TytoTagus Project: Common Barn Owl post-fledging dispersal and survival in the Tagus Valley, Portugal

Projeto TytoTagus: dispersão pós-natal e sobrevivência da coruja-das-torres no Vale do Tejo, Portugal

Inês Roque[1*], Ana Marques[1], Rui Lourenço[1], J. Tiago Marques[2,3,4], Carlos Godinho[1], Pedro Pereira[1], João E. Rabaça[1,5]

1 MED – Instituto Mediterrâneo para a Agricultura, Ambiente e Desenvolvimento, LabOr - Laboratório de Ornitologia, Universidade de Évora, Núcleo da Mitra Ap.94 7002-554, Évora, Portugal

2 MED – Instituto Mediterrâneo para a Agricultura, Ambiente e Desenvolvimento, Núcleo da Mitra Ap.94 7002-554, Évora, Portugal

3 CIBIO/InBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, Universidade de Évora, Pólo de Évora, Casa do Cordovil 2o Andar, 7000-890 Évora, Portugal

4 cE3c – Centre for Ecology, Evolution and Environmental Changes, Departamento de Biologia Animal, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal

5 Departamento de Biologia, Escola de Ciências e Tecnologia, Universidade de Évora, Núcleo da Mitra, Ap.94 7002-554, Évora, Portugal

*** Corresponding author:** iroque@uevora.pt

ABSTRACT

The Tagus Estuary hosts a high concentration of juvenile Common Barn Owls (*Tyto alba*) during the post-fledging dispersal period with more than 15 owls/km detected along roads in the south floodplain of Vila Franca de Xira (SF). The Tyto Tagus project examined the origin of these birds with six re-sightings of 136 colour-ringed nestlings (2006–2008) and subsequently (2009-2012) with 41 VHF radio-marked juveniles from three areas: 16 in Benavente, 13 in the SF and 12 in Coruche. Five re-sightings were of colour-ringed juveniles from nests in Benavente (<15 km from the SF) and one from a nest from Coruche (45–60 km from the SF). One tag failed while the owl was still near the nest, contact was lost with 19 radio-marked owls (15 during fledging), 19 owls were found dead (13 during fledging), and the battery was used up for two owls. One juvenile was found dead immediately after leaving the nest, but 11 others were tracked during dispersal, in which they used a succession of temporary settlements with single or several roosts alternating with longer movements. Six of these owls moved towards SF. Others remained in Coruche or roosted in a northern area of the floodplain near their nests. The distance between roosts and hunting areas was generally <3 km, but some juveniles hunting in the SF had roosts >11 km away. Juvenile Common Barn Owls mainly roosted in trees along roadsides and riparian areas but also in forest patches (i.e., in mixed stands of cork oak (*Quercus suber*) and pine (*Pinus* spp.), montados and pine forests) adjacent to open agricultural areas. Between 7.3% and 43.9% of the owls survived the post-fledging dispersal period. Future studies should assess the impact of road mortality near the SF and consider the use of new technologies to track juveniles until they nest.

Keywords: colour marking, juvenile dispersal and survival, Tagus Estuary, telemetry, *Tyto alba*

RESUMO

O Estuário do Tejo reúne um elevado número de corujas-das-torres (*Tyto alba*) durante o período de dispersão pós-natal, com valores de abundância superiores a 15 indivíduos/km ao longo de algumas estradas não pavimentadas na lezíria sul de Vila Franca de Xira (SF). O Projeto TytoTagus avaliou a origem destas aves através de seis recapturas visuais de 136 juvenis marcados com anilhas coloridas (2006-2008) e, subsequentemente (2009-2012), através de 41 juvenis marcados com emissores VHF em três áreas: 16 em Benavente, 13 na SF e 12 em Coruche. Cinco recapturas corresponderam a juvenis provenientes de Benavente (<15 km da SF) e uma recaptura correspondeu a um juvenil de Coruche (45–60 km da SF). Um emissor falhou ainda no ninho, foi perdido o contacto com 19 juvenis (16 durante a emancipação),19 juvenis foram recapturados mortos (13 durante a emancipação), e duas corujas foram seguidas até ao fim de vida da bateria. Uma coruja foi encontrada morta imediatamente após dispersar, e 11 outras foram seguidas durante a dispersão, que consistiu na ocupação sucessiva de áreas de fixação temporárias, onde foi usado um único ou vários poisos próximos, alternando com movimentos longos de dispersão. Seis destes indivíduos aproximaram-se da SF. Nos outros casos, as corujas permaneceram em Coruche ou na área norte da lezíria, na proximidade dos seus ninhos. A distância entre poisos e áreas de caça foi no geral <3 km, embora os juvenis a caçar no estuário tivessem poisos diurnos a mais de 11 km. As corujas usaram como poiso principalmente árvores ao longo de estradas e galerias ripícolas, bem como áreas florestais (i.e., povoamentos mistos de sobreiro (*Quercus suber*) e pinheiro (*Pinus* spp.), montados e pinhais) contíguas a áreas agrícolas abertas. Entre 7.3% e 43.9% das corujas sobreviveram ao período de dispersão pós-natal. Estudos futuros deverão analisar o impacto da mortalidade por atropelamento nas imediações da SF e considerar a utilização de novas tecnologias que permitam seguir os juvenis até à primeira nidificação.

Palavras-chave: dispersão e sobrevivência de juvenis, Estuário do Tejo, marcação com anilhas coloridas, telemetria, *Tyto alba*

Introduction

The Common Barn Owl (*Tyto alba*) [hereafter Barn Owl] occupies farmland habitats, feeds mainly on small mammals and nests in man-made structures (Bunn et al. 1982, Roulin et al. 2002), and is an effective alternative to toxic pest control chemicals (Kross et al. 2016). It also is an indicator of environmental contamination (Sheffield 1997, Roque et al. 2016). On the other hand, its close association with people exposes it to several threats such as the loss of hunting habitat and increased road mortality (Hindmarch et al. 2017, Arnold et al. 2018) and it has experienced short-term declines in Portugal (Lourenço et al. 2015), Spain and in several other European countries, often due to changes in agricultural practices (Hagemeijer and Blair 1997, Martí and Del Moral 2003, BirdLife International 2004a,b, SEO/ BirdLife 2013).

The Tagus Valley has one of the highest concentrations (> 15 owls/km along roads, I. Roque unpublished data) of Barn Owls globally. Previous studies in the south floodplain of Vila Franca de Xira (SF), in the Tagus Estuary, suggest its importance as feeding area for Barn Owls during the post-fledging dispersal period (Tomé 1994, Tomé and Valkama 2001). The TytoTagus Project marked owls from the SF and adjacent nesting populations to determine the origin of birds congregating in the SF, which factors influenced their aggregation in the SF, and what management measures will be needed to conserve them.

