The effects of resprouting natural forest on reproductive traits of blue tits (*Cyanistes caeruleus*) in a stone pine afforestation

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ABSTRACT

The reproductive performance achieved by blue tits (*Cyanistes caeruleus*) in a low-quality habitat with a regular grid of nest boxes during a 6-year period (2007–2012) was tested. The variables used as sources of variation for analysis were the habitat quality (resprouted holm oak abundance) in the territories, the spatial distribution of territories (peripheral or interior nest boxes), the entrance-hole size of available nest boxes, the social context around the nesting territories (breeding neighbour density: conspecific or Great tits *Parus major*) and temporal pattern of reproduction (laying date). For whole breeding population, the proportion of successful nests and the breeding success were dependent on the location of territories and entrance-hole of nest boxes. The prediction concerning the relationship between habitat quality and reproductive performance is supported only for clutch size. This trait, but not the hatching and breeding success, clearly depended on resprouted holm oak abundance in the territories, increasing with the abundance of trees. Blue tits exhibited a clustered territoriality and the conspecific and Great tit *P. major* densities around blue tit territories were mutually influenced in a negative way. The breeding success variation in successful nests is positively associated to the conspecific density: individuals with more conspecific neighbours achieved best breeding success. For all nests pooled (successful and unsuccessful), reproductive performance was not dependent on the great tit density. Reproductive failure was higher in the large-holed nest boxes than in the small-holed ones. The clutch size also showed a significant gradient as a function of the egg-laying date: females laying eggs earlier in the season had larger clutch sizes than those who did later. From these results, we draw some implications for the management strategies of hole-nesting passerines using nest boxes in large areas of stone pines plantations.

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1. Introduction

During the fifties and early sixties large territories of southern Spain were reforested with pines. For this purpose, the original mediterranean vegetation was cleared and replaced by large monospecific plantations of pines (*Pinus pinea* and *Pinus pinaster*) (Groome, 1989; Maícas and Fernández Haeger, 2004). Decades later, these plantations have resulted in dense monotonous forests where the trees have very similar ages and shapes. One characteristic of the individuals of both *Pinus* species in these forests is the lack of cavities where hole-nesting insectivorous birds could nest. For these bird species, availability of cavities in trees is a limiting factor. To try to solve this problem, various programs have been implemented, erecting artificial nests with different spatial patterns and types of nest boxes. Years later, natural vegetation has also regrown under the pine canopy and therefore young medium-sized arboreal individuals of *Quercus rotundifolia* and *Quercus suber* are currently irregularly distributed under pines. These individuals are, for the moment, too young to have cavities suitable for hole-nesting birds.

Reproductive performance and population attributes in hole-nesting birds are shaped by the effect of multiple factors, such as territory quality, hole availability and location, size of entrance-hole, competitor density, timing, etc., (Newton, 1994; Svensson and Nilsson, 1995; Both, 2000; Przybylo et al., 2001; Wesolowski, 2002; Tremblay et al., 2003; Stauss et al., 2005; Forsman et al., 2008; Maicas et al., 2012b). Such factors can explain the spatial distribution of reproductive pairs across the habitat, affecting their breeding success and the regulation of populations.

In this paper, we analyze the reproductive performance in a blue tit population from a multivariate scope. For this analysis, different explanatory variables (spatial, temporal and social context) were selected. These variables may be crucial for the choice of the breeding habitat and the resulting fitness of breeding individuals.

In experimental designs involving nest boxes as potential nest-sites for cavity-nesting birds, spatial distribution of nest boxes may have important consequences on the reproductive performance of individuals (Maícas and Fernández Haeger, 2004; Maicas et al., 2012a,b). In plots of regularly distributed nest boxes forming a grid, some of them are obviously located in the core of the plot, whilst others are located in the periphery. From the point of view of potential interactions between conspecific and heterospecific neighbours, the territory of individuals breeding in the core would have more contiguous territories of other breeding pairs than peripheral ones, since these have fewer nest boxes around. According to this relationship, we hypothesize that breeding performance will be higher in blue tits nesting in peripheral territories than those doing it in core nest boxes.

On the other hand, given the strong association between blue tits and holm oaks in mediterranean forests (Pulido and Díaz, 1997; Blondel, 2007), the reproductive performance of blue tits would be better in those territories in the pine forest reforestations with more resprouted holm oaks (high quality territories) than in territories with fewer or without holm oaks (low quality territories). If this hypothesis is true it would emphasize the positive effect of resprouted young *Quercus* trees on reproductive traits in this insectivorous species. Therefore, we hypothesize that habitat quality (holm oak number under the pine canopy) positively influences the reproductive performance of blue tits.

