Independence and juvenile dispersal distances in wild and reintroduced Spanish imperial eagles

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ABSTRACT

Reintroductions have been increasingly used for species restoration and it seems that this conservation tool is going to be more used in the future. Consequently a better knowledge of consequences of this kind of management is needed. Several authors have found differences in dispersal distances among wild and reintroduced individuals; although no common explanation for this general trend (*i.e.* released animals moving farther than wild ones) has been proposed. Here we compared the dates of dispersal and the distribution of maximum distances during juvenile dispersal between a natural high density population and an alternative situation where young Spanish imperial eagles (*Aquila adalberti*) were reintroduced in a new area with a very low intra-specific density, and *ad libitum* feeding until the onset of dispersal. Results showed that maximum dispersal distances were longer in translocated (mean = 205 km) than in control juvenile eagles (mean = 119.70 km), and the shape of the distribution changed from leptokurtic right-skewed to quasi-normal. According to our results, for reintroduced young fed *ad libitum*, we can predict that effective dispersal distances will be longer in reintroduced young during juvenile dispersal than in natural populations. But dispersal distances might also depend on the distance from the release area to the nearest breeding population of the species. For reintroductions close to other existing populations, immigration of released young into existing populations would be greater than expected.

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1. Introduction

Animal reintroductions are man-induced colonizations that provide unique opportunities to investigate the dispersal process (Sarrazin and Barbault, 1996). Released individuals act like propagules in new habitats with initial absence or very low density of conspecifics, allowing discrimination of the relative role played by competition on the dispersive response of founders prior to first reproduction. In addition, understanding the dispersal behavior of reintroduced individuals is of central importance for conservation and management purposes (Skjelseth et al., 2007; Margalida et al., 2013).

Reintroductions have been increasingly used for species restoration, though traditionally have shown low success rates (Lyles and May, 1987; Griffith et al., 1989; Seddon et al., 2007). Hence, monitoring and research strategies aimed to increase our knowledge on reintroduction biology should be undertaken in order to improve the outcome of reintroductions (IUCN, World Conservation Union, 1998; Armstrong and Seddon, 2008). In this context, movements of individuals of long-lived vertebrates early in life are especially informative, because it is during this period when mortality rates are highest. At the same time, dispersal is the main mechanism behind population spread and gene flow. Consequently, estimation of the dispersal distances during juvenile dispersal for wild and reintroduced animals are critical in designing programs to restore extinct populations.

Several authors have found differences in dispersal distances among wild and reintroduced individuals. For example relocated individuals of the tiger snake (*Notechis scutatus*) dispersed longer distances than the residents, although the frequency of movement was the same for both groups (Butler et al., 2005). Also reintroduced house sparrows (*Passer domesticus*; Skjelseth et al., 2007) and bearded vultures (*Gypaetus barbatus*; Margalida et al., 2013) dispersed longer distances than wild ones. No common explanation for such differences between released and wild animals has been proposed.

In most dispersal studies of birds a typical leptokurtic and skewed distribution has been found (*e.g.* Buechner, 1987; Miller and Carroll, 1989; Rodgers and Klenner, 1990; Ferrer, 1993b; Paradis et al., 1998; Newton, 2008). It has been suggested that such a distribution could be generated by competition among dispersing individuals during territory acquisition (*i.e.* competitive displacement hypothesis). Those individuals that disperse longer distances, forming the tail of the distribution, are individuals at lower competitive advantage, which would probably be the last to hatch and also take a longer time after fledging to disperse

(Murray, 1967; Waser, 1985). An alternative explanation for polymorphism of dispersal distances was proposed by Ferrer (1993b). In the 'wandering' hypothesis, a leptokurtic distribution of dispersal distances is also expected but with individuals in better nutritional condition leaving the natal area earlier and moving longer distances, forming therefore the tail of the distribution. In contrast, those young in poorer nutritional condition that hatched later in the season dispersed short distances, remaining closer to their natal nests. Additionally, social attraction would be important in influencing the settlement patterns of individuals. Reintroduction program typically starts with no breeding pairs in the release area, causing dispersing young to move on and search elsewhere. Consequently, under the social attraction hypothesis we expect an increase in dispersal distances for released young. Nevertheless, no differences in timing of dispersal between wild and released young can be derived from this hypothesis. Reintroduction programs are a good opportunity to test predictions derived from the competition displacement hypothesis in a situation characterized by the extremely low density of dispersing young (Gray et al., 1987).

In the present study, we investigate the dates of dispersal and the distribution of juvenile maximum dispersal distances in a territorial long-lived species with deferred maturity, the Spanish imperial eagle (*Aquila adalberti*). We examine the movement behavior of both wild young eagles in a natural high density population in Doñana National Park (southern Spain), and translocated juveniles in a nearby reintroduction program with no breeding pairs and low density of young eagles. Under a context of competitive displacement, we expect later dispersal dates and a decrease of maximum dispersal distances in the translocated population, with a more pronounced leptokurtic and positively skewed distribution of distances, *i.e.* more young eagles dispersing shorter distances than in an existing population, due to lower conspecific density and resource competition in the release area. In contrast, under the 'wandering' hypothesis, earlier dispersal dates as well as an increase in mean dispersal distances, showing a quasi-normal distribution, would be expected due to a general improvement of the nutritional conditions of released young that have been fed *ad libitum* during the last part of the nestling period and all the post-fledging dependence period, as is usual in reintroduction programs. We also discuss the potential effects of social attraction to dispersal distances when there are no breeding birds in the area.