Barn Owls disperse along linear landscape features like water courses to locate prey (van der Hut et al. 1992, de Bruijn 1994, Taylor 1994). They also disperse as predicted by the balanced dispersal hypothesis: an equal exchange of individuals between any two areas (Pulliam 1988, McPeek and Holt 1992). Marginal vegetation (i.e., natural hedges) provides good microhabitat for small mammals, the main prey of the Barn Owl (Sabino-Marques and Mira 2011, Arnold et al. 2018). The Tagus Estuary floodplains contain suitable Barn Owl hunting habitat; open farmland with ditches bordered by dense vegetation (Tome and Valkama 2001). Moreover, the SF has abundant fence poles used as perches by hunting owls (Tomé and Valkama 2001).

Therefore, we predicted that the Tagus River and its tributaries continue to support a high number of non-breeding Barn Owls and serve as an ecologically important dispersal corridor for juveniles (Tomé and Valkama 2001). These predictions were supported by (1) the high density of breeding pairs along the Sorraia River which flows into the Tagus (Roque and Tomé 2004); (2) the very low number of breeding pairs in the SF, where potential nesting sites are very scarce (Tomé 1994); and (3) the dispersal period coinciding with the increase of owl density in the SF (Tomé 1994, Roque 2003). These predictions fit with known dispersal patterns of juvenile raptors which prefer non-breeding areas with abundant prey and few territorial adults (Ferrer and Harte 1997, Balbontin 2005, Fasciolo et al. 2016). The goals of this study were to document Barn Owl post-fledging dispersal movements to the Tagus Estuary, identify priority conservation habitats and roosts relative to hunting areas, and to determine survival and threats to owls and the habitats on which they depend.

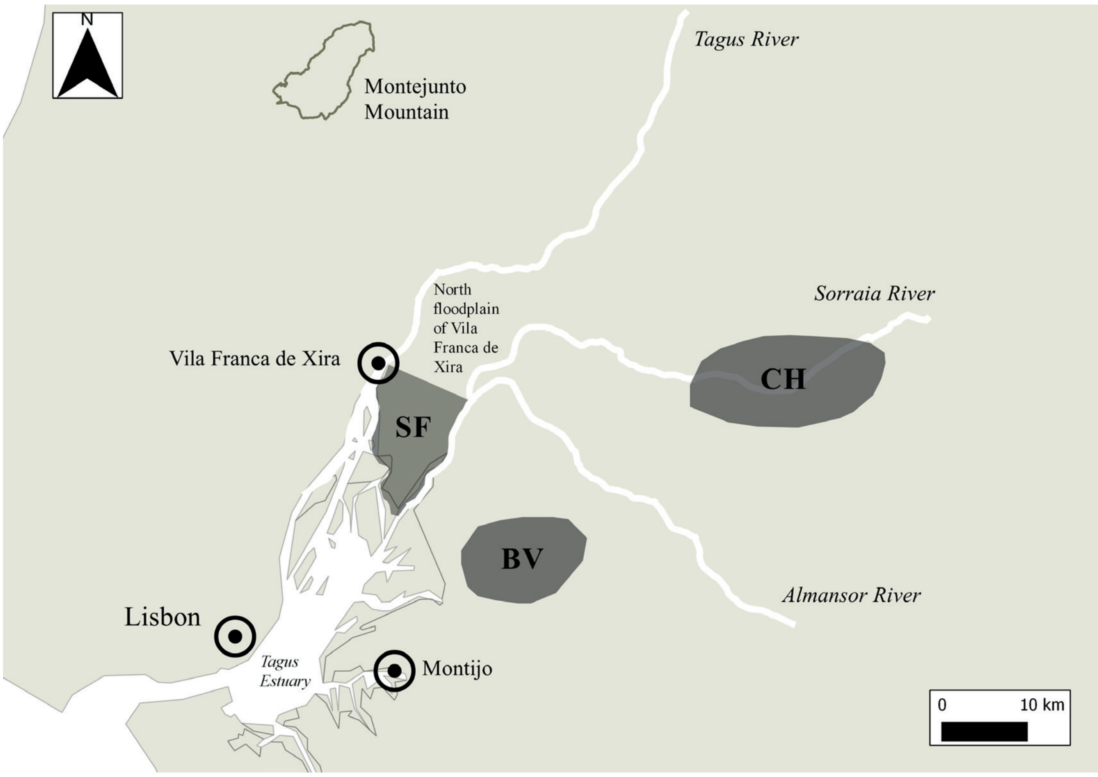
Methods

Study area

The study area was in west-central Portugal, southwest of Lisbon, and was comprised of (1) south floodplain (SF) of Vila Franca de Xira (*lezíria*) in the Tagus Estuary (38°50'N, 8°80'W); (2) Coruche (CH), the floodplain of the Sorraia River (the main tributary of Tagus River); and (3) Benavente (BV), contiguous woodland areas known as *charneca* and dominated by cork oaks (*Quercus suber*) and maritime pines (*Pinus pinaster*) (Fig.1). Winters are mild and wet, and summers hot and

Figure 1 - Common Barn Owl study area, Portugal. South floodplain (SF) of Vila Franca de Xira (Tagus Estuary), Benavente (BV) woodlands, and Coruche (CH) floodplain of Sorraia.

Figura 1 - Área de estudo. SF – Lezíria Sul de Vila Franca de Xira (Estuário do Tejo). BV – Benavente (10–20 km da SF). CH – Coruche (20–40 km da SF).



dry. The floodplains encompass temporary small-scale polyculture and intensive crops (>100 ha) of maize, rice, tomato and sugar beet. The Sorraia River flows into Tagus River in an area known as Ponta da Erva in the south floodplain of Vila Franca de Xira, an alluvial plain of ~6,219 ha on the left bank of the Tagus Estuary. The area is almost totally occupied by agricultural fields (mainly rice) and pastures. Farming plots are delineated by a vast system of wire fences, dirt roads and ditches. Natural salt marsh vegetation subsists only in narrow plot edges and in ditch margins. A small number of houses and barns are the only buildings present. The area is part of a National Nature Reserve, a Special Protection Area for Birds (Directive 79/409/EC), and an Important Bird Area (IBA 021 – Tagus Estuary; Heath and Evans 2000).

Colour-ringing study

An intensive nest search was conducted in 2006 followed by an annual monitoring through to 2012 during which 302 Barn Owl nestlings were ringed. From 2006 to 2008, 136 were also marked with colour rings (coded by nest location) to later identify them by spotlight along 22.2 km of transects on dirt roads in the SF (Fig. 2). Transects were driven twice a week in 2007 and every week thereafter (2008-2012) between August and

Figure 2 - Car transect in the south floodplain of Vila Franca de Xira (Tagus Estuary), Portugal.

Figura 2 - Transecto na Lezíria Sul de Vila Franca de Xira (Estuário do Tejo).

