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Expert system for modelling stopover site selection by barnacle geese

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ABSTRACT

The study of stopover sites has received a lot of attention in avian ecology, being especially important for many long-distance migrants, some of which have to pause several times during migration. The survival of many migratory birds depends primarily on food availability at these stopovers. However, previous studies show that there is a lack of knowledge about site selection where migratory birds stop to refuel energy stores. In the present study, a Bayesian expert system has been used to incorporate environmental parameters, to determine their relationship with the presence of barnacle geese at stopover sites. Data on stopover sites was obtained from satellite-tracked barnacle geese (*Branta leucopsis*) for three different breeding populations in the Western Palearctic (i.e. Russian, Svalbard and Greenland). The results from the present study showed that the posterior probability of presence at the stopover sites obtained from the Bayesian model was close to one. Therefore, the Bayesian expert system detected the stopover sites of the geese correctly and can be used as a proper method for modelling the presence of barnacle geese at the stopover sites in the future. This study introduces a new method into movement ecology to identify and predict the importance of different environmental parameters for stopover site selection by migratory geese. This is particularly important from both a conservation and an agro-economic point of view with the goal of reducing possible conflicts between geese and agricultural interests.

1. Introduction

Stopovers are places along a migration route where birds mostly rest and forage to replenish energy reserves before continuing their journeys (Newton, 2008). Having such breaks during migration is especially important for Arctic-nesting geese as many of them are partial capital breeders and may bring body stores to the breeding grounds, in order to survive initial adverse conditions and produce a clutch of eggs soon after arrival (Gauthier et al., 2003). However, there is a lack of knowledge about the selection of these sites, where birds choose to stop and forage (Newton, 2008).

Habitat selection is greatly influenced by a variety of environmental parameters, which includes food availability and the costs related to predation or disturbance risks, e.g. from farmers, as well as inter- and intra-specific competition (Chudzińska et al., 2015). Since, herbivore species follow peaks in the availability of high-quality forage, it is presumed that variation in this resource drives annual migration (Owen, 1980; Shariatinajafabadi et al., 2014; van der Graaf et al., 2006). Sites selected by the geese were generally located in a lowland region and far from woodland edges, possibly to minimize predation risk (Jankowiak et al., 2008; Roder et al., 2008; Rosin et al., 2012). Moreover, geese prefer large fields that are remote from human settlements (Rosin et al., 2012). The negative impact of human settlements on foraging sites has been attributed by farmers, domestic dogs, foxes, traffic volumes and windfarms (for more information see Jensen et al., 2008; Keller, 1991; Langston, 2013; Rosin et al., 2012)

Lakes and coastal waters are usually used by geese as roosting and daily resting sites during migration (Rosin et al., 2012).

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Distance to open water (i.e. sea or lakes) is related to energy expenditure as geese must use additional energy to move from a roosting site to a distant foraging site. It is also shown in studies that goose occurrence declined significantly with the increase in distance from feeding sites to open water (Jensen et al., 2008). Therefore, geese primarily use fields that are closer to roosting sites (e.g. Jensen et al., 2008).

It is seen that effective conservation and management of migratory birds, requires species distributional data to determine the distribution of stopovers and the pathways used between them (Faaborg et al., 2010). It is recommended that specific attention should be given to stopover sites, as the functional role of a given stopover site in meeting the needs of migrants is highly dynamic with respect to resource availability, landscape context, the physiological condition of the migrants and mortality risks (Mehlman et al., 2005). Moreover, recent technological advances, such as satellite tracking, allow to track birds throughout the annual cycle, determine their migratory routes and map the often remote stopovers with great accuracy (Klaassen et al., 2014; Pedrana et al., 2015). For instance, the migration routes and location of stopover sites of bar-headed geese (*Anser indicus*) in China (Guo-Gang et al., 2011) and Svalbard barnacle geese (Griffin, 2008) has been determined with the use of satellite tracking.

Moreover, species distribution modelling (SDM) has been widely applied to quantify the relationship between species distribution and environmental parameters and to predict species' occurrence across un-sampled areas (Guisan and Thuiller, 2005; Miller, 2010). Currently, a variety of statistical models are being used for modelling species distributions (see review by Guisan and Thuiller, 2005). However, an intensive field survey for generating in-situ data is costly in terms of time and resources (James et al., 2001). In such cases, expert knowledge can be a less expensive source of information where there is insufficient field data for remote breeding and wintering areas (Murray et al., 2009). In addition, Bayesian statistics provide a mechanism to incorporate such knowledge into species distribution models (Choy et al., 2009). With the use of a priori probability of occurrence (prior knowledge), conditional to the value of each environmental parameter (likelihood function) which is obtained based on experts' rules, the Bayesian expert system can be formulated (Skidmore, 1989).

