BTO RESEARCH REPORT 692

Informing best practice for mitigation and enhancement measures for Barn Owls

A report by the British Trust for Ornithology to High Speed Two Ltd

Henrietta Pringle, Gavin Siriwardena and Mike Toms

BTO
Looking out for birds

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SUMMARY

1. The introduction of the High Speed Two (HS2) rail line represents a national-level impact on Barn Owls and appropriate measures have been identified as required to minimise and to mitigate the mortality risk. Examining patterns of Barn Owl movement, and any influences upon, them can help to determine where such measures should be placed, in order to ensure that measures do not have unintended negative effects, for example by attracting birds to the vicinity of the railway line.

2. The BTO's ring-recovery database was used to analyse dispersal movements, with the aim of providing insight into national and, where possible, regional patterns in Barn Owl movements within the UK.

3. Adult birds dispersed an average of 2.2 km between breeding sites, and 2.8 km throughout the rest of the year. Chicks dispersed further, making the bulk of their movements in the first few months after ringing, with evidence of initial forays further afield before settling closer to the natal site, an average of 7.8 km away.

4. Further examination of dispersal distances indicated differences between the sexes, with female chicks dispersing further than males (although there was no difference for adults). In some instances, dispersal distance varied between regions; birds in the north west tended to disperse further than those in the south east. This pattern was not consistent across dispersal types, but it does show the potential influences of regional conditions.

5. Dispersal distance appeared to be influenced by nearby habitat, with birds moving further through better quality habitat and to circumnavigate barriers, while habitats offering fewer resources tended to restrict movements.

6. The results suggest that new, high-quality habitat aimed at mitigating negative effects of HS2 on Barn Owls should be located between 3 km and 15 km away from the railway route, depending on the importance placed on minimizing juvenile, as opposed to adult, mortality. Further, introducing barrier habitats may not be effective at restricting movements. Instead, locating poor quality foraging habitat near the railway line (or removing high-quality habitat) could help to minimise train strikes by restricting movements. However, this conclusion must be applied with caution because the results involved considered habitat only at large spatial scales. Nominally unsuitable habitat, such as intensive farmland, may actually include significant fine-scale habitat features that attract Barn Owls.

2. INTRODUCTION

Barn Owl, by Alan Price/BTO

The HS2 Environmental Statement identifies a national-level impact on Barn Owls *Tyto alba* due to train strike; in response, High Speed Two (HS2) Ltd have committed to developing a Barn Owl Action Plan in consultation with a range of organisations. The Action Plan will identify measures to mitigate mortality risk and provide areas of habitat enhanced for Barn Owls.

To ensure that mitigation and habitat enhancement measures are located so that they do not create a new, additional risk by attracting birds to the vicinity of the railway route, it is important to understand the patterns of movement that the birds are likely to follow. Mitigation and enhancement measures may then be placed in optimum locations with respect to distance from the railway, minimizing mortality risks and with the potential to enhance the population within the wider landscape – although this is dependent on the nature and location of the planned enhancement measures with respect to existing Barn Owl populations. The evidence that is critical to support this decision-making process centres around the dispersal and settlement patterns of Barn Owls and this study investigates these issues using the best available evidence.

2.1. BARN OWL HABITAT PREFERENCES

The Barn Owl has a wide breeding distribution within Britain and Ireland, with pairs breeding as far north as Caithness and Sutherland (Balmer *et al.* 2013). Maps of breeding abundance produced for *Bird Atlas 2007–11* (Balmer *et al*. 2013) suggest that the Barn Owl is more abundant in eastern England than elsewhere; however, it is worth noting that the species appears to show higher levels of diurnal activity within this region compared with elsewhere in the UK, which may lead to overestimation of breeding population size (Palmer 2013). Barn Owl distribution within the UK is limited by altitude, climatic conditions and the availability of suitable breeding habitat (Shawyer, 1987, Dadam *et al*. 2011).

Although breeding Barn Owls occupy a range of different 'open-country' and woodland edge habitats, they favour areas with rough grassland and a well-developed sward structure. Young conifer plantations, unimproved grassland and arable landscapes with linear strips of tussocky grassland (such as those present alongside hedgerows or ditches) provide suitable hunting opportunities, supporting the populations of voles, mice and shrews on which these birds depend. Vole densities are negatively related to grazing intensity and the increased stocking levels seen on modern pastures are likely to have greatly reduced their suitability for hunting Barn Owls (Schmidt *et al*. 2005).

Significant emphasis has been placed on the importance of rough grassland, with its Field Vole *Microtus agrestis* populations, for hunting Barn Owls, leading to the suggestion that pairs need at least 40 ha of unimproved grassland within their foraging range in order to breed successfully (Shawyer & Shawyer, 1995). However, many successful Barn Owl nest sites are located in areas without this amount of rough grassland, underlining that the species can make use of secondary prey species (such as Wood Mouse *Apodemus sylvaticus* or Common Shrew *Sorex araneus*), more common in other habitats. Wood Mouse is of particular importance to those pairs nesting within the intensive arable landscapes of the Fens.

While several local studies (Bond *et al*. 2005; Meek *et al*. 2009) have failed to find any influence of the amount of rough grassland available on breeding success, a nationwide study (Leech *et al.* 2009; Dadam *et al.* 2011) found that nest boxes located within grassland areas had a higher degree of occupancy, a greater proportion of pairs attempting breeding, and had females that were heavier than those associated with farmland or improved pasture habitats. This national study also revealed that pairs breeding in arable areas laid small clutches and produced smaller broods than in grassland areas. This suggests that rough grassland is important for breeding Barn Owls, seemingly supporting higher densities of favoured prey.

The habitat preferences seen within the breeding season may also influence the way in which birds move through a landscape. Home ranges are likely to be smaller in areas with a greater proportion of favoured hunting habitat, with birds moving shorter distances; movement patterns will also be influenced by the spatial arrangement of favoured habitats within the home range, something that will also influence dispersal behaviour (see below) at a wider spatial scale.

