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Original Investigation

Positive and negative unintended human-induced effects on Iberian mole abundance at the edge of its distribution area

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ABSTRACT

Humans can unintentionally induce both positive and negative effects on wildlife presence and abundance, with organisms living in or associated with agricultural areas being good examples. Our study focused on a 1500 ha area (75 sampled 100 m × 50 m plots) at the driest edge of the endemic Iberian mole *Talpa occidentalis* distribution range, where the species is listed as "Vulnerable". Here, poplar cultivations dominate wasteland and other irrigated and non-irrigated crops. The poplar irrigation system was traditionally based on a network of straight ridges, although it is rapidly being replaced with a sophisticated procedure which permits water to spread with ridges no longer being needed. In these habitats, ridges are relevant for moles because they provide dry shelters for nests. In this paper we explore (a) mole local habitat preferences and (b) the impact of changes in poplar irrigation systems on mole abundance. Iberian mole abundance positively related to earthworm biomass and numbers; however, multivariate analyses highlighted the effect of herbaceous cover (positive relationship), rocks cover and soil hardness (negative relationship), and habitat type (poplar being the preferred one). Furthermore, mole abundance was substantially higher in poplar groves where ridges were still present than where they were not. We conclude that Iberian moles in semi-arid environments are favoured by poplar plantations but, at the same time, they are highly vulnerable to recent changes in traditional agriculture practices. Therefore, this study shows how agricultural habitats can benefit some species of conservation concern, especially some temperate species at the edge of their range or in extreme ecological conditions. Changes in agricultural practices that negatively affect the suitability of such habitats can compromise these species's conservation, as we found for the Iberian mole.

Introduction

Current human activity is affecting the distribution and abundance of many species at an unprecedented rate, at multiple spatial scales and in numerous ways (either intentionally or unintentionally). This scenario ultimately compromises the persistence of a wide array of organisms and the structure of natural systems, leading to a 'biodiversity crisis' of planetary dimensions (e.g. Kerr and Currie 1995; Sala et al. 2000). Yet not all human-related consequences are necessarily negative. In some situations, humans have at least favoured important population growth of some species, such as those which perceive human settlements as habitats free of predators with plenty of food (e.g. house sparrows *Passer domesticus*; Anderson 2006). Thus, the effects that humans exert on wildlife can be both positive and negative, and very frequently they are induced non-premeditatedly (as in the case of the sparrow).

Organisms living in or associated with agricultural areas are a good example of this situation: they can benefit from the expansion of new suitable habitats, but can be simultaneously jeopardised by changes in management practices. For instance, a large number of bird species linked to open areas in Europe was probably formerly favoured by the expansion of cereal farming, but the intensification of agriculture practices since the mid-20th century has been claimed to be an important contributing factor in their recent widespread decline (e.g. Donald et al. 2001; Benton et al. 2002).

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In the last two decades, agri-environment schemes mainly relating to new management practices have promoted some population recoveries (Vickery et al. 2004). The case of birds enlightens the high vulnerability of certain species to broad scale improvements to agricultural techniques and policies, which typically neither involve nor integrate (enough) science-based environmental criteria. In this context, studies that aim to ascertain the impact of such changes on the presence and density of natural populations are most welcome from an applied viewpoint, particularly when species of conservation concern are involved.

The best option to determine how species abundance and distribution are shaped by human activity is to perform habitat-species models (reviewed in Guisan and Zimmermann 2000; Guisan and Thuiller 2005). In these models, abundance or presence is related to habitat (or niche) requirements, such as climate, soil characteristics, vegetation cover, food availability or competition (Andrewartha and Birch 1954; Brown et al. 1995). Modelling can indicate the exact environmental determining factors for species occurrence and how these key factors are modified by human activity, with the subsequent effect on species abundance and conservation and on management implications.

The Iberian mole *Talpa occidentalis* is a burrowing endemic species that extends throughout the Iberian Peninsula, except the NE quadrant (where it is replaced with the European mole *T. europaea*; Román 2007). As reported for the European mole (Funmilayo 1977), the Iberian mole tends to avoid aridity to the extent that in xeric regions, the species is usually constrained to areas where either rainfall or other water supply sources are locally abundant. A large offer of water can increase the availability of moles' main food prey, earthworms (Funmilayo 1977; Gorman and Stone 1990). Availability of earthworms has been shown to be a major determining factor for the distribution and abundance of mole species (Funmilayo 1977; Macdonald et al. 1997; Edwards et al. 1999). Large abundance of earthworms is shaped by other factors such as presence of deep soil that is not excessively stony, sandy or waterlogged (Buckerfield 1992; Carter et al. 1994; Virgós et al. 2004). In central and southern parts of the Iberian Peninsula, these conditions are mainly restricted to areas with irrigated crops, pastures with high organic matter content and deep soft soils, as well as forests with streams (Purroy and Varela 2003). In these regions, those areas offering suitable conditions for Iberian moles appear to be spatially discontinuous and linked to mountain areas with locally increased rainfall or lowlands with a reliable water supply and good soils. In the Iberian Peninsula, aridity increases from NW to SE (Font 1983), and, accordingly, mole populations become rarer and highly fragmented and isolated towards the SE areas of Spain (Soriguer and Palomo 2001). However, Lara-Romero et al. (2012) indicated that temperate species linked to wet habitats can benefit from some changes in agricultural use (irrigated crops, orchards), especially in the more arid areas of the Iberian Peninsula where these species have reached their distribution edge. Thus, particular land uses may notably increase the regional presence and abundance of these species under such extreme conditions.