Bayesian method has been argued to be advantageous over frequentist statistics and its use in ecological studies has been encouraged (Ellison, 1996). For instance, the Bayesian method has the ability to incorporate various kinds of uncertainty into the analysis (e.g. uncertainty of the estimate) even for unknown parameters (Taylor et al., 1996). Moreover, the results that are presented in Bayesian frameworks can be understood more easily by decision-makers. Also, additional environmental parameters can be quickly incorporated into a Bayesian expert system as data layers and the posterior probability can be kept updated (Skidmore, 1989; Wade, 2000). However, despite the beneficial aspects of using the Bayesian method, it has been used relatively rare in ecological studies (McCarthy, 2007).

The Bayesian approach can also be applied in habitat distribution modelling (Guisan and Zimmermann, 2000; Niamir et al., 2011). Aspinall (1992) applied a GIS-based Bayesian modelling method for predicting the spatial distribution of red deer (*Cervus elaphus*) in Scotland. Moreover, Kynn (2005) also incorporated expert knowledge as prior knowledge, to a Bayesian logistic regression for modelling species habitat distribution. Nevertheless, as far as we know, this method has never been used to model stopover selection of migratory birds.

The present study investigates stopover behaviour of 37 satellite-tracked barnacle geese from three different populations in the Western Palearctic, transiting between temperate and high Arctic latitudes. Considering the practical advantages of Bayesian statistics, such as taking uncertainty into account and simplicity in explaining the results (Wade, 2000) we were interested to assess, whether a Bayesian expert system can appropriately model stopover site selection of barnacle geese during spring migration, by utilizing the detailed knowledge of goose ecologists.

2. Material and method

2.1. Satellite tracking data and stopover sites

Barnacle geese from three long-distance migratory populations in the Western Palearctic (Russia, Svalbard and Greenland) were captured at their overwintering sites and equipped with solar GPS/ARGOS transmitters attached to the back of the birds, using a nylon elasticated harness. The transmitters used in this study were 30 g Solar GPS 100 PTT (PTT-platform transmitter terminal; Microwave Telemetry, Inc., Columbia, MD, USA) for the Russian birds and a mix of 30 g and 45 g PTTs for the Svalbard and Greenland birds (Table 1). In total 30 full data tracks for 12 individuals of the Russian population (2008–2011), 20 full data tracks for 18 individuals of the Svalbard population (2006–2011) and 7 full data tracks for 7 individuals of the Greenland population (2008–2010) were collected during spring migration (Table 1). The barnacle goose tracking data has been stored in Movebank (https://www.movebank.org: Russian population: "Migration timing in barnacle geese (Barents Sea), data from Kölzsch et al., 2015 and Shariatinajafabadi et al., 2014", DOI: 10.5441/001/1.ps244r11 (ii) Svalbard population: "Migration timing in barnacle geese (Svalbard), data from Kölzsch et al., 2015 and Shariatinajafabadi et al., 2014", DOI: 10.5441/001/1.5k6b1364 (iii) Greenland population: "Migration timing in barnacle geese (Greenland), data from Kölzsch et al., 2015 and Shariatinajafabadi et al., 2014", DOI: 10.5441/001/1.5d3f0664.

For each GPS track, stopover sites were defined as an area where the geese would remain within a radius of 30 km for at least 48 h (for more information see Shariati-Najafabadi et al., 2015). In total, 64 stopover sites were identified along the Russian flyway (2008–2011), 32 along the Svalbard flyway (2006–2011), and 14 along the Greenland flyway (2008–2010) for 12, 18 and 7 geese, respectively, during the spring migration (see Table 1 and Fig. 1). Also, from the Russian and Svalbard barnacle geese that were tracked for more than 1 year, only two from year to year. Nevertheless, none of them arrived at these stopover sites on the same date as in other years.

2.2. Environmental parameters

A set of environmental parameters known to be important in determining stopover selection of barnacle geese have been reviewed (Amano et al., 2006; Jensen et al., 2008; Rosin et al., 2012; Si et al., 2011). The selected parameters have been categorized into four groups based on Rosin et al. (2012): human disturbance (1), site safety (2), distance from the roosting area (3) and the foraging habitat (4) (Table 2). Distance to roads, cities, towns and wind farms were used as indicators of human disturbance, distance to the forest as an indicator of site safety from predators, and distance to river, inland water and ocean as the proximity to roosting areas. The maps of roads, cities, town, rivers, ocean area and inland waters were derived from ESRI (2016), and the wind farm data was obtained from The wind power (2016).

Also, in the present study, factors like the site elevation, greenness factor, percentage of grassland/cropland, percentage of salt marsh and snow cover, at each stopover site were used to describe foraging habitat. Study involved extracting site elevation from a digital elevation model (DEM) generated by Global