The findings of Leech *et al.* 2009 and Dadam *et al*. 2011 suggest a basis for defining habitat categories based on their suitability for Barn Owls, with, for example, urban, woodland and mountain land cover classes defined as barriers to Barn Owl movements and semi-natural grassland and fen defined as suitable (see Table 2).

2.2. BARN OWL BREEDING ECOLOGY

In addition to suitable hunting habitat, Barn Owls also require access to a nesting cavity, often a hollow cavity in a mature deciduous tree, a ledge within a farm building or, increasingly, a nest box erected specifically for the species. Barn Owls do not defend breeding territories in the strict sense but do defend the area immediately around the nest site and do have home ranges within which activity is concentrated. Taylor (1994) and the Barn Owl Trust (2012) put the size of these home ranges at 313.4 ha and 550 ha within mixed farmland in Scotland and England respectively. Radio-tracking studies by Cayford (1992) and Taylor (1994) show that Barn Owl home ranges may overlap extensively.

Barn Owls have been recorded breeding in every month of the year within the UK but the core season, as identified by BTO Nest Record Scheme data, runs from April through to the end of October. The proportion of pairs initiating breeding is influenced by weather conditions and prey availability over the preceding winter and both clutch and brood sizes are lower following colder and wetter winters (Dadam *et al.* 2011). The average date for the first egg being laid has become earlier, shifting by roughly half a day per year between 2002 and 2007 (*Leech et al.* 2008), a response to a changing climate.

Activity becomes increasingly concentrated around the breeding site during the early stages of the breeding season, with an associated reduction in the size of the hunting range, and the pair spends increasing amounts of time together. Eggs are typically laid at two to three day intervals and, since incubation is initiated with the first egg, hatching occurs over a protracted period some 30–34 days later. Average clutch size is 4–6 eggs and breeding pairs may begin a second breeding attempt if feeding conditions are favourable. Chicks fledge on average between 53 to 61 days after hatching and initially spend time exploring their local surroundings before initiating dispersal proper.

2.3. BARN OWL MOVEMENT PATTERNS

The national ring-recovery database holds data on every bird ringed under the UK and Ireland bird Ringing Scheme since the early 20th century. The Scheme is supported by an independent Ringing Committee and a number of technical subcommittees, which oversee the development of the Scheme and ensure that all activities are conducted to high scientific and welfare standards. This dataset had been used extensively to monitor survival, dispersal and settlement patterns (e.g. Paradis *et al*. 1998, 1999; Baillie *et al.* 2004; Thorup *et al.* 2014), and was used to produce the *Migration Atlas* in 2002 (Wernham *et al.* 2002), which presented analyses of the migration and dispersal patterns of 192 species regularly occurring in Britain, including Barn Owl. In recent years, a growth in the online submission of ringing data has led to fast-growing computerized data sets for many species and consequent increases in the number of analyses that are possible. These data provide a unique resource to inform about bird movements and how they are related to landscape and habitat.

Barn Owls in the UK are non-migratory, meaning that that they remain in restricted areas throughout their lives. The size of this home range is therefore a critical factor in determining how far the 'footprint' of the HS2 route extends in respect of risk to the species. However, Barn Owl movements, in common with those of other bird species, are more complex than this because (i) home ranges may be different in winter and summer, even if there is no directional migratory movement, and (ii) specific behavioural processes are likely to have particular associated movement patterns. Particularly noteworthy in respect of the latter are the dispersal movements of juveniles from their natal area to where they settle to breed and dispersal of adults from breeding sites in one year to those in the next. Natal dispersal often sees the longest movements that birds make in their lives, in which naïve individuals encounter novel habitats and locations, making them potentially more vulnerable than at other times. Breeding dispersal determines whether distributions of breeding birds can be considered to be stable, or whether they are plastic, such that there is high turnover in the local bird populations that are potentially at risk from proximity to the railway.

Young Barn Owls typically leave their natal sites soon after fledging. An analysis of ring recovery data, undertaken for the *Migration Atlas* and covering Britain & Ireland, revealed that the median dispersal distance for ring-recoveries made in the second month after ringing as pulli was 3 km, rising to 7.5 km and 12 km in the third and fourth months, respectively (Wernham *et al.* 2002). These data (n=384) suggest a median natal dispersal distance of 12 km, underlining that chick dispersal is largely completed within the first four or five months post-fledging. Work in south-west Scotland has suggested that there may be a statistically significant difference between the natal dispersal distances of male and female chicks, with females dispersing further, as is typical among birds (Taylor 1994). Comparable data for breeding dispersal, again from the *Migration Atlas*, suggested that adults were largely sedentary, but that they showed a degree of inter-seasonal movement (breeding to winter range), with a median of 4 km. However, there findings were based on a small sample size and now require revision.

The ring-recovery dataset has grown substantially since the *Migration Atlas* analyses were carried out in the late 1990s, and there is an opportunity to re-examine national patterns in natal and breeding dispersal and to look for regional/habitat related variation within these. The database now holds around 24,000 Barn Owl recoveries (up until 2015), thus allowing more detailed analysis of dispersal patterns. In this study, the analyses published by Wernham *et al.* (2002) are updated with the larger sample sizes now available and extended to consider variation with respect to habitat variation. The results are then discussed with respect to their relevance to the context of HS2.

Ring-recovery analyses do not permit the investigation of fine-scale habitat effects on movements. The often-repeated assertion that dispersing Barn Owl chicks follow river corridors and other linear features lacks supporting evidence, with the limited amount of radio-tracking data available suggesting that local movements may actually be completely unrelated to linear habitat features (Barn Owl Trust 2012). The technologies currently available do not permit the monitoring of chick dispersal over the entire dispersal period; the limiting factors being the battery life of the tags and the number of fixes obtainable. However, this is something that is likely to become achievable within the next few years thanks to the emergence of new tracking technologies. In the meantime, new analysis of the ring-recovery dataset should provide evidence to inform the placement of mitigation measures in respect of the planned HS2 proposal.