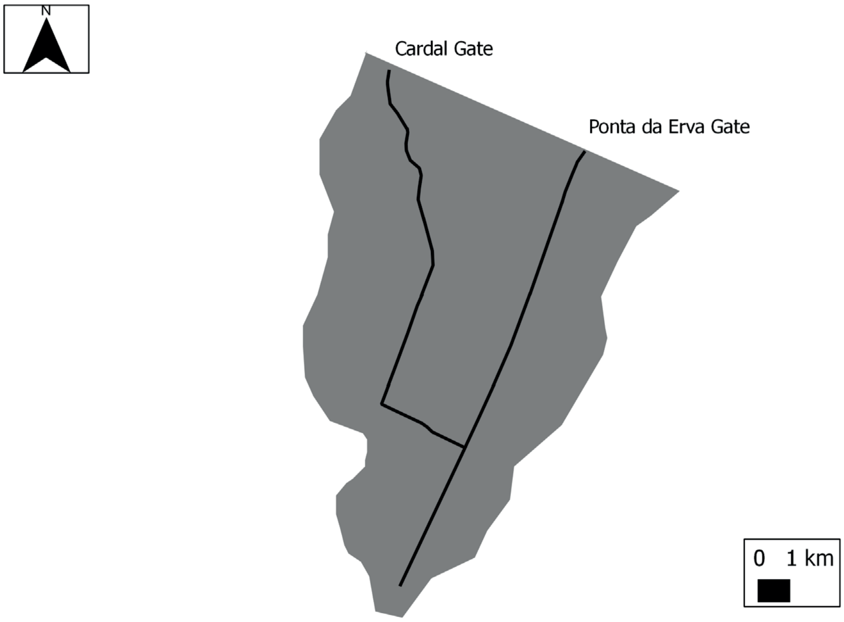


Figure 3 - Aerial telemetry sampling grids in the Tagus Estuary and adjacent area: 1 – North Grid, 2 – Northwest Grid, and 3 – South Grid. Shaded areas are South Floodplain (SF), Benavente (BV), and Coruche (CH), Portugal.

Figura 3 - Grelhas de amostragem de telemetria aérea (1 100 km) cobrindo uma área de 40–70 km em redor da lezíria sul de Vila Franca de Xira (Estuário do Tejo). 1 - Grelha Norte (cobrindo o norte da lezíria sul de Vila Franca de Xira). 2 - Grelha Noroeste (cobrindo a área de Coruche). 3 - Grelha Sul (cobrindo a área de Benavente).

December, when Barn Owls frequent the area. Transects were driven at ~40 km/h, with stops to identify colour ringed owls, and started alternately at Ponta da Erva and Cardal gates (Fig. 2). Owls were surveyed in the first transect pass through the non-circular transect to avoid double-counting.

Ground radio-tracking

Between May 2009 and September 2012, 41 Barn Owl juveniles (34–58 d after hatching) were radio-marked with VHF Biotrack TW3 transmitters (~11g) attached by backpack mount. Owls were radio-marked in three areas (Fig. 1) based on the earlier colour-marking study as follows: BV area – 9, 2 and 5 owls in 2009, 2010 and 2012, respectively; CH – 6 owls in 2009 and 6 in 2010; SF – 6, 4 and 3 owls in 2010, 2011 and 2012, respectively. Owls were radio-tracked until January 2013 and visually relocated at their day roosts by homing or triangulation, and by triangulation when hunting outside the estuary. The presence of radio-marked owls was also noted during nocturnal car transects in SF (2009–2012).

Aerial radio-tracking

Aerial searches for lost radio-marked owls were conducted using two directional "H" (two-element) type RA-2A antennas (Telonics™) mounted on a Cessna 172 aircraft via TAB-1 brackets (www.telonics.com/literature/aircraft/). The antennas were connected to a TAC-2 switch system, which allowed directional relocation of radio-transmitter signals. Two radio operators recorded GPS coordinates associated with maximum signal intensity, and then ground searches to locate the transmitters were conducted the following days. Three sampling grids covered 40–70 km around the SF but excluded a prohibited area near the Lisbon airport (Fig.3). The detectability of known transmitters was confirmed and we aerially searched for a total of 12 hr from the Santa Cruz (Torres Vedras) aerodrome (20-22 January 2011).

Data analysis

The locations of unobserved radio-marked owls were estimated using bearings from at least two georeferenced points (LOAS 4.0 Ecological Software Solutions). Dispersal and other distances were calculated and maps created in Quantum GIS 1.8.0 Lisboa software.

Results

Preliminary mark-recapture study

In 2007 and 2008, six Barn Owls were visually identified (100 to 745 d after colour-marking) in SF car transects and confirmed that BV (15 km from SF) and CH (61 km from SF) were the source of some of the owls using the estuary during dispersal (Table 1).

Radio-tracking

On average, 40 radio-marked owls were tracked for 125 ± 124 d (range 0–555 d); one transmitter failed while the juvenile was near its nest. During the fledging phase, 15 transmitters were lost and 13 radio-marked juvenile owls died. A total of 551 relocations from 12 radio-marked juveniles were obtained during the post-fledging dispersal phase (mean ± SD: 50 ± 15) (Table 2). One of these owls was found dead immediately after dispersal. Most of the juvenile owls from CH (63%) were tracked during dispersal and most from BV (43%) died after fledging. None of the owls radio-marked in SF were tracked during dispersal and most (69.2%) were lost during fledging (Table 2).

Table 1 - Re-sightings of colour-marked Common Barn Owls during nocturnal car transects in the Tagus Estuary in 2007–2008, Portugal.
a) Identified by area-specific ring colour code.

Tabela 1 - Recapturas visuais de corujas-das-torres durante os transectos nocturnos no Estuário do Tejo em 2007–2008.

RING NO.	RINGING DATE	RECAPTURE DATE	ORIGIN	DISTANCE TO NEST (KM)	DIRECTION FROM NEST (DEGREES)	NO. DAYS
M27887	09/05/2007	23/10/2008	Coruche	61	106	745
M27728	21/05/2007	24/09/2007	Benavente	15	291	126
M27732	21/05/2007	03/09/2007	Benavente	15	291	105
M27743	21/05/2007	29/08/2007	Benavente	15	291	100
N/A a)	2007	29/08/2007	Benavente	NA	NA	NA
N/A a)	2008	17/09/2008	Benavente	NA	NA	NA

Table 2 - Origin, tracking period, reason for the end of tracking, and last location of 41 Common Barn Owls tracked in the Tagus Valley, Portugal, 2009–2012. Legend: D – death; EB – end of battery; LC – loss of contact; TF – tag failure; F – fledging; PD – post-fledging dispersal.
* Tags recovered and reused in the next year.

Tabela 2 - Origem, período de seguimento, motivo para o fim do seguimento e última localização de 41 corujas-das-torres seguidas no Vale do Tejo, Portugal, em 2009–2012. Legenda: D – morte; EB – fim da bateria; LC – perda de contacto; TF – falha do emissor; F – emancipação; PD – dispersão pós-natal.

