Journal for Nature Conservation 37 (2017) 12–20

Contents lists available at ScienceDirect

Journal for Nature Conservation

journal homepage: www.elsevier.de/jnc

Species distribution models as a tool to predict range expansion after reintroduction: A case study on Eurasian beavers (*Castor fiber*)

Sonia Smeraldo[a,1], Mirko Di Febbraro[b,1], Duško Ćirović[c], Luciano Bosso[a], Igor Trbojević[d], Danilo Russo[a,e,*]

[a] *Wildlife Research Unit, Dipartimento di Agraria, Università degli Studi di Napoli Federico II, Via Università 100, 80055 Portici, Napoli, Italy*
[b] *EnvixLab, Dipartimento Bioscienze e Territorio, Università del Molise, Pesche, Italy*
[c] *Faculty of Biology, University of Belgrade, Studentskitrg 16, 11000 Belgrade, Serbia*
[d] *Faculty of Science, University of Banja Luka, Mladena Stojanovića 2, 51000 Banja Luka, Bosnia and Herzegovina*
[e] *School of Biological Sciences, University of Bristol, 24 Tyndall Avenue, BS8 1TQ Bristol, United Kingdom*

ARTICLE INFO

Article history:
Received 9 September 2016
Received in revised form 19 January 2017
Accepted 20 February 2017

Keywords:
Bosnia and Herzegovina
Conservation gap analyses
Habitat suitability
Riparian habitats
Serbia

ABSTRACT

Species Distribution Models (SDMs) may provide important information for the follow-up phase of reintroduction operations by identifying the main areas most likely to be colonized by the reintroduced species. We used SDMs to identify the potential distribution of Eurasian beavers (*Castor fiber*) reintroduced to Serbia and Bosnia and Herzegovina in 2004–2006 after being historically driven to extinction by overhunting. Models were also used to carry out a gap analysis to assess the degree of protection granted by the national reserve networks to the potentially expanding population. Distances from hydrographic network, broadleaved forest, main watercourses and farmland were the main factors influencing model performance. We estimated that suitable habitat covers 14.0% (31,000 km^2) of the whole study area. In Serbia, in 2004–2013 beavers expanded their range at a mean colonization speed of 70.9 ± 12.8 km/year (mean ± SD). Only 2.89% of and 9.72% of beaver's suitable habitat lie within the national network of protected areas of Bosnia and Serbia respectively. We detected new potential areas where beavers will likely settle in the near future, advising on where further monitoring should be carried out. We also identified low suitability areas to be targeted with appropriate management to improve their conditions as well as important regions falling outside reserve boundaries to which protection should be granted.

1. Introduction

Reintroduction– i.e. the intentional translocation of species into parts of their historically known range from which they have been extirpated (IUCN/SSC, 2012) – is one of the key strategies adopted to restore biodiversity and ecosystem functioning. Forecasting the expansion of a reintroduced species over a given region as part of reintroduction's follow-up phase may be essential to anticipate events that might otherwise jeopardise the operation's success in order to secure appropriate protection in the newly colonised areas, prevent conflicts with humans, optimise monitoring strategies and apply adaptive management of habitat quality (e.g. Armstrong & Reynolds, 2012; Breitenmoser, Breitenmoser-Wursten, Carbyn, & Funk, 2001; McCarthy, Armstrong, & Runge, 2012).