3. METHODS

Barn Owl, by Paul Newton/BTO

Records from the ring-recovery and ring-recapture database were filtered prior to analysis, to minimize any bias in the data. This filtering followed that used by Wernham *et al.* (2002). Birds were excluded if they were ringed in unusual circumstances, such as after a period of being held in captivity, if they had been hand-reared or if they were in poor condition, as these birds will be unrepresentative of the population. Any birds that were ringed or recovered in unknown locations were excluded; this included those sites that have been treated as confidential and therefore given deliberately imprecise coordinates in the database.

Also excluded were birds that were recorded as 'moved before finding', birds that were recovered more than a week after death, and rings that were found without any part of the bird. In all these cases, the birds may not have died where they were found, thus potentially causing biases in the distances recorded between ringing and recovery. Some birds were recaptured on multiple occasions; in these instances, only information from the first recapture was used.

In contrast to the analysis by Wernham *et al*. (2002), both live and dead recoveries were used for the analysis. Prior to 2005, live recaptures were only entered into the database if the distance travelled was over 5 km, hence their exclusion from earlier analyses to avoid bias from the under-recording of shorter movements. Now, however, more than 10 years of unbiased live recapture data are available, and these data were used here (live recaptures from before 2005 were still omitted).

However, it is important to note that both dead recoveries and live recaptures are subject to biases. Birds recovered dead are those found by members of the public, so they will be influenced by the distribution of people and of factors causing fatalities (Taylor 1994). This is especially relevant with respect to roads in the case of Barn Owls: roadkill owls are conspicuous and in locations frequented by people. Conversely, the distribution of birds recaptured alive will be influenced by the distribution of trapping effort and the methods used by ringers. Hence, the majority of live Barn Owl recaptures will be of those monitored in nest boxes, mostly during the breeding season (although note that boxes may also be used as roosting sites at other times). This is important because birds that nest in natural nest sites are likely to be under-recorded and also points to a bias in the sample of birds ringed as well as in that of recaptures.

Dispersal movements were categorized into different types according to the age at which the bird was ringed and subsequently recovered, as follows:

i) **Breeding dispersal** – ringed as adults and then recovered or recaptured as adults in any subsequent breeding season. Birds were classed as adults at the start of the breeding season of the year after the hatching year.

ii) **Inter-seasonal movements** – ringed as adults in the breeding season and recovered or recaptured in any subsequent non-breeding season, or ringed as adults in the non-breeding season and recovered or recaptured in any subsequent breeding season. Sample sizes did not allow splitting movements into those from breeding season to non-breeding season and non-breeding season to breeding season. There were no records of movements between non-breeding seasons.

iii) **Natal dispersal** – ringed as chicks and recovered in any subsequent breeding season.

iv) **Juvenile dispersal** – ringed as chicks and recovered within the subsequent 12 months. Chicks begin to move away from the natal area at around three months old (Bunn *et al.* 1982); examining movements of chicks in fortnightly blocks after ringing (the finest temporal temporal resolution possible given data availability) will provide novel insight into the timing and distance of these initial dispersal events.

Breeding and non-breeding seasons were defined following Wernham *et al*. (2002); the breeding season was 1st April – 31st October and the non-breeding season was 1st November – 30th March. Barn Owls have a long breeding season, and have been recorded on eggs in the UK in every month of the year. Median first egg date, calculated using data from the BTO's Nest Record Scheme, is 6th May with dates ranging between 30th March – 4th July, but second broods or very late first broods mean that young may still be in the nest in October. The range of dates used here will, nevertheless, cover the vast majority of nesting attempts made in the UK.

Ringing and recovery locations were assigned into four regions – north-west, north-east, south-west and south-east, following Wernham *et al.* (2002). The route for the first phase of HS2 falls within the south-east region. Dispersal distances were calculated as straight line distances between ringing and recovery locations, each location being accurate to within 1 km. Note that these distances are minima and a gross simplification of the real paths that will have been followed; very little work has been done in the UK on the dispersal behaviour of Barn Owls to support more sophisticated data extraction.

To examine whether dispersal distances were influenced by habitat, the proportions of different habitat types within buffers around ringing locations and around straight line routes between ringing and recovery locations were calculated, based on 1 km square summary data from the Centre for Ecology and Hydrology Land Cover Map 2000 (Morton *et al.* 2011). Spatial data processing was conducted using ArcMap 10 (ESRI, Ltd., www.esri.com).

Buffers were chosen that encompassed 75% of movements within each dispersal category, so that the habitat data used described the most relevant part of the landscape for average observed movements, given that habitat could have influenced movements by facilitating or by inhibiting travel, as well as by influencing recovery/recapture location per se. Six different buffer sizes (radii) were drawn around ringing locations (Table 1). Given the fact that ringing locations were accurate to within a 1 km grid square only, the smallest buffers indicated by the data, 1.0 and 1.4 km, were not used in the analysis. Thus, habitat influences on breeding dispersal and inter-seasonal movements of live recaptures were not analysed.

For the movement types with larger mean distances, these circular buffers (hereafter, ringing buffers) were accordingly very large. Hence, in order to consider habitat more directly relevant to likely paths of movements, additional buffers of 1 km either side of the straight-line route between ringing and recovery locations (hereafter, route buffers) were drawn. Areas of habitat (land cover) per buffer were estimated using the sum of the areas of land cover variables per 1 km square that intersected each buffer, weighted by the proportion of the 1 km square that fell within the buffer. Land cover classes were grouped into habitats defined as suitable, unsuitable or barrier habitats for Barn Owl

Table 1. Buffer size (radius) used in analysis

Recovery type	Breeding dispersal	Natal dispersal	Inter-seasonal movements
Live	1.0 km	10.8 km	1.4 km
Dead	5.0 km	15.8 km	6.0 km

The 75th percentile of the dispersal distance of each type was used to delineate buffer size.

dispersal, based on ecological knowledge (Table 2). Suitable habitats were those in which Barn Owls might forage, which would therefore potentially encourage movement across or within them. Unsuitable habitats were largely not as valuable as foraging habitat, but also do not prevent movement across or within them. Barrier habitats would restrict movements such that the birds would be expected to fly around them. Each of these habitats might tend to slow or to stop movements, or to increase their speed or direction.