ORIGIN	TAG	START DATE	END DATE	STATE	PHASE	LAST LOCATION
Coruche 1	1	21/05/2009	13/09/2009	D	PD	South floodplain, Vila Franca de Xira
Coruche 1	2	21/05/2009	19/11/2009	LC	PD	Adema, Benavente
Coruche 2	3	01/06/2009	28/09/2010	D	PD	Quinta Grande, Coruche
Coruche 2	4	01/06/2009	14/07/2009	LC	F	Nest, Coruche
Coruche 3	5	21/05/2009	21/05/2009	TF	F	Nest, Coruche
Coruche 3	6	21/05/2009	02/09/2009	LC	PD	Casal dos Apupos, Alcochete
Benavente 1	7	02/06/2009	21/07/2009	D	F	Catapereiro, Benavente
Benavente 1	8	02/06/2009	21/12/2009	LC	PD	Fatel, Vila Franca de Xira
Benavente 1	9	02/06/2009	09/12/2010	EB	PD	Atalaia, Montijo
Benavente 2	10	02/06/2009	30/07/2009	LC	F	Nest, Benavente
Benavente 2	11	02/06/2009	10/03/2010	LC	F	Carrasqueira, Benavente
Benavente 2	12	02/06/2009	03/09/2009	LC	F	Nest, Benavente

ORIGIN	TAG	START DATE	END DATE	STATE	PHASE	LAST LOCATION
Benavente 3	13	02/06/2009	14/12/2009	D	F	Nest surroundings, Benavente
Benavente 4	14	15/06/2009	31/05/2010	LC	PD	Margin of Sorraia river, Samora Correia
Benavente 4	15	15/06/2009	09/02/2010	D	PD	Adema, Benavente
Coruche 1	17	24/06/2010	19/04/2011	EB	PD	Cavaleiros, Coruche
Coruche 1	18	24/06/2010	11/08/2010	D	F	Montinhos, Coruche
Coruche 4	19	06/07/2010	31/01/2011	D	PD	Pancas, Benavente
Coruche 4	20	06/07/2010	22/01/2011	D	PD	Campelos, Bombarral
Coruche 4	21	24/06/2010	13/09/2010	LC	F	Nest, Coruche
Coruche 4	22	24/06/2010	11/11/2010	D	F	Nest, Coruche
V. Franca 1	23	30/07/2010	21/09/2010	LC	F	Porto Alto, Benavente
V. Franca 1	24	30/07/2010	21/09/2010	LC	F	South floodplain, Vila Franca de Xira
V. Franca 1	25	30/07/2010	22/09/2010	D	F	South floodplain, Vila Franca de Xira
V. Franca 1	26	30/07/2010	11/01/2011	LC	F	Margin of Sorraia river, Samora Correia
V. Franca 1	27	30/07/2010	21/09/2010	LC	F	South floodplain, Vila Franca de Xira
V. Franca 1	28	30/07/2010	21/09/2010	LC	F	Nest, Vila Franca de Xira
Benavente 2	29*	16/08/2010	17/09/2010	D	F	Nest, Benavente
Benavente 2	30*	16/08/2010	07/09/2010	D	F	Nest, Benavente
V. Franca 2	29	20/06/2011	28/08/2011	LC	F	Nest, Vila Franca de Xira
V. Franca 2	30	20/06/2011	25/07/2011	LC	F	Nest, Vila Franca de Xira
V. Franca 2	31	20/06/2011	24/08/2011	LC	F	Nest, Vila Franca de Xira
V. Franca 2	32	20/06/2011	17/08/2011	D	F	Nest, Vila Franca de Xira
Benavente 5	33	01/08/2012	03/12/2012	D	PD	Adema, Benavente
Benavente 5	34	27/07/2012	28/09/2012	D	F	Poceirão - Fonte Lobo, Benavente
Benavente 5	35	01/08/2012	17/09/2012	D	F	Poceirão - Fonte Lobo, Benavente
Benavente 6	36	01/08/2012	16/08/2012	LC	F	Cabeço do Aranha, Benavente
Benavente 6	37	01/08/2012	20/09/2012	D	F	Cabeço do Aranha, Benavente
V. Franca 2	38	10/09/2012	10/09/2012	LC	F	South floodplain, Vila Franca de Xira
V. Franca 2	39	12/10/2012	25/01/2013	D	F	South floodplain, Vila Franca de Xira
V. Franca 2	40	10/09/2012	11/10/2012	D	F	South floodplain, Vila Franca de Xira

Table 3 - Dispersal distances moved by 11 Common Barn Owls in the first 120 days after fledging in the Tagus Valley, 2009-2013, Portugal.

Tabela 3 - Distâncias de dispersão percorridas por 11 juvenis de coruja-das-torres nos primeiros 120 dias após a emancipação no Vale do Tejo, entre 2009 e 2013.

DAYS AFTER FLEDGING	MEDIAN DISTANCE (RANGE)	AVERAGE DISTANCE (± SD)
7	784.0 (84.6–3 876.5)	1,143.7 ± 1,224.8
14	909.3 (120.2–19 267.1)	2,816,7 ± 5,585,7
30	3,363.6 (565.5–18,890.8)	6,978.2 ± 6,588.2
60	20,029.3 (4,013.3–38,516.7)	20,393.9 ± 11,551.7
90	18,666.4 (4,020.7–38,516.7)	19,938.0 ± 12,434.0
120	20,057.3 (4,323.5–38,516.7)	21,042.6 ± 12,384.8

Movement patterns

Juvenile Barn Owls dispersed between June and August; most in June (58.3%) and July (25%), when they were on average nine weeks old (range 6–11 weeks). Dispersing owls used successive temporary settlement areas (TSA) and roosted by day in one or more nearby roosts. TSA distance from nests increased in the first two months post-fledging but this decreased in the next month (Table 3). At the end of radio-tracking, the average distance (nest to post-dispersal area) moved by the owls was 20.7 ± 11.8 km (mean ± SD; median 19.9, range 3.86–38.5). Owls remained in a TSA from 3-166 d (mean ± SD 51.3 ± 48.5; median 35) and got successively closer to SF: four from CH (Fig. 4) and two from BV (Fig. 5). Two owls from CH remained in their nest areas (Fig. 4), and three owls from BV (Fig. 5) were in TSAs equidistant to SF. Average dispersal direction in the first (and longest) movement of owls from BV was NNE (327.6° ± 16.7°) and from CH was W (270.2° ± 43.1°). The two owls from CH that remained in their nest areas dispersed to the N and SW. Therefore, most (82%) of the radio-tracked owls dispersed in the direction of and/or to the Tagus Estuary.