Blue and great tits share ecological resources (cavities for nesting, breeding phenology, food resources) (Dhondt and Eyckerman, 1980; Minot, 1981; Dhondt, 1989; Török and Toth, 1999; Maícas and Fernández Haeger, 2004; Nilsson and Kallander, 2006; Goodenough et al., 2009). As a result, both species would compete for these resources, allowing us to predict a competitive interaction in order to get the best territories. The number of conspecific and heterospecific breeding neighbours make up the social context of reproduction. Blue tit territories may differ as a function of a gradient of nearest neighbour density, namely according to the number of conspecific and heterospecific individuals. Competition intensity would vary according of the degree of overlap in the use of resources. According to the model of density-dependent habitat selection (Fretwell and Lucas, 1970; Pimm and Rosenzweig, 1981; Rosenzweig, 1981; Petit and Petit, 1996; Morris, 2003), territory selection should be a negative function of competitor density. As a result, we hypothesize that a negative relationship between neighbour density (conspecific or great tits) and the reproductive performance should appear.

From the point of view of architectural traits of nest-boxes, entrance-hole size is a factor increasing fitness in cavity-nesting birds. Small-holed cavities have anti-predator effects (Nilsson, 1984; Wesolowski and Stawarczyk, 1991; Christman and Dhondt, 1997; Wesolowski, 2002). In the current study, large-holed and small-holed nest boxes were available for nesting and we consider this factor in relation to the reproductive performance of blue tits. Therefore, we also hypothesize that the reproductive performance should be higher in small-holed nest boxes than in large-holed ones.

Finally, timing of reproduction and the resulting breeding success are strongly related in birds. Individuals laying eggs earlier in the season achieve a better breeding success than those laying eggs later (Martin, 1990; Dias and Blondel, 1996; Tremblay et al., 2003; Garcia-Del-Rey et al., 2006; Thomas et al., 2010; Maícas et al., 2011, 2012b). This relationship is explained in terms of the matching or mismatching between food availability and the peak of food demand by nestlings. For this population, we predict that blue tits breeding earlier would achieve best breeding success and we hypothesize that a negative relationship should also appear between laying date and breeding success.

2. Materials and methods

2.1. Study area and nest boxes

The study area with nest boxes is located in a stone pine plantation in the mountain ridge Sierra Morena (38°02′N; 5°07′W), southern Spain, at an altitude of 550–650 m.a.s.l. This plantation was introduced about 1950 and covers a surface of 515 ha. The dominant tree species is the stone pine *P. pinea* with a density of 238.7 trees per hectare (Maícas and Fernández Haeger, 1996). Despite the apparent homogeneity of this forest, there is a spatial heterogeneity due to the regeneration of young Iberian holm oaks (*Q. rotundifolia*) and Cork oaks (*Q. suber*) formerly growing in this area and resprouted after the afforestation. Both tree species are unevenly scattered throughout the stand, with a density (both species pooled) of 52.9 trees per hectare and ranging their height between 4 and 6 m. The pine stand with nest-boxes is included into the pine plantation, so the habitat away the nest box plot is similar to the core stone pine stand. More details about study area and regional history of vegetation can be found in González-Bernáldez et al. (1976) and Maicas et al. (2011).

The annual reproductive cycle of blue tit breeding in nest boxes (model Schwegler 2 M; wood concrete material) was monitored over a 6-year period (2007–2012). The number of available nest boxes slightly varied between years, due to accidental lost or vandalism, ranging from 106 nest boxes in year 2007 to 109 in year 2012, 50% of them being small-holed nest boxes (26 mm Ø) and 50% large-holed nest boxes. The mean height of nest boxes above the ground was 4.66 ± 0.57 m. Both types of nest boxes were spaced along rows with an almost regular distance of 50 m and following an alternate distribution: e.g., each small-holed nest box was located between two large-holed nest boxes and vice versa. Such distribution makes up a grid of nest boxes that can be classified into two groups according to their location in the nest box plot: inner nest boxes (located in the nest box plot inner area) and peripheral ones (located in the perimeter of the nest box plot). Peripheral nest boxes were slightly more abundant than inner ones: 75 (53.6%) and 65 (46.4%), respectively. As result of this spatial distribution, the periphery nest boxes had three neighbouring nest boxes contrasting with the inner ones that had four nest boxes around. In order to test if the spatial distribution of blue tit pairs throughout nest box plot followed a random pattern, the conspecific nearest neighbour distances were calculated and compared with the expected ones using a χ^2 test.

Habitat quality in some periphery territories is better than in the inner ones in terms of mean number of holm oaks (7.6 and 4.1, respectively; Kruskall–Wallis test: $H_{1,101} = 8.771$, $p < 0.01$). However, this difference is not evenly distributed across nest box plot.

2.2. Neighbour numbers and holm oak sampling

We used the tessellation technique with GIS software (ArcGis programme) to establish Thiessen polygons around each nest box (occupied and non-occupied) in the plot. Using such technique straight line segments are placed midway between adjacent neighbours, producing convex polygons (Thiessen areas or Voronoi polygons) (Adams, 2001). As a measure of the intraspecific and interspecific competition (with great tit), the number of conspecific neighbours (hereafter, NCN) and neighbouring great tits (hereafter, NGT) around a blue tit nest were determined counting the number of polygons of occupied nest boxes by both species and bordering with a blue tit polygon. As most blue tit nested in small-holed nest boxes, most nest boxes around these nests were large-holed nest