Table 2. Habitat types used in analysis

Habitat category	Land cover class
Suitable	Semi-natural grass (excl. acid grassland) Fen/marsh/swamp Saltmarsh
Unsuitable	Arable Improved grass
Barrier	Mountain/heath/bog Urban Woodland

3.1 ANALYSIS

Mean and median dispersal distances were calculated for each dispersal type among live recaptures and dead recoveries. The effect of region and sex on dispersal distance within dispersal type was tested using non-parametric tests, which avoid assumptions about the statistical distribution of the data. Wilcoxon rank tests (two samples) or Kruskal-Wallis tests (more than two samples) were used: Wilcoxon tests for differences in dispersal distance between sexes, and Kruskal-Wallis tests for differences between regions. To examine dispersal distance of chicks throughout the year after hatching, differences in the distance travelled per fortnight after ringing were tested using the same non-parametric tests.

Associations between habitat and dispersal distance were examined using generalized linear models, in which dispersal distance was modelled with respect to the amount of suitable, unsuitable and barrier habitats within buffers around ringing locations and dispersal routes. Each habitat was tested separately in models assuming a normal distribution for the transformed response variable log(distance+1). The number of years between ringing and recovery/recapture was included as a covariate in the models to determine whether time between ringing and recovery affected dispersal distance, or the effect of habitat on dispersal distance (via an interaction term). Squared terms for habitat type were also included in the models to test for evidence of non-linear relationships in the form of quadratic functions.

Note that all tests required sufficient sample sizes of recoveries or recaptures to be available to provide reliable inference and this was not always the case for comparisons that would have been of interest a priori, such as some comparisons with respect to sex. Tests were conducted only where individual categories to be compared contained at least 30 recoveries or recaptures.

4. RESULTS

Barn Owl, by Ron Marshall/BTO

In assessing the dispersal distances of Barn Owls, several filters were applied to the data to ensure that the most accurate records were used. After this filtering, 10,424 records remained, of which 7,174 birds were recovered dead and 3,250 birds were recaptured alive. Dispersal distances for dead and live records were significantly different (dead recoveries were found an average of 7.0 km (quartile range=2.83 – 16.12 km) away from ringing locations, live birds were found an average of 2.2 km (quartile range=0.00 – 6.40 km) from ringing locations ($p<0.0001$), so the two recovery types were analysed separately.

4.1 DISPERSAL DISTANCES OF DEAD RECOVERIES

4.1.1 Natal and juvenile dispersal

Of birds recovered dead, those that had been ringed as chicks were found on average 7.8 km (quartile range=4.12 – 16.28 km) away from the natal site in a subsequent breeding season (Table 3, Fig.1). In the first year after ringing, median dispersal distance rose to a peak of 11.0 km in the ninth fortnight after ringing with a slight decline in median distance dispersed by the end of the year, to 8.3 km (Fig. 2).

Table 3. Dispersal distances (km) by dispersal type. Median distances are presented with 5th and 95th percentiles (P5 and P95), means with standard errors (se). N=number of birds in each category.

Dispersal type	N	Median Dispersal Distance	P5	P95	Mean ± se
Breeding Dispersal	134	2.24	0	19.1	6.18 ± 1.44
Inter-seasonal movements	102	2.83	0	28.28	6.79 ± 1.17
Natal dispersal	1,439	7.81	1	63.25	17.53 ± 0.92
Juvenile dispersal*	4,597	6.70	0	76.40	18.03 ± 0.54

** Juvenile dispersal is the dispersal of all chicks in any period up to 12 months after ringing and, therefore, will include natal dispersal movements.*

Fig. 1 Dispersal distances of birds travelling from natal site to breeding site (dead recoveries).