Lost and found

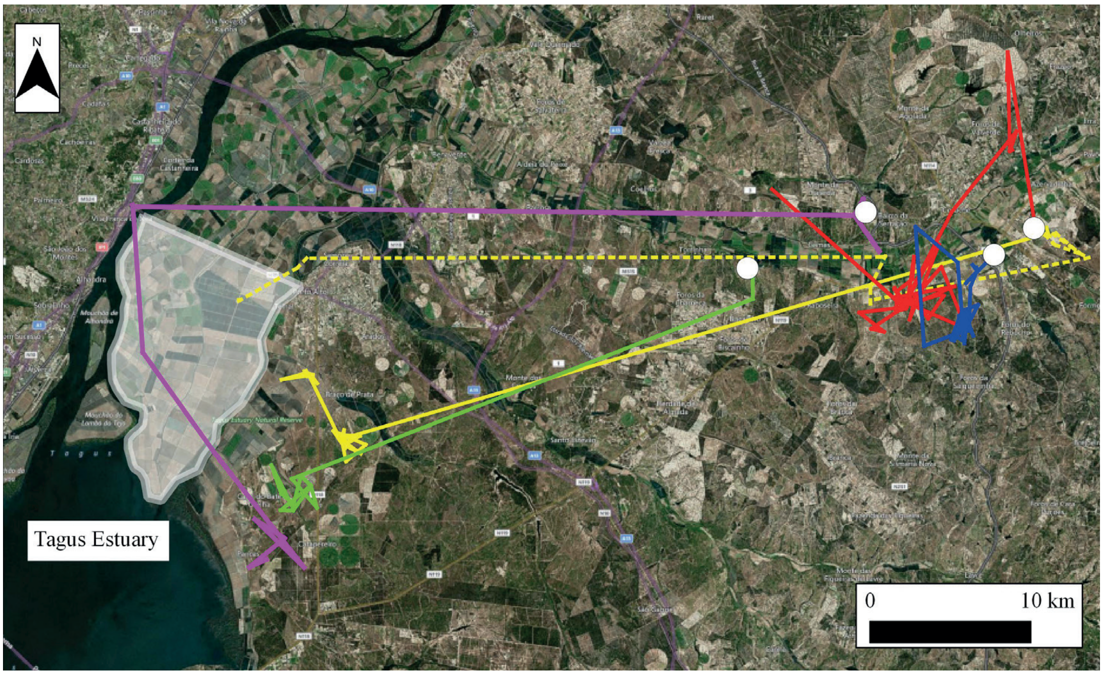
Only two lost radio-marked owls were relocated by aerial radio-tracking; one was located dead on a road ~60 km NW of its nest, while the lost transmitter of the other owl was found in an area 40 km SW from its nest. The first had never been detected in the Tagus Valley, and most likely had flown over Montejunto Mountain to reach its position. The latter was transmitting a signal ranging only ~50 m and therefore it could not be detected during regular ground searches.

Roosting sites during dispersal

The habitats and roosting sites most used during dispersal were mixed cork oak and pine stands (28.9%) and isolated trees (26.9%), followed by cork oak woodlands

Figure 4 - Post-fledging dispersal roost locations of six Common Barn Owls from nests located in Coruche (20–40 km from the south floodplain of Vila Franca de Xira), 2009-2010, Portugal. Lines uniting locations are to assist reading and do not represent owl movements. Same colour represents owls from the same brood. White circles – nest sites. White shaded area – south floodplain of Vila Franca de Xira.

Figura 4 - Localização dos poisos diurnos de seis corujas-das-torres provenientes de ninhos localizados em Coruche (20–40 km da lezíria sul de Vila Franca de Xira) durante a dispersão pós-natal em 2009 e 2010. As linhas que unem as localizações servem para facilitar a leitura e não representam os movimentos das corujas. Linhas da mesma cor representam corujas da mesma ninhada. Círculos brancos - locais de nidificação. Zona sombreada a branco – lezíria sul de Vila Franca de Xira.



(12.9%), tree rows (8.7%), pine stands (8.2%), riparian galleries (3.5%), buildings (3.1%) and urban gardens (3.1%). Individual owls demonstrated considerable variation in roost site preferences.

Distances between roosting sites and hunting areas

Five fledged owls tagged at nests in the SF roosted 0.82–8.6 km from their hunting areas. One owl from BV also hunted in SF while roosting 4.9–11.7 km away. Another individual from CH hunted in SF but returned to its nest the next day, documenting that juveniles can carry out exploratory flights up to 30 km prior to dispersal.

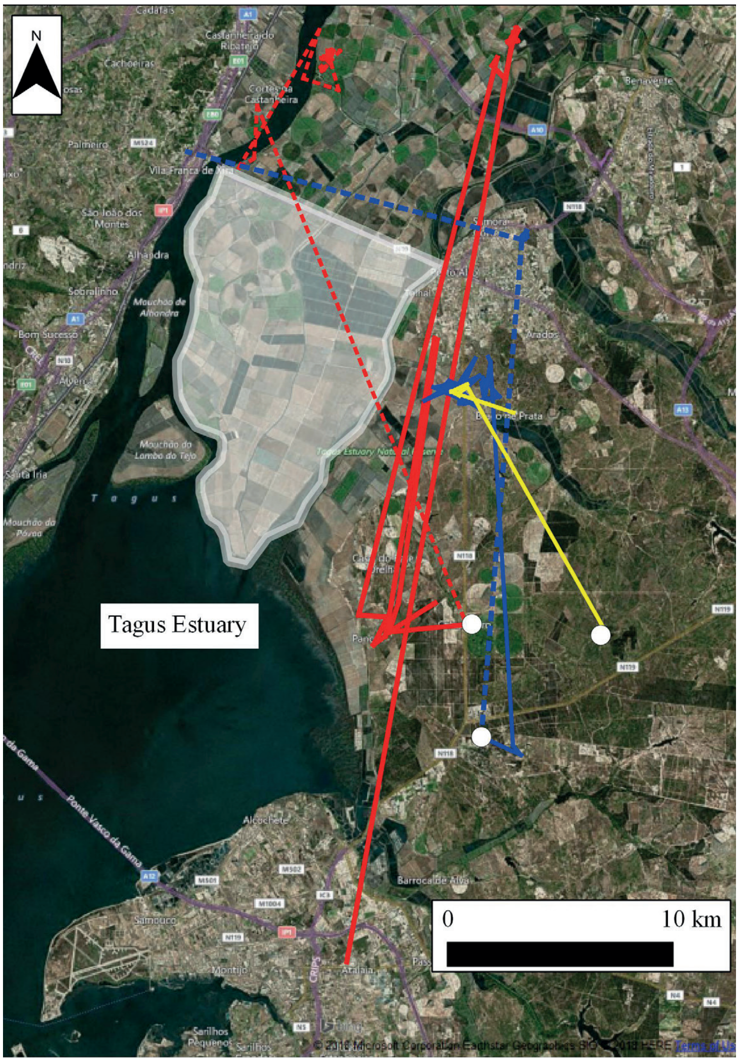
Five out of 11 dispersing owls roosted in the floodplains of Vila Franca de Xira; two from CH and three from BV (two of the latter were also detected hunting in the estuary). Other distances between roosts and hunting areas were 0.36–2.9 km in CH and 1.6–2.0 km near Montijo (Fig. 1).