Spain has a rich diversity of agricultural landscapes that vastly differ in terms of type of land use, the size and shape of fields, and the abundance and pattern of semi-natural elements. Poplar *Populus* spp groves are human-made habitats that are widespread throughout the country. In central and southern Spain, they are mostly associated with the middle courses of rivers, forming artificial wetlands that could prove favourable for species like the Iberian mole since maintained soil moisture increases the abundance of earthworms, and also makes the construction of mole tunnels and molehills network easier (Purroy and Varela 2003). One striking peculiarity of poplar groves is that they are irrigated all year round, so that, unlike other irrigated crops, they remain humid all seasons; moreover, poplars are harvested every 8–10 years in S Spain (pers. obs.), so these cultivations maintain almost the same conditions for long periods of time. In these groves, the traditional poplar cultivation system involved the use of a network of strait ridges to guide water during irrigation, even if the terrain was slightly sloped. However, this system has been rapidly abandoned in recent years and new plantations are irrigated by complete flooding because they are prepared to be perfectly flat and horizontal by means of sophisticated laser-based devices. This may endanger moles because these animals require non-floodable areas to inhabit and place their nests on (Milner and Ball 1970; Funmilayo 1977; Stone and Gorman 1985).

Thus, the Iberian mole seems a paradigmatic model to explore the unintentional consequences of habitat use and management by humans. In particular, the Iberian mole is a very useful species to test how particular agricultural practices can modify habitat suitability for temperate species at the xeric edge of their range or in extreme ecological conditions. Furthermore, because of its regional rarity (including several documented local extinctions; Soriguer and Palomo 2001) in S Spain (Andalusia), the species is considered "Vulnerable" (IUCN criteria: A1bc, B1, 2abd, 3abc, C1, 2) in the regional Red List of Threatened Vertebrates (Soriguer and Palomo 2001). In order to improve current management measures and design new ones for mole populations, conducting ecological studies with conservation applications, which are virtually absent for this species, has been explicitly recommended (Soriguer and Palomo 2001).

By focusing on an agricultural area at the most xeric edge of the Iberian mole distribution range, the goals of this study were: (a) to explore habitat-related differences in the abundance of this species, and (b) to determine the impact of recent changes in agricultural practices on mole abundance. We hypothesise that mole abundance would be (a) positively related to the presence of poplar cultivations and (b) negatively related to poplar modern irrigation techniques (i.e. no ridges).

Material and methods

Study area

This study was conducted in a 1500 ha area in the province of Granada, SE Spain (37°12′N 3°43′E, 580 m.a.s.l.), within the natural distribution range of the Iberian mole (Román 2007). According to climate, this province lies in the transition from the genuine to the subarid Mediterranean regions of the Iberian Peninsula (Rivas-Martínez 1986). The study area, called Vega de Granada, is an alluvial plain formed by the Genil river and surrounded by hills covered by meso-Mediterranean vegetation and non-irrigated cultivations. The area has been highly transformed by humans for agriculture purposes, and consists in irrigated cultivations (mainly poplar, alfalfa and onion), which is scattered with non-irrigated cereal crops and wasteland. Herbaceous and poplar crops differ in their daily treatment, the former supporting more intensive care (including spraing, irrigating and ploughing) than the latter (only irrigating). Besides agriculture, stock-rearing (mainly goats) and small-game hunting are common activities in the study area. The mean annual temperature is 14 °C, and annual rainfall is 500 mm.

Sampling design and measures of ecological correlates

Seventy-five plots of 100 m × 50 m were sampled in February and March 2010. According to the relative abundances of the main habitat types in the study area, 53.3% of the plots ($n = 40$) fell on poplar groves, 21.3% ($n = 16$) on irrigated herbaceous crops (e.g. alfalfa and onion), 10.7% ($n = 8$) on non-irrigated herbaceous crops (e.g. cereal), 8.0% ($n = 6$) on harvested poplar groves and 6.7% ($n = 5$)