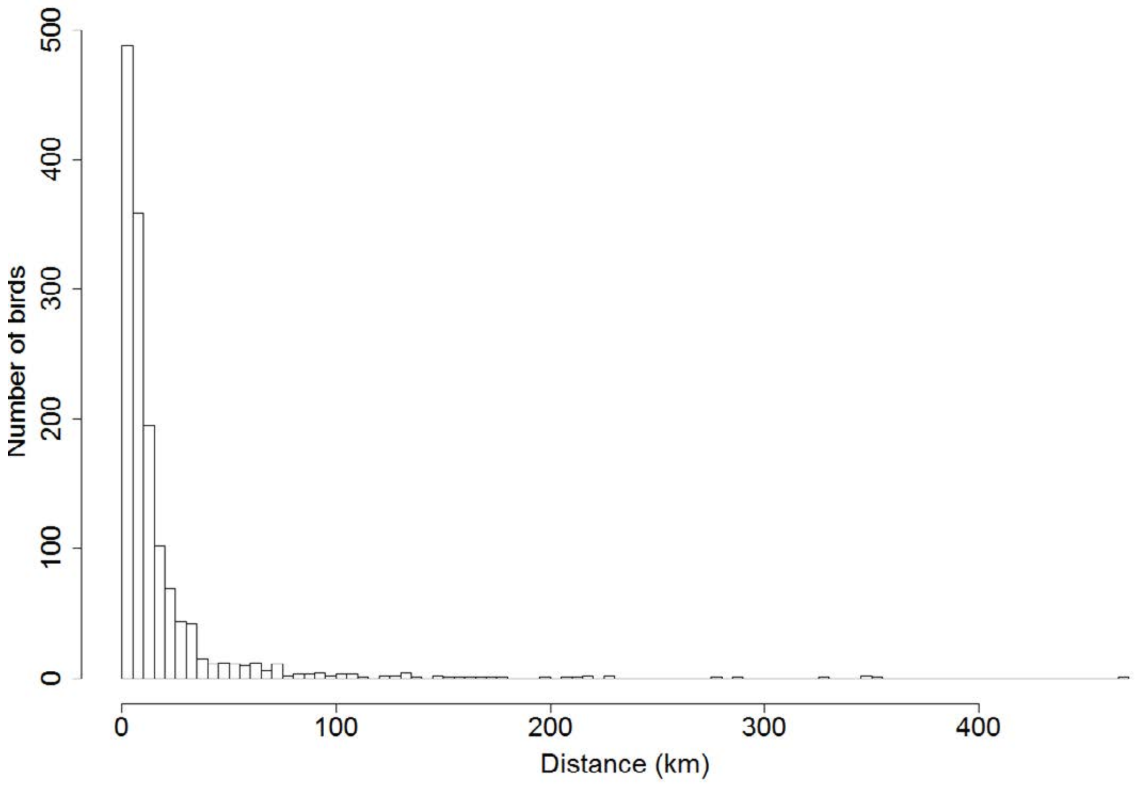
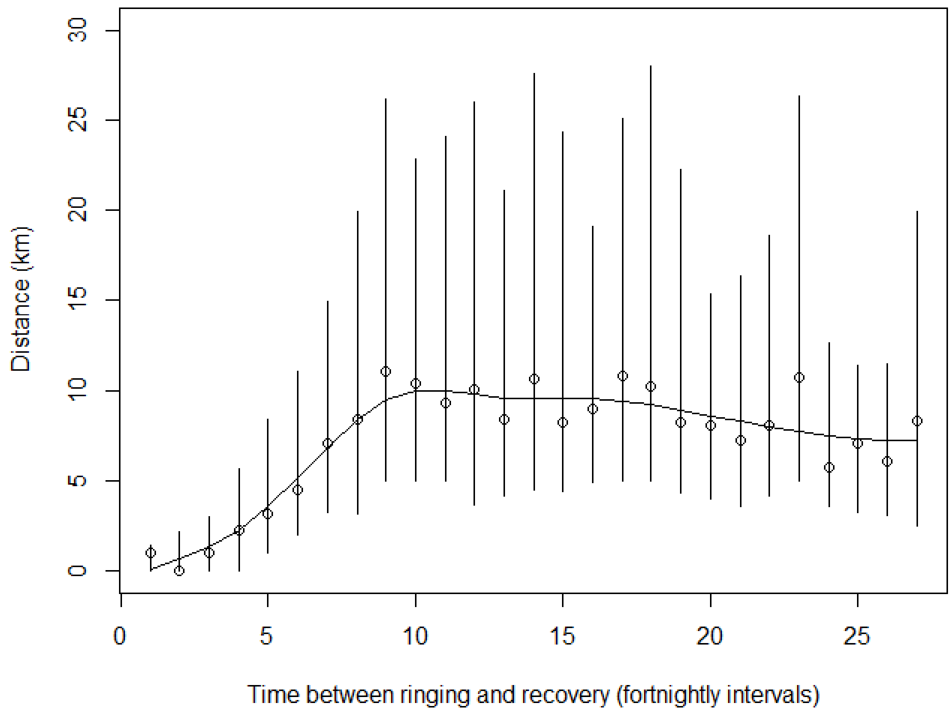


Fig. 2 Median distance (and interquartile range) travelled by chicks between ringing and recovery locations per fortnight, for birds recovered dead.



Female chicks dispersed further than males, (Table 4), particularly within the first year after hatching (z=4.12, p<0.0001). The differences were less significant once birds were more than one year old (z=2.01, p=0.040 Table 4).

Natal dispersal distances showed strong regional variation, with those ringed in the south-east dispersing the shortest distances, an increase in distance from south-western to north-eastern birds (no significant difference between south-west and north-east: z=1.15, p=0.250) and those ringed in the northwest dispersing the furthest to breeding areas (H=24.30, df=3 p<0.0001, Table 5). Similar regional variation was also seen in chicks recovered dead within 12 months of ringing (H=39.47, df=3, p<0.0001, Table 5). Again chicks ringed in the southeast and northwest dispersed the shortest distances, but the dispersal distances of chicks ringed in the north-east and south-west were not significantly different from each other (z=0.09, p=0.931).

Table 4. Natal and juvenile dispersal distances (km) of birds recovered dead. Median distances are presented with 5th and 95th percentiles (P5 and P95), means with standard errors (se). N=number of birds in each category.

	Natal dispersal					Juvenile dispersal				
Sex	**N**	**Median dispersal distance**	**P5**	**P95**	**Mean ± se**	**N**	**Median dispersal distance**	**P5**	**P95**	**Mean ± se**
Male	152	6.00	1.00	55.80	15.05 ± 3.27	429	4.47	0.00	47.07	10.89± 0.90
Female	138	8.03	1.00	60.08	17.16 ± 3.20	514	7.07	0.00	78.79	18.59± 1.54

Natal dispersal is defined as the movement of chicks from the nest site to recovery locations in any subsequent breeding season. Juvenile dispersal is the movement of chicks from the nest site to recovery locations within 12 months of ringing.

Table 5. Regional variation in natal and juvenile dispersal distance (km) of birds recovered dead. Median distances are presented with 5th and 95th percentiles (P5 and P95), means with standard errors (se). N=number of birds in each category.

	Natal dispersal					Juvenile dispersal				
Ringing region	**N**	**Median dispersal distance**	**P5**	**P95**	**Mean ± se**	**N**	**Median dispersal distance**	**P5**	**P95**	**Mean ± se**
NE	51	10.05	2.24	107.45	25.09 ± 7.54	175	6.40	0.00	107.45	21.97 ± 3.33
NW	233	10.77	0.00	62.97	18.73 ± 1.79	680	10.00	0.00	94.55	23.97 ± 1.97
SE	869	7.00	1.00	63.32	16.13 ± 1.10	2710	6.00	0.00	68.62	16.16 ± 0.60
SW	286	8.15	1.41	61.03	19.44 ± 2.47	1032	7.28	0.00	71.87	18.34 ± 1.09

Natal dispersal is defined as the movement of chicks from the nest site to recovery locations in any subsequent breeding season. Juvenile dispersal is the movement of chicks from the nest site to recovery locations within 12 months of ringing.

4.1.2 Breeding dispersal and inter-seasonal movements

Adult birds were more sedentary than juveniles, with median breeding dispersal being 2.2 km (Table 3, Fig. 3) and no difference observed between the sexes (z=0.001, p=0.991; Table 6); dispersal distance also did not vary with respect to the number of years since ringing (H=3.38, df=9 p=0.999). There were no regional differences in distances dispersed by adult birds (Table 7); birds ringed in the north were grouped together due to small sample sizes, and although these birds dispersed a median of 4.23 km while those ringed in the southeast and southwest dispersed 2.24 and 2.12 km respectively, these differences were not statistically significant (H=2.49, df=2, p=0.300).

