still present in the Cantabrian Mountains but highly sensitive to habitat degradation, such as capercaillie (Obeso and Bañuelos, 2003).

In this context, a wide number of connectivity indices have been developed (Bunn et al., 2000; Calabrese and Fagan, 2004; Jordan et al., 2003). However, several of these indices do not allow the inclusion of any qualitative difference between adjacent landscape patches in the computation of the index (Acosta et al., 2003), or they present serious limitations that make them inadequate for effectively integrating connectivity in forest conservation planning (Pascual-Hortal and Saura, 2006).

Recent studies (Estreguil and Mouton, 2009; Saura et al., 2011) propose new methodologies based on the use of: (1) Morphological Spatial Pattern Analysis (MSPA) of forest habitats (Soille and Vogt, 2009; Vogt et al., 2007a,b); and (2) the probability of connectivity (PC) (Pascual-Hortal and Saura, 2006; Saura and Pascual-Hortal, 2007; Saura and Rubio, 2010). These aspects offer considerable synergies and potential relevant benefits for forest planning at a variety of scales, and address some of the concerns and limitations that forest managers face when identifying key structural connecting elements (Saura et al., 2011).

The objectives of this study are: (1) determining critical areas for the maintenance of connectivity of Cantabrian capercaillie habitats; and (2) evaluating the importance of public forests and their appropriate management to maintain the habitat connectivity for this species.

2. Material and methods

2.1. Study area

For this study, we adopted a potential territory for the Cantabrian capercaillie based on land use and species distribution's map criteria. The public forests of the Asturias and León regions (Spain), located in the Cantabrian Mountains (Fig. 1), are of particular interest because it is expected that management plans could be applied relatively easily.

2.2. Method

The general outline of the method is shown in Fig. 2. The method includes derivation of a hybrid land-cover map by combining standardized land-cover classes from CORINE Land Cover 2006 (Pérez-Hoyos et al., 2012) with higher spatial resolution data from SIOSE (Sistema de Información sobre Ocupación del Suelo de España; Spanish land use and land cover information system) (Valcárcel et al., 2008).

2.2.1. Phase 1: potential territory assessment

The first step of the method is to determine the area of potentially suitable habitat. The vast majority of capercaillie populations inhabit boreal coniferous forests (Storch, 2007b). However, Cantabrian capercaillie shows substantial ecological differentiation associated with its distinctive habitat (Blanco-Fontao et al.,

2009). The Cantabrian population lives in mature beech (*Fagus sylvatica*) and mixed beech/oak (*Quercus* spp.) forests with bilberry (*Vaccinium myrtillus*) (Quevedo et al., 2006a; Storch, 2007b), and also in meadow habitats, heathlands and shrublands (Espinosa et al., 2004).

For this study areas that fulfill the following two conditions were defined as suitable habitat: (i) areas that were less than 5 km from the actual distribution area of capercaillie in the Cantabrian Mountains (MARM, 2007); and (ii) areas that were labelled with the land cover classes CLC3.1 "Forest" (including broad-leaved forest, coniferous forest and mixed forest), and CLC3.2 "Shrub and/or herbaceous vegetation associations" (including natural grassland, moors and heathland, sclerophyllous vegetation and transitional woodland/shrub). This potential suitable habitat has a total area of 8274.2 km² (Fig. 3). Of this area 7256.6 km² is public forest.

2.2.2. Phase 2: morphological spatial pattern analysis (MSPA)

The second step of the method is the connectivity analysis through the Morphological Spatial Pattern Analysis (MSPA) (Soille and Vogt, 2009); MSPA has been implemented into a stand-alone freeware called GuidosToolbox available at <http://forest.jrc.ec.europa.eu/>. MSPA performs a segmentation on a binary map at pixel level, resulting in seven mutually exclusive spatial pattern classes: Core, Islet, Perforation, Edge, Loop, Bridge, and Branch (Soille and Vogt, 2009).

Amongst other parameters, the MSPA segmentation process may be fine-tuned by a user-defined edge width parameter. In this study three edge widths (EW) were assessed for a number of important capercaillie habitat areas, ranging in size from 132 ha to 1207 ha (Gjerde and Wegge, 1987; Schroth, 1991; Storch, 1995). The identified habitats had a mean area of 500 ha (Obeso, 2004). For this estimation, we assumed EW was equivalent to the radius of an ideal circular vital area (Table 1).

2.2.3. Phase 3: connectivity index

The method to measure connectivity in this study uses the Probability of Connectivity (PC) index calculated with an adapted version of the software Conefor Sensinode (Saura and Torne, 2009) <http://www.conefor.org/>.

PC is recommended as a connectivity measure because it reacts meaningfully to habitat loss and network fragmentation (Saura and Pascual-Hortal, 2007). PC also possesses the richest connection model of the measures in widespread use in connectivity evaluation (Laita et al., 2011).

The method is based on topology (inter-patch distances) and patch attributes (area) for forest dwelling species with a specific dispersal ability. The index combines landscape graph theory, a probabilistic connection model and the habitat availability concept. As a result, a landscape graph is made up of a set of nodes and links between nodes (Estreguil and Mouton, 2009). Each link between two patches is characterized by a probability of dispersal, obtained as a function of distance.

For our study, we need to define a typical dispersal distance for Cantabrian capercaillie. The data reported in the literature present averages ranging between 2.7 km in Sweden (Kempf, 1982) and 1.5 km in Norway (Rolstad et al., 1988). More recent studies show mean dispersal distances of 2.4 km in Norway and 2.2 km in Russia (Hjeljord et al., 2000) or median values of 11 km in Scotland (Moss and Picozzi, 1994). However, there is little available data on dispersal distance for Cantabrian capercaillie (Abajo, 2007). We assumed an average ranging distance of 2.3 km, following Gómez-Manzanedo's (2009) study of capercaillie in the Cantabrian Mountains.

From the seven pattern classes provided by MSPA only the classes Core and Bridge are relevant for a graph-theory investiga-

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