Survival and causes of mortality

Of 41 radio-marked owls, 19 were lost, one transmitter failed (prior to fledging), and 19 died; of the latter, 12 died while fledging and six died during dispersal (Table 2). On average, the owls that died during fledging were 104 ± 40.8 d old (mean ± SD; range 56–192 d; n = 10); and the owls that died during dispersal were 205 ± 49.7 d old (range 160–250; n = 4). Two owls that survived until the transmitter battery expired were 351 and 602 d old. Causes of mortality included vehicle collision, possible predation, shooting and starvation; when carcasses were found partly eaten, it is possible they were scavenged after the owl had died from other causes.

Figure 5 - Post-fledging dispersal roost locations of five Common Barn Owls from nests located in Benavente (10–20 km from the south floodplain of Vila Franca de Xira), 2009–2012, Portugal. Lines uniting locations are to assist reading and do not represent owl movements. Same colour represents owls from the same brood. White circles – nest sites. White shaded area – south floodplain of Vila Franca de Xira.

Figura 5 - Localização dos poisos diurnos de cinco corujas-das-torres provenientes de ninhos localizados em Benavente (10–20 km da lezíria sul de Vila Franca de Xira) durante a dispersão pós-natal, em 2009 e 2010. As linhas que unem as localizações servem para facilitar a leitura e não representam os movimentos das corujas. Linhas da mesma cor representam corujas da mesma ninhada. Círculos brancos - locais de nidificação. Zona sombreada a branco – lezíria sul de Vila Franca de Xira.



Discussion

The Tagus Estuary as a temporary settlement area

The observed convergence of post-fledging dispersing juvenile Barn Owls from different areas to the Tagus Estuary confirms its importance as a TSA. The use of TSAs as a survival strategy is common in raptors (Delgado et al. 2009, Mellone et al. 2011, Prommer et al. 2012) and familiarizes them with regional habitats (Stamps and Krishnan 1999). The Tagus Estuary is used by several other raptor species during the non-breeding period including the Common Kestrel (*Falco tinnunculus*), Osprey (*Pandion haliaetus*), Eurasian Buzzard (*Buteo buteo*), and Black-winged Kite (*Elanus caeruleus*; Lourenço et al. 2018). The Eurasian Buzzard also is likely to use the estuary as a TSA, since its abundance increases when juveniles disperse. The SF is also an important wintering area for the Short-eared Owl (*Asio flammeus*), where it reaches its highest densities in Portugal (Catry et al. 2010).

The selection of TSAs by raptors can be based on habitat preferences (Balbontín 2005), prey availability, predator avoidance, and/or landscape composition (Ontiveros et al. 2005, Palma et al. 2006, Cadahía et al. 2010). The SF is open, low farmland with seasonal habitat variation such as rice fields with flood-drought phases and pastures with grazing rotation. While a small number of Barn Owls nest in the SF, more owls are counted there in the non-breeding season (I. Roque, unpublished data). They are seen hunting while perched on fence posts along dirt roads and ditches bordered by dense vegetation, or when flying or hovering along the roadsides, and in grazed pastures. Owls are more often seen in rice fields in autumn, when these are dry and harvested, possibly because fallen seeds attract large numbers of prey (Tomé and Valkama 2001). The percentage of small mammals trapped in rice fields in autumn was 32.5% higher than in pastures with cattle grazing rotation (H. Vale Gonçalves, unpublished data). It is possible that cattle grazing concentrated small mammal prey in the vegetation margins along ditches and roadsides (Santos et al. 2007, Sabino-Marques and Mira 2011, Ruiz-Capillas et al. 2013), which could explain the use of these marginal habitats by Barn Owls in the Tagus Estuary and its value in sustaining this population of owls.

Movement patterns

The Barn Owl post-fledging dispersal in Portugal starts earlier (June–August) than in northern populations (UK: August–September, Barn Owl Trust 2012; Netherlands: September–November, de Bruijn 1994), consistent with latitudinal climate variation. Post-fledging dispersal distance in the Iberian population (this study) appears to be intermediate between the British and central-European populations. Recovery distance of Barn Owls in Spain was 13.9 km (geometric mean, Martínez and López 1994) whereas the median ring recovery distance of juvenile Barn Owls was 7.5 km in the UK (Wernham et al. 2002), while in Germany, 40% of the Barn Owls were recovered at distances over 50 km from their nests (Bairlien 1985).

One of our Barn Owls was recovered as a roadkill ~60 km away from the nest 200 d after fledging and had flown over Montejunto Mountain (543 m asl, Fig. 1). Another owl flew at least 30 km from CH to SF and back in one night before starting dispersal. The Barn Owl often flies over hills rather than following valleys, disregarding favourable hunting grounds (Barn Owl Trust 2012). Random movements during exploratory flights are described in other owl species, and probably are the best strategy to cover larger areas while learning new surroundings, when the birds are still developing their flight and other abilities (Delgado et al. 2009). In raptors, floaters wander over large areas prospecting vacant territories and gathering information on habitat quality for future settlement (Tanferna et al. 2013, Whitfield et al. 2009). Most (82%) of the tracked owls approached and/or used the Tagus Estuary during dispersal; therefore, it is likely that there are strong ecological factors leading the Barn Owl to the area. Seven TSAs were used at some point by two or more owls with different geographical origins and in different years: three patches of riparian vegetation (in CH, BV, and Vila Franca de Xira), three areas of cork oak forest (one in CH and two in BV), and the floodplain of the Tagus Estuary. Further examination of individual dispersal patterns is needed to understand what ecological factors might be driving different owls to these TSAs in the Tagus Valley.

Roosting sites and hunting areas during dispersal

Dispersing juvenile Barn Owls generally used habitats in proportion to their availability in the study area and this varied by location. Forest habitats, especially Mediterranean woodlands, were mainly used by owls >20 km from the Tagus estuary. In contrast, owls used a higher diversity of roosting sites and habitats in and within 20 km of the open agricultural fields and farmland of the floodplains of the Tagus and Sorraia Rivers. Isolated trees and tree rows consistently were used for roosting throughout the study area. The use of trees by the Barn Owl as day-time roosts during post-fledging dispersal was also noted by Seel et al. (1983). Owls hunting in the Tagus Estuary had to move further between their roosts and foraging areas (up to 11.7 km) than owls hunting in other areas (up to 2.9 km) due to the scarcity of roost sites in open farmland and in adjacent dense human settlements near Lisbon.