The median distances moved by adults between breeding and wintering sites was 2.8 km (Table 3, Fig. 4), again with no difference between sexes (z=0.5, p=0.473, Table 6), or between regions (H=2.28, df=3, p=0.318, Table 7).

Fig. 3. Dispersal distance of adults from breeding to breeding site (dead recoveries).

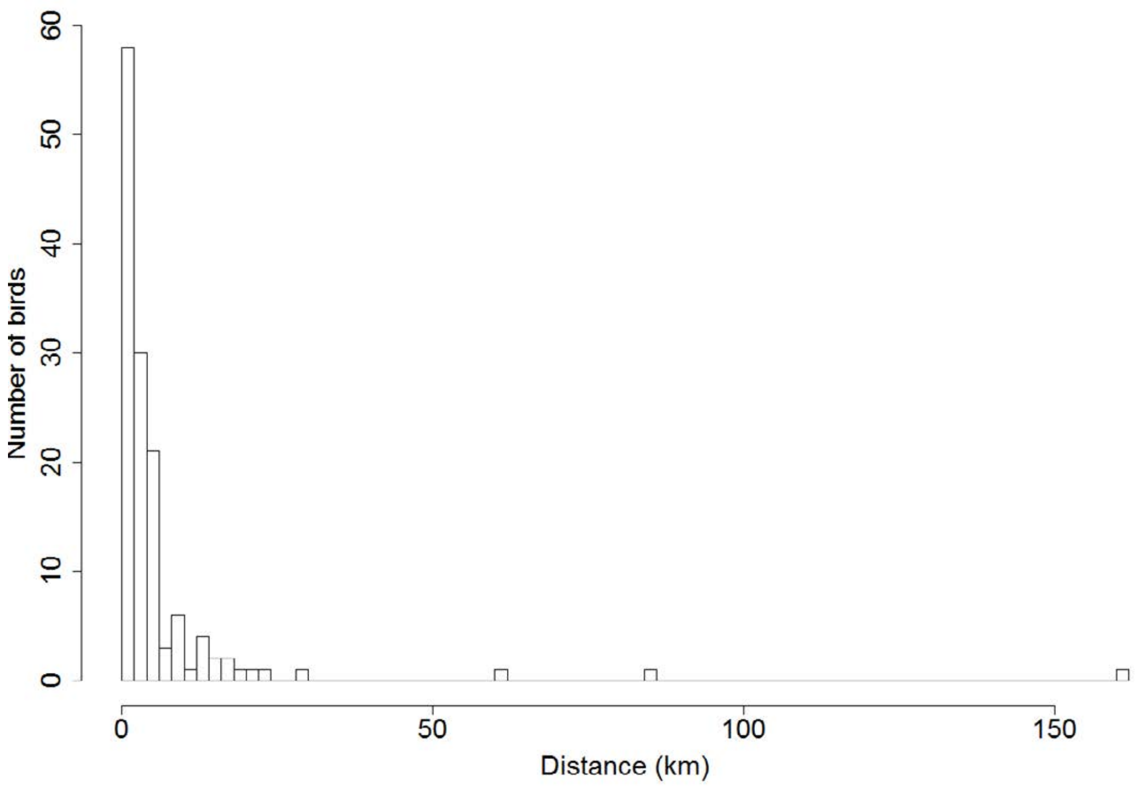


Table 6. Distances (km) travelled by males and females ringed and recovered as adults (dead recoveries). Median distances are presented with 5th and 95th percentiles (P5 and P95), means with standard errors (se). N=number of birds in each category.

	Breeding dispersal					Inter-seasonal movements				
Sex	N	Median dispersal distance	P5	P95	Mean ± se	N	Median distance moved	P5	P95	Mean ± se
M	48	2.24	0	16.16	4.32 ± 0.81	23	12.53	0	12.53	3.42± 0.84
F	69	2.24	0	16.28	6.78± 2.46	56	2.53	0	53	6.63± 0.84

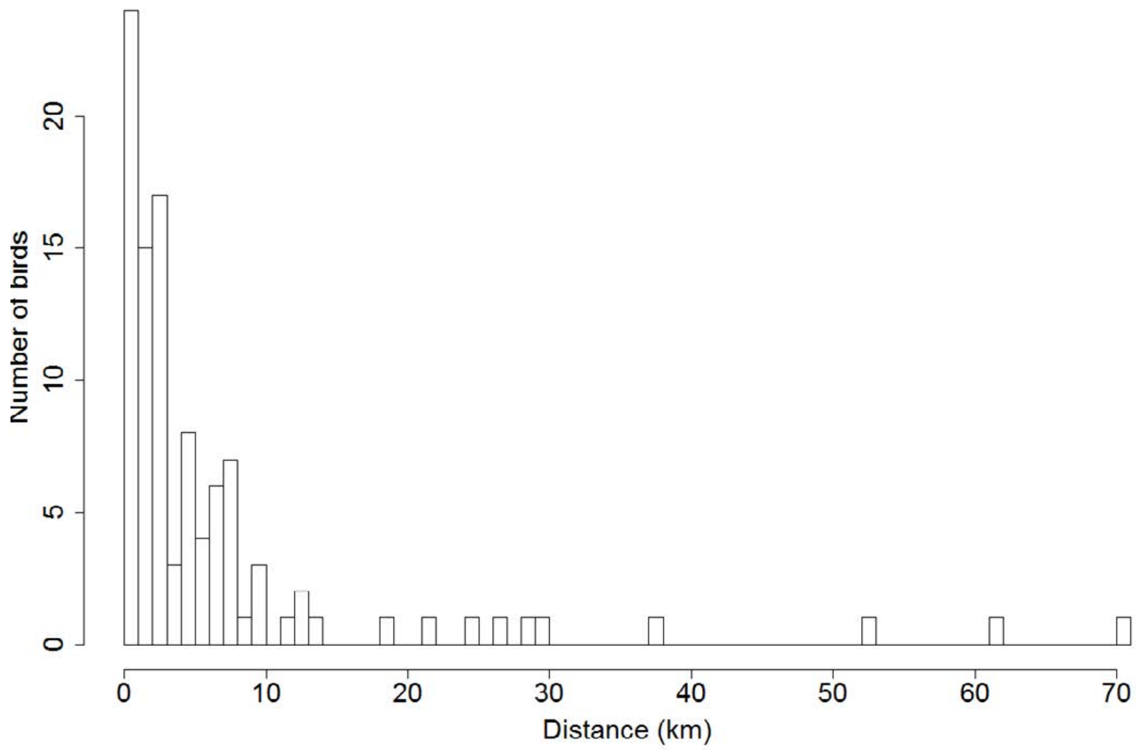
Breeding dispersal is movement from breeding season to breeding season, inter-seasonal movement is movement from breeding season to non-breeding season or vice-versa.