Habitat suitability mapping is frequently used to inform habitat restoration or preservation actions (Gibson, Wilson, Cahill, & Hill, 2004) or to identify suitable sites for species reintroduction (e.g. Ardestani, Tarkesh, Bassiri, & Vahabi, 2015; Olsson & Rogers, 2009). This approach has become an important component of conservation planning in recent years, and a wide variety of modelling techniques have been developed for this purpose (Elith et al., 2006; Elith & Leathwick, 2009; Guisan & Thuiller, 2005). Although Species Distribution Models (hereafter SDMs) appear to be a promising tool to guide the planning of reintroduction operations by conservation biologists and landscape managers, so far their applications to this field have been scarce (see e.g. Adhikari, Barik, & Upadhaya, 2012; Wilson, Roberts, & Reid, 2011). Such models may predict the probability of species presence by relating current occurrences and environmental features at sample locations (Guisan & Zinnermann, 2000; Phillips, Anderson, & Schapire, 2006). In this way the areas that are more likely to be re-colonized as well as the most

* Corresponding author at: Wildlife Research Unit, Dipartimento di Agraria, Università degli Studi di Napoli Federico II, Via Università 100, 80055 Portici, Napoli, Italy.
E-mail address: danrusso@unina.it (D. Russo).
[1] These authors contributed equally to this manuscript.

http://dx.doi.org/10.1016/j.jnc.2017.02.008

probable routes followed in the process can be forecast, drawing valuable inferences on the establishment, expansion and persistence of a reintroduced species (Armstrong & Seddon, 2008). A clear understanding of species-habitat relationships makes it possible to identify highly suitable release sites that offer the maximum chance of post-release survival or guide habitat restoration prior to reintroduction (Seddon, Armstrong, & Maloney, 2007).

Despite the outstanding potential of SDMs in predicting the expansion of a newly introduced species to a given region (Armstrong & Reynolds, 2012), their use to achieve this goal has been largely neglected. In our study we apply SDMs to assess the post-release expansion of Eurasian beavers (*Castor fiber*) in Serbia and Bosnia and Herzegovina and evaluate the potential role of nature reserves to assist this process. The species was once common across Eurasia from the British Isles to eastern Siberia, inhabiting freshwater habitats surrounded by forest but also reaching into the tundra and steppe zones (Halley & Rosell, 2002; Macdonald & Barrett, 1993;Macdonald, Tattersall, Brown, & Balharry, 1995; Nolet & Rosell, 1998). Prized for its fur, meat and castoreum (a urine-based fluid secreted from castor sacs for scent marking valued by humans for medic or cosmetic applications), beavers were wiped out by overhunting from most of their range by the middle 19th century (Djoshkin & Safonow, 1972). By the beginning of the 20th century, only 1200 individuals had persisted in eight isolated populations across the entire species' range (Nolet & Rosell, 1998). The remnant populations received legal protection, and since 1922 reintroductions started in many European regions to pursue species conservation and ecosystem restoration (Halley & Rosell, 2002; Kollar & Seiter, 1990; Nolet & Rosell, 1994). To date, the return of *C. fiber* has not yet taken place in Portugal, Italy, southern Balkans (Greece, Albania, Bulgaria, Macedonia and Montenegro) and Ireland (Halley & Rosell, 2002; Halley, Rosell, & Saveljev, 2012), while two wild populations now occur in Scotland on a trial basis (Stringer & Gaywood, 2016). Currently, the species is strictly protected in the European Union under the Bern Convention (Appendix III) and the EU Habitats and Species Directive (Annex V for the Swedish and Finnish populations, Annex II and IV for all others).

The Serbian population of beavers was driven to extinction by overhunting by the second half of the 19th century, apart from an unconfirmed report of a beaver shot near Belgrade at the beginning of the last century (Ćirović, Stamenković, & Bjedov, 2003; Ćirović, Bjedov, & Stamenković, 2007). By then, the species had also disappeared from the whole course of the Danube and its tributaries. In 1999, following the shooting of a beaver in Northern Serbia (Vojvodina, Bačka region) that had dispersed from the re-established population of Hungary, a reintroduction operation was started in Serbia and Bosnia and Herzegovina (Ćirović, Savić, & Bjedov, 2001; Ćirović et al., 2003). In 2004 and 2005, 75 subjects imported from Bavaria were reintroduced to the Obedska Bara and Zasavica Special Reserves in Serbia, and 40 were released in Semešnica and Sokočnica rivers in Bosnia and Herzegovina in 2005 and 2006 (Appendix S1).