2. Material and methods

2.1. Study species

The Spanish imperial eagle is a long-lived large (2500–3500 g) endemic bird of prey from the Iberian Peninsula. It is the most threatened raptor in the European continent and one of the rarest in the World (Vulnerable in the IUCN Red List, BirdLife International, 2008) with 430 breeding pairs in 2013 (National Working Group, unpublished data 2013). The species is monogamous, sedentary and territorial, with a low annual productivity of 0.75 chicks/pair in the case of the Doñana population (Ferrer and Calderón, 1990). Reproduction usually lasts 8 months from February, when laying starts, until October when last juveniles leave the natal area, though courtship and displays begin in the previous autumn. Young Spanish imperial eagles leave their natal population on average at the age of 135 days and thereafter use different temporary settling areas; the average age at first settlement is 164 days (Ferrer and Calderón, 1990). Young eagles use different temporary settling areas. Temporary settlements are characterized by open lands with high prey density (European rabbit, *Oryctolagus cuniculus*), without medium-large breeding raptors and low human disturbance (Ferrer and Harte, 1997). Each area is used intensively for a variable but short period, and each individual used the same areas (between three and eight) in rotation during at least the first 3 years of life, returning occasionally to the natal area (Ferrer, 1993a) until recruiting to the breeding population when 4–5 years old on average.

2.2. Study area and data collection

We studied birds hatched in 10 non-consecutive years, during 1986 to 2009, from the breeding population of Doñana National Park (1049.7 km²; 36°56′N, 6°30′W) and a reintroduction project in the province of Cadiz (≈36°20′N, 5°48′W), in Andalusia (southern Spain; Fig. 1). Dispersal monitoring extended to a large part of southern Iberian Peninsula, characterized by a wide altitudinal range (0–2000 m.a.s.l.), a dry-humid Mediterranean climate (annual rainfall: 300–2000 mm, average annual temperature: 9–19 °C) and a landscape represented by a mosaic of Mediterranean forests, scrubland and grasslands in hilly and mountainous areas, crops in lowlands and coastal wetlands. Hatching dates were accurately known from previous checks during reproduction. Mean hatching date was 25th April ± 8 days, n = 46, being significantly earlier in Doñana (21th April) than in Sierra Morena (27th April).

During the study period, the eagle population at Doñana National Park consisted of a maximum of 15–16 breeding pairs at a high density (occupying 20,000 ha of available habitat inside the National Park with a mean territory size of 1200 ha, range = 980–1870 ha; Ferrer, 2001). Eagle territories were exclusive and vigorously defended throughout the year (Ferrer, 1993a). Nests were located in cork oaks and stone pines not far from the marshland. The Spanish Imperial Eagle population at Doñana is well separated from other breeding populations, the nearest of which is 150 km away. Consequently, the probability of floaters coming from other populations is low (Ferrer and Calderón, 1990; Ferrer et al., 2003).

The reintroduction program of the Spanish imperial eagle in the province of Cadiz started in 2002 (Muriel et al., 2011). Preliminary analyses for the reintroduction program showed that in the release area the potential number of breeding pairs would be around 47–52, with a highly homogeneous distribution. Between 2002 and 2009, 47 young Spanish imperial eagles were collected when 47.8 ± 6.1 days old from the breeding population of Sierra Morena (northern Andalusia), translocated to the hacking facilities, and released after 28.8 ± 6.2 days. Young were fed *ad libitum* at least until 2–3 days after last young left the release area definitely (mean length of *ad libitum* feeding 90 days). No nestling for translocation was extracted from the Doñana population (for more details see Muriel et al., 2011).

The initial sample size consisted of a total of 46 young eagles, including 20 non-manipulated birds from the Doñana breeding population and 26 reintroduced birds in Cadiz. Before fledging, all nestlings (40–70 days old) were ringed and equipped with backpack radio-transmitters (three models: TW-3, Biotrack Ltd., UK; HSPB 14003, Wildlife Materials Inc., USA; and 5/XOB 17-04, Wagener Telemetrieanlagen, Germany) that did not exceed a maximum of 2.5% of their body mass at fledging (Kenward, 2001). Sex of young was determined by means of the forearm measurement (Ferrer and De le Court, 1992) and molecular methods (Fridolfsson and Ellegren, 1999) using blood samples from 2006–2009.

We estimated nutritional condition using plasma urea levels. As is well known for many bird species (raptors, penguins and gulls among others), when tissue protein sources are mobilized actively by starvation or undernourishment, urea values increase (Garcia-Rodriguez et al., 1987; Alonso-Alvarez et al., 2002; Alonso-Alvarez and Velando, 2003). The latter is caused by an increase in the nitrogenous excretion components released into the blood. Since this parameter is not sensitive to recent ingestion, and its blood levels vary slowly (Garcia-Rodriguez et al., 1987; Ferrer and Calderón, 1990), it is a good indicator not only of acute fasting but also of mid-term nutritional condition (around two weeks according to Garcia-Rodriguez et al., 1987 and Alonso-Alvarez and Velando, 2003). For these reasons, the urea concentration in blood has been used as a reliable indicator of nutritional condition in several species in different ecological contexts (*e.g.* Ferrer et al., 1987; Ferrer, 1994; Alonso-Alvarez and Ferrer, 2001; Casado et al., 2002; Balbontín and Ferrer, 2005; Muriel et al., 2013).