Table 7. Regional variation in dispersal distance of adult birds (dead recoveries). Median distances are presented with 5th and 95th percentiles (P5 and P95), means with standard errors (se). N=number of birds in each category.

	Breeding dispersal					Inter-seasonal movements				
Ringing region	**N**	**Median dispersal distance**	**P5**	**P95**	**Mean ± se**	**N**	**Median distance moved**	**P5**	**P95**	**Mean ± se**
NE	3	4.00	2.24	160.12	55.45 ± 52.34	6	3.16	0.00	70.72	14.93 ± 11.35
NW	23	4.47	0.00	24.00	8.32 ± 3.65	17	2.83	0.00	29.21	8.82 ± 2.53
SE	84	2.24	0.00	16.16	4.45 ± 0.88	55	2.83	0.00	24.84	5.12 ± 1.21
SW	24	2.12	0.00	13.00	4 ± 0.92	24	4.08	0.00	18.38	7.15 ± 2.54

Breeding dispersal is movement from breeding season to breeding season, inter-seasonal movement is movement from breeding season to non-breeding season or vice-versa.

Fig. 4. Inter-seasonal movements of adults from breeding to non-breeding site and non-breeding site to breeding site (dead recoveries).



4.2 DISPERSAL DISTANCES OF LIVE RECAPTURES

Birds recaptured alive (those recaught by ringers) dispersed shorter distances than those recovered dead (2.2 km across all dispersal types, p<0.0001), but the patterns among these birds echoed those of dead recoveries.

4.2.1 Natal and juvenile dispersal

Birds ringed as chicks and recaptured alive in any subsequent breeding season travelled a median of 6.0 km (quartile range=3.16-10.78 km; Table 8, Fig. 5).

Chicks recaptured in the eleventh fortnight after ringing travelled the furthest (11.3 km, Fig. 6) and female chicks dispersed further than males, both within the year of hatching and beyond (z=-3.12, p=0.001 and z=6.58, p<0.001 for natal and juvenile dispersal respectively; Table 9).

There was no regional variation in natal dispersal distance of birds recovered alive in any breeding season after hatching (H=4.08, df=3, p=0.254; Table 10), but distance did vary among chicks recovered within 12 months of ringing (H=20.65, df=3, p=0.0001; Table 10).

Table 8. Dispersal distances (km) by dispersal type for live recaptures. Median distances are presented with 5th and 95th percentiles (P5 and P95), means with standard errors (se). N=number of birds in each category.

Dispersal type	N	Median Dispersal Distance	P5	P95	Mean ± se
Breeding Dispersal	875	0.00	0.00	4.47	1.42 ± 0.26
Inter-seasonal movements	36	0.00	0.00	6.08	3.37 ± 2.69
Natal dispersal	1,547	6.00	1.00	34.06	10.56 ± 0.52
Juvenile dispersal*	867	3.16	0.00	31.05	7.84 ± 0.60

**Juvenile dispersal is the dispersal of all chicks in any period up to 12 months after ringing and, therefore, will include natal dispersal movements.*

Fig. 5. Dispersal distances of birds travelling from natal site to breeding site (live recaptures).