Survival and causes of mortality

Two of eight radio-marked owls whose signals were lost were relocated through aerial radio-tracking and confirmed dead. The fate of the remaining six was unknown and they may have dispersed further. Hence, between 7.3% and 43.9% of the owls survived the post-fledging dispersal period. These estimates were more extreme than the range of values previously reported for juvenile Barn Owl (15–35%; Sauter 1956; Bairlein 1985; De Bruijn 1994; Taylor 1994; Altwegg et al. 2009). The lower estimate may explain the negative short-term population trend of the species in Portugal (Lourenço et al. 2015), and negative short- and long-term trends in Spain and in other European countries (Hagemeijer and Blair 1997, Martí and Del Moral 2003, BirdLife International 2004a,b, SEO/ BirdLife 2013). These trends have been attributed to mortality related to land-use changes such as expanding road networks (Ramsden 2003, Gomes et al. 2009, Hindmarch et al. 2012).

Mortality from vehicle collisions was common in our study area and in Spain (Martínez and López 1994). Extensive roads and intense traffic near the Tagus Estuary resulted in high post-fledging mortality in September; up to 1.13 owls/km per road transect (I. Roque, unpublished data). In southern Portugal, road mortality estimates were reported to be 0.49 owl/km/year (Silva et al. 2008, Gomes et al. 2009). Overall, road mortality estimates for Barn Owls are among the highest for raptors, ranging between 0.07 and 2.61 owls/km/year (Illner 1992; Boves and Belthoff 2012).

Conclusions

The Tagus Estuary is a key TSA for the Barn Owl due to high prey availability, but its role in sustaining this species is not fully understood. The convergence of Barn Owls to the SF, and their use of other TSAs, suggests post-fledging dispersal movements in our study area were non-random. Mortality during the post-fledging dispersal period was higher in and near the Tagus Estuary since owls had longer foraging flights while hunting there than in other TSAs. The impact of, and mitigation measures to counter road mortality should be examined and developed along with examining other mortality factors (e.g., power lines, land-use, pesticides, predation). Radio-tracking raptors during the post-fledging dispersal is challenging due to their ability to move long distances quickly resulting in signal loss prior to their first breeding efforts. The use GPS-GSM telemetry with longer battery life (~1 year), reduced weight, greater range for tracking location, and practical data recovery would address these issues and provide more reliable data and dispersal and survival estimates. These estimates are needed to determine if this population is a source or a sink population, and to develop and assess effective mortality mitigation measures to sustain this population of the Barn Owl.

Acknowledgments

Fieldwork was partly supported by INTERREG IIIC – South 2005–2007 under the project RIPIDURABLE, by QREN/INALENTEJO 2007–2013 under the project ECOMEDBIRDS and by Companhia das Lezírias, S.A. through a Business & Biodiversity Protocol with the University of Évora, under the project TytoTagus. The aerial telemetry equipment was provided by ICNF – Instituto da Conservação da Natureza e das Florestas. IR was supported by a doctoral Grant (SFRH/ BD/72163/2010), and RL by a post-doctoral Grant (BPD/78241/2011) from FCT – Fundação para a Ciência e a Tecnologia. Thank to James Duncan, David H. Johnson and Steve Sheffield for reviewing the manuscript.

References

Altwegg, R., Roulin, A., Kestenholz, M. & Jenni, L. 2009. Variation and covariation in survival, dispersal, and size in barn owls *Tyto alba* population. Journal of Animal Ecology 72: 391–399.

Arnold, E.M., Hanser, S.E., Regan, T. et al. 2018. Spatial, road geometric, and biotic factors associated with Common Barn Owl mortality along an interstate highway. Ibis doi: 10.1111/ibi.12593

Bairlien, F. von. 1985. [Dismigration and mortality in ringed Barn Owls (*Tyto alba*) in southern Germany]. Vogelwarte 33: 81-108. In German.

Balbontín, J. 2005. Identifying suitable habitat for dispersal in Bonelli's eagle: an important issue in halting its decline in Europe. Biological Conservation 126: 74-83.

Barn Owl Trust. 2012. Barn Owl Conservation Handbook: a comprehensive guide for ecologists, surveyors, land managers and ornithologists. Pelagic Publishing, Exeter.

BirdLife International. 2004*a*. Birds in Europe: population estimates, trends and conservation status. BirdLife International, Wageningen.

BirdLife International. 2004*b*. Birds in the European Union: a status assessment. BirdLife International, Wageningen.

Boves, T.J. & Belthoff, J.R. 2012. Roadway mortality of barn owls in Idaho, USA. Journal of Wildlife Management 76: 1381–1392.

Bunn, D.S., Warburton, A.D. & Wilson, R.D.S. 1982. The Barn Owl. T & AD Poyser, Calton.

Cadahía, L., López-López, P., Urios, V. & Negro, J.J. 2010. Satellite telemetry reveals individual variation in juvenile Bonelli's eagle dispersal areas. European Journal of Wildlife Research 56: 923-930.

Catry, P., H. Costa, G. Elias & R. Matias. 2010. Aves de Portugal. Ornitologia do território continental. Assírio & Alvim, Lisbon.

de Bruijn, O. 1994. Population ecology and conservation of the Barn Owl *Tyto alba* in farmland habitats in Liemers and Achterhoek (The Netherlands). Ardea 82: 1–109.

Delgado, M.D.M., Penteriani, V. & Nams, V.O. 2009. How fledglings explore surroundings from fledging to dispersal. A case study with Eagle Owls *Bubo bubo*. Ardea 97: 7-15.

Fasciolo, A., Delgado, M.M., Cortés, G., Soutullo, A. & Penteriani, V. 2016. Limited prospecting behaviour of juvenile Eagle Owls *Bubo bubo* during natal dispersal: implications for conservation. Bird Study 63: 128-135.

Ferrer, M. & Harte, M. 1997. Habitat selection by immature Spanish imperial eagles during the dispersal period. Journal of Applied Ecology 34: 1359-1364.

Gomes, L., Grilo, C., Silva, C. & Mira, A. 2009. Identification methods and deterministic factors of owl roadkill hotspot locations in Mediterranean landscapes. Ecological Research 24: 355-370.

Hagemeijer, W.J.M. & Blair, M.J. (eds). 1997. The EBCC atlas of European breeding birds: their distribution and abundance. T. & A.D. Poyser, London.

Heath, M.F. & Evans, M. (eds). 2000. Important Bird Areas in Europe: priorities for conservation. BirdLife Conservation Series No. 8, BirdLife International, Cambridge.

Hindmarch, S., Elliot, J.E., Mccan, S. & Levesque, P. 2017. Habitat use by Common Barn Owls across a rural to urban gradient and an assessment of stressors including, habitat loss, rodenticide exposure and road mortality. Landscape and Urban Planning 164: 132-143.

Hindmarch, S., Krebs, E.A., Elliott, J.E. & Green, D.J. 2012. Do landscape features predict the presence of barn owls in a changing agricultural landscape? Landscape and Urban Planning 107: 255-262.