Although many studies have assessed beaver habitat requirements (Fustec, Lodé, Le Jacques, & Cormier, 2001; Halley et al., 2012; Parker et al., 2001; Vorel, Válková, Hamšíková, Malon, & Korbelová, 2008; Zurowsky & Kasperczyk, 1990) only few applications of habitat suitability models have been carried out, e.g.in the Czech Republic (John, Baker, & Kostkan, 2010) and Austria (Maringer & Slotta-Bachmayr, 2006). In our study, we quantify the potential distribution of *C. fiber* for Serbia and Bosnia and Herzegovina to predict the species' spatial pattern of expansion. We hypothesize that (1) given the overwhelming importance of riparian habitat and the tendency of beavers to feed on crops (Campbell-Palmer et al., 2016), hydrographical network, riparian broadleaved forest and farmland will be the main environmental variables influencing potential distribution; and that (2) since most reserves in the study region do not comprise rivers, the network of protected areas will offer little protection to the aforementioned distribution.

2. Materials and methods

2.1. Study area

The study area included the whole territories of Serbia and Bosnia and Herzegovina, covering approximately 139570 km^2 between latitudes 41°N–47°N and longitudes 15°E–23°E. Elevation ranges from 0 up to 2500 m a.s.l. The area is largely mountainous and forested (c. 50% of Bosnia and 25% of Serbia). Arable land covers 53.2% of Serbia and 28.7% of Bosnia and Herzegovina (Corine land cover 2006, www.eea.europa.eu). Agricultural production is mostly prominent in the fertile Pannonian Plain situated in the northern part of Serbia (Vojvodina) and in the region of Serbia between the Sava, Drina and Great Morava rivers, while in Bosnia farmland is found in the valleys of Sava, Una, Sana, Vrbas, Bosna and Drina rivers.

2.2. Presence records of the eurasian beaver

We used 71 presence records of Eurasian beavers from authors' personal databases obtained from the post-reintroduction monitoring in Serbia and Bosnia and Herzegovina (Grubešić et al., 2015) (Fig. 1). Records cover years 2004–2014, matching the year of production (2006) of the land cover map used for our study (Russo et al., 2014, 2015).

Each record represented the centroids of a beaver's territory, corresponding to a beaver's shelter (burrow or lodge) or, if this was not found, to the central part of the winter feeding territory. We checked for spatial autocorrelation in species occurrences by using Clark & Evans's (1954) aggregation index – for further details, see also Ducci et al. (2015) and Di Febbraro et al. (2015).

We implemented a sampling procedure to obtain a representative set of the environmental conditions occurring throughout the area of each territory. Specifically, we defined the boundaries of each territory by intersecting two buffer areas:

i) a first 1.7 km radius circular buffer was drawn around each occurrence record, whose intersections with the watercourse's main axis were assumed to represent the territory's outer limits along the watercourse. The 1.7 km value corresponds to the maximum length known for a beaver's linear territory (Vorel et al., 2008);
ii) a second 200-m buffer from each river bank was applied to encompass the territory portions alongside the river stretch, expressing the maximum territory width observed in the study area. This is approximately the longest distance covered by beavers from riverbanks to forage according to published observation and our own records (Allen 1983; D. Ćirović, pers. comm.). Subsequently, a point was taken randomly from each of the areas comprised within the above buffers, repeating this sampling procedure 10 times and obtaining 10 independent sets of 45 "occurrence" points, one for each territory. Each of the 10 replicated sets was used to train a separate SDM.

To fit SDMs with the global scale (Gallien, Douzet, Pratte, Zimmermann, & Thuiller, 2012 – see below), we used GBIF records (Appendix S2).

2.3. Environmental variables

To generate SDMs we started from a set of 13 environmental predictors rasterized at a resolution of 100 m, including