Illner, H. 1992. Road deaths of Westphalian owls: methodological problems, influence of road type and possible effects on population levels. In: Galbraith, C.A., Taylor, I.R. & Percival, S. (eds) Proceedings of the Ecology and Conservation of European Owls Symposium. Joint Nature Conservation Committee, Peterborough, pp. 94-100.

Kross, S.M., Bourbour, R.P. & Martinico, B. 2016. Agricultural land use, Common Barn Owl diet, and vertebrate pest control implications. Agriculture, Ecosystem and Environment 223: 167-174.

Lourenço, R., Roque, I., Tomé, R., et al. 2015. Current status and distribution of nocturnal birds (Strigiformes and Caprimulgiformes) in Portugal. AIRO 23:36-50.

Lourenço, P.M. 2009. Rice field use by raptors in two Portuguese wetlands. AIRO 19:13-18.

Lourenço, P.M., Alonso, H., Alves, J.A. et al. 2018. Monitoring waterbird populations in the Tejo estuary, Portugal: report for the decade 2007-2016. AIRO 25:3-31.

Martí, R. & J.C. Del Moral (eds). 2003. Atlas de las aves reproductoras de España.

Dirección General de Conservación de la Naturaleza-Sociedad Española de Ornitología, Madrid.

Martínez, J.A. & López, G. 1994. Dispersal and causes of mortality of the Barn Owl (*Tyto alba*) in Spain. Ardeola 42: 29-37.

McPeek, M.A. & Holt, R.D. 1992. The evolution of dispersal in spatially and temporally varying environments. American Naturalist 140: 1010-1027.

Mellone ,U., Yáñez, B., Limiñana, R., Muñoz, A.R. et al. 2011. Summer staging areas of non-breeding Short-toed Snake Eagles *Circaetus gallicus*. Bird Study 58: 516-521.

Ontiveros, D., Pleguezuelos, J.M. & Caro, J. 2005. Prey density, prey detectability and food habits: the case of Bonelli's eagle and the conservation measures. Biological Conservation 123: 19-25.

Palma, L., Beja ,P., Pais, M. & Cancela Da Fonseca, L. 2006. Why do raptors take domestic prey? The case of Bonelli's eagles and pigeons. Journal of Applied Ecology 43: 1075-1086.

Prommer, M., Bagyura, J., Chavko, J. & Uhrin, M. 2012. Migratory movements of central and eastern European Saker Falcons (*Falco cherrug*) from juvenile dispersal to adulthood. Aquila 119: 111-134.

Pulliam, H.R. 1988. Sources, sinks, and population regulation. American Naturalist 132: 652-661.

Ramsden, D.J. 2003. Barn Owls and major roads: results and recommendations from a 15-year research project. The Barn Owl Trust, Somerset.

Roque, I. 2003. A população de coruja-das-torres *Tyto alba* (Scopoli 1769) no concelho de Coruche: abundância e distribuição, selecção de habitat, biologia de reprodução, alimentação e mortalidade. Unpublished Report, Universidade de Évora, Évora.

Roque, I., Lourenço, R., Marques, A. et al. 2016. Barn owl feathers as biomonitors of mercury: sources of variation in sampling procedures. Ecotoxicology 25: 469-480.

Roque, I., & R. Tomé 2004. Estimativa populacional e selecção de habitat pela coruja-das-torres *Tyto alba* no concelho de Coruche (Santarém, Portugal). AIRO 14: 11-19.

Roulin, A. 2002. Barn Owl. BWP Update 4: 115-138.

Ruiz-Capillas, P., Mata, C. & Malo, J.E. 2013. Road verges are refuges for small mammal populations in extensively managed Mediterranean landscapes. Biological Conservation 158: 223-229.

Sabino-Marques, H. & Mira, A. 2011. Living on the verge: are roads a more suitable refuge for small mammals than streams in Mediterranean pastureland? Ecological Research 26: 277-287.

Santos, S.M., Mathias, M.L., Mira, A. & Simões, P. 2007. Vegetation srtucture and composition of road verge and meadow sites colonized by Cabrera vole (*Microtus cabrerae* Thomas). Polish Journal of Ecology 55(3): 481-493.

Saurola, P. 2002. Natal dispersal distances in Finnish owls. In: Newton, I. Kavanagh, R., Olsen, J. & Taylor, I. (eds). Ecology and Conservation of Owls. CSIRO Publishing, Collingwood, pp 42-55.

Sauter, U. 1956. [Contributions to the ecology of barn owl (*Tyto alba*) through ring recoveries]. Vogelwarte 18: 109-151. *In German.*

Seel, D.C., Thomson, A.G. & Turner, J.C.E. 1983. Distribution and breeding of the barn owl *Tyto alba* on Anglesey, North Wales. (Bangor Occasional Paper No.16) Institute of Terrestrial Ecology, Bangor, 19pp.

SEO/BirdLife. 2013. Resultados del programa Noctua 2006-2013. SEO/BirdLife, Madrid.

Sheffield, S.R. 1997. Owls as biomonitors of environmental contamination. Pp. 383-398, in Proceedings of the 2nd International Symposium on Biology and Conservation of Owls of the Northern Hemisphere. USDA Forest Service, Northcentral Forest Experimental Station, GTRNC-190, 635 pp.

Silva, C., Grilo, C. & Mira, A., 2008. Modelling owl mortality on roads of Alentejo (southern Portugal). AIRO 18: 3-12.

Stamps J.A. & Krishnan, V.V. 1999. A learning-based model of territory establishment. Quarterly Review of Biology 74: 291-318.

Tanferna, A., López-Jiménez, L., Blas, J. et al. 2013. Habitat selection by black kite breeders and floaters: Implications for conservation management of raptor floaters. Biological Conservation 160: 1-9.

Taylor, I.R. 1994. Barn Owls: predator-prey relationships. Cambridge University Press, Cambridge.

Tomé, R. 1994. A coruja-das-torres (*Tyto alba* Scopoli, 1769) no estuário do Tejo: fenologia, dinâmica populacional, utilização do espaço e ecologia trófica. Unpublished Report, Faculdade de Ciências da Universidade de Lisboa, Lisbon.

Tomé, R. & Valkama, J. 2001. Seasonal variation in the abundance and habitat use of Barn Owls *Tyto alba* on lowland farmland. Ornis Fennica 78: 109-118.

van der Hut, R.M.G., de Jong, J. & Osieck, E.R. 1992. [Biology and conservation of the Barn Owl *Tyto alba*: towards a conservation plan.] Technical Report No. 7, Netherlands Society for Protection of Birds, Zeist.

Wernham, C.V., Toms, M.P., Marchant, J.H. et al. 2002. The migration atlas: movements of the birds of Britain and Ireland. T. & A.D. Poyser, London.

Whitfield, D.P., Duffy, K., McLeod, D.R.A. et al. 2009. Juvenile dispersal of White-tailed Eagles in western Scotland. Journal of Raptor Research 43: 110-120.