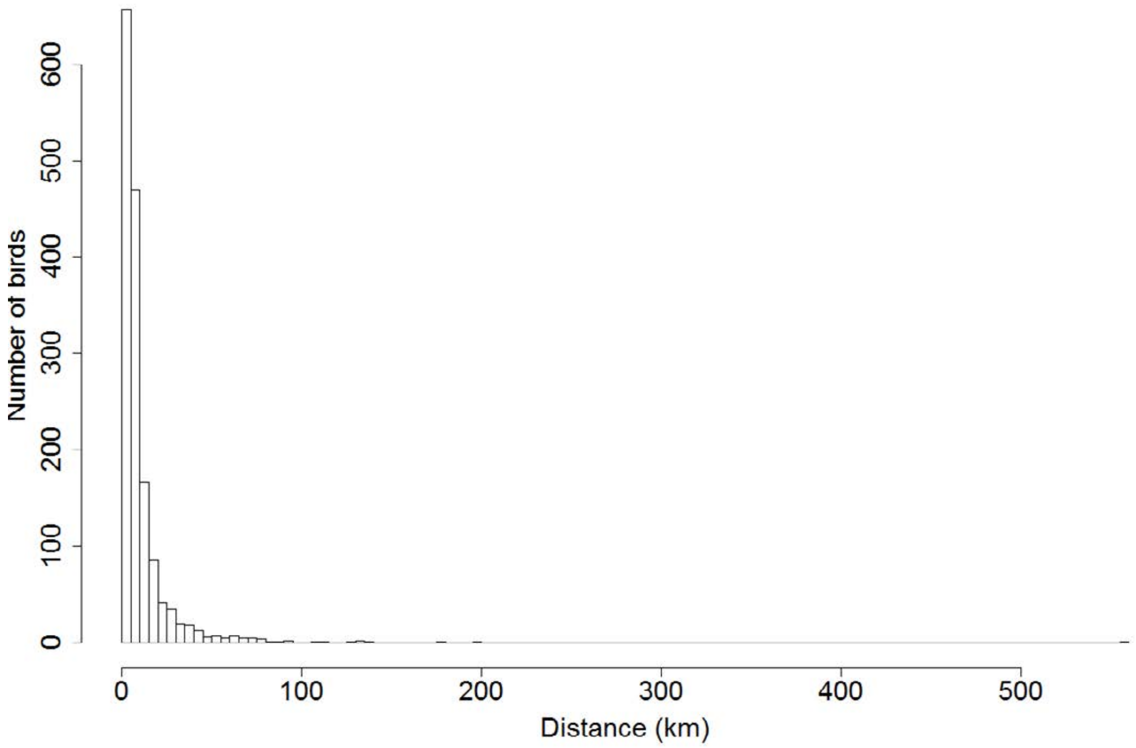


Table 9. Natal and juvenile dispersal distances (km) of birds recaptured alive. Median distances are presented with 5th and 95th percentiles (P5 and P95), means with standard errors (se). N=number of birds in each category.

	Natal dispersal					Juvenile dispersal				
Sex	N	Median dispersal distance	P5	P95	Mean ± se	N	Median dispersal distance	P5	P95	Mean ± se
M	334	5.83	1.41	28.32	9.23 ± 0.69	134	5.00	0.00	27.46	7.45 ± 0.81
F	696	8.00	2.00	45.52	13.9 ± 1.03	329	7.00	0.00	49.98	12.23 ± 0.94

Natal dispersal is defined as the movement of chicks from the nest site to recovery locations in any subsequent breeding season. Juvenile dispersal is the movement of chicks from the nest site to recovery locations within 12 months of ringing.

Table 10. Regional variation in natal and juvenile dispersal distance (km) of birds recaptured alive. Median distances are presented with 5th and 95th percentiles (P5 and P95), means with standard errors (se). N=number of birds in each category.

	Natal dispersal					Juvenile dispersal				
Ringing region	N	Median dispersal distance	P5	P95	Mean ± se	N	Median dispersal distance	P5	P95	Mean ± se
NE	14	6.03	2.00	42.52	11.15 ± 3.34	27	0.00	0.00	13.42	3.67 ± 1.4
NW	220	5.24	1.00	27.38	8.49 ± 0.67	115	5.00	0.00	52.40	12.25 ± 3.17
SE	1,051	6.00	1.00	37.70	10.74 ± 0.49	578	2.83	0.00	32.39	7.65 ± 0.62
SW	262	6.36	1.41	20.25	11.55 ± 2.31	147	4.12	0.00	18.60	5.92 ± 0.65

Natal dispersal is defined as the movement of chicks from the nest site to recovery locations in any subsequent breeding season. Juvenile dispersal is the movement of chicks from the nest site to recovery locations within 12 months of ringing.

4.2.2 Breeding dispersal and inter-seasonal movements

Median breeding dispersal distance of birds recaptured alive was 0 km (quartile range=0–1 km, Table 8, Fig. 7). There was no clear difference in the median breeding dispersal distance between the sexes (z=-1.58, p=0.099; Table 11), but median distances did vary with region (H=16.65, df=3, p=0.0008; Table 12).

Median distance moved by live adult birds from breeding to non-breeding season (and vice versa) was 0 km (quartile range =0–1.41 km, Table 8, Fig. 8) Distance varied with sex (z=-2.03, p=0.048, Table 11) but not region (H=1.31, df=3, p=0.732, Table 12).

Fig. 6. Median distance (and interquartile range) travelled by chicks between ringing and recovery locations per fortnight, for birds recaptured alive.

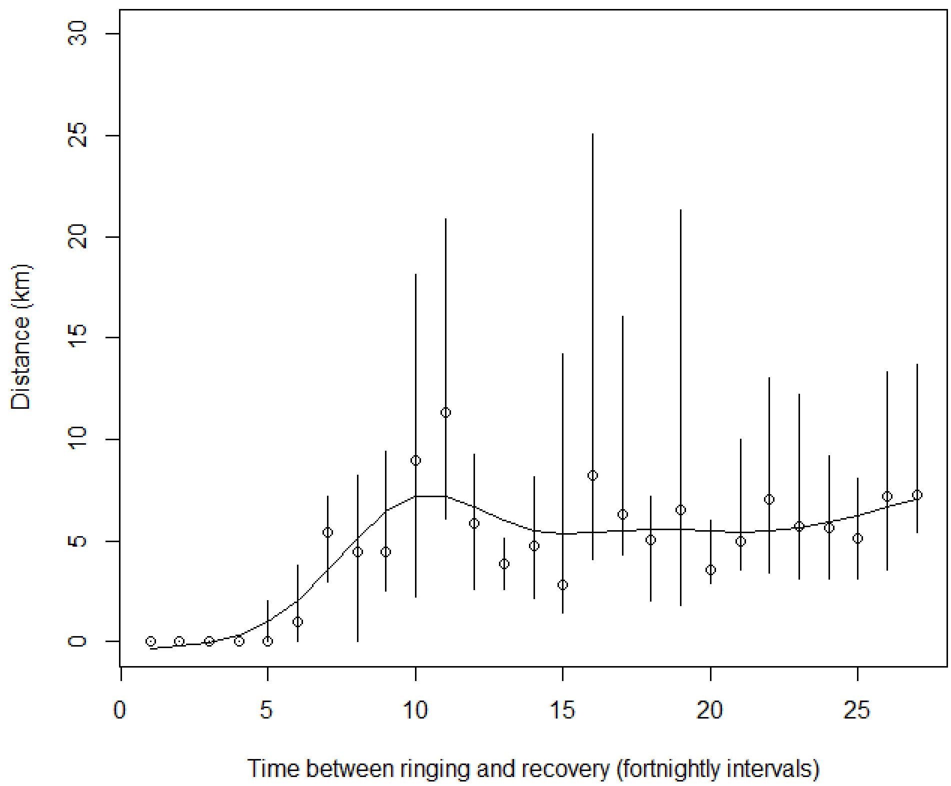


Fig. 7. Dispersal distance of adults from breeding to breeding site (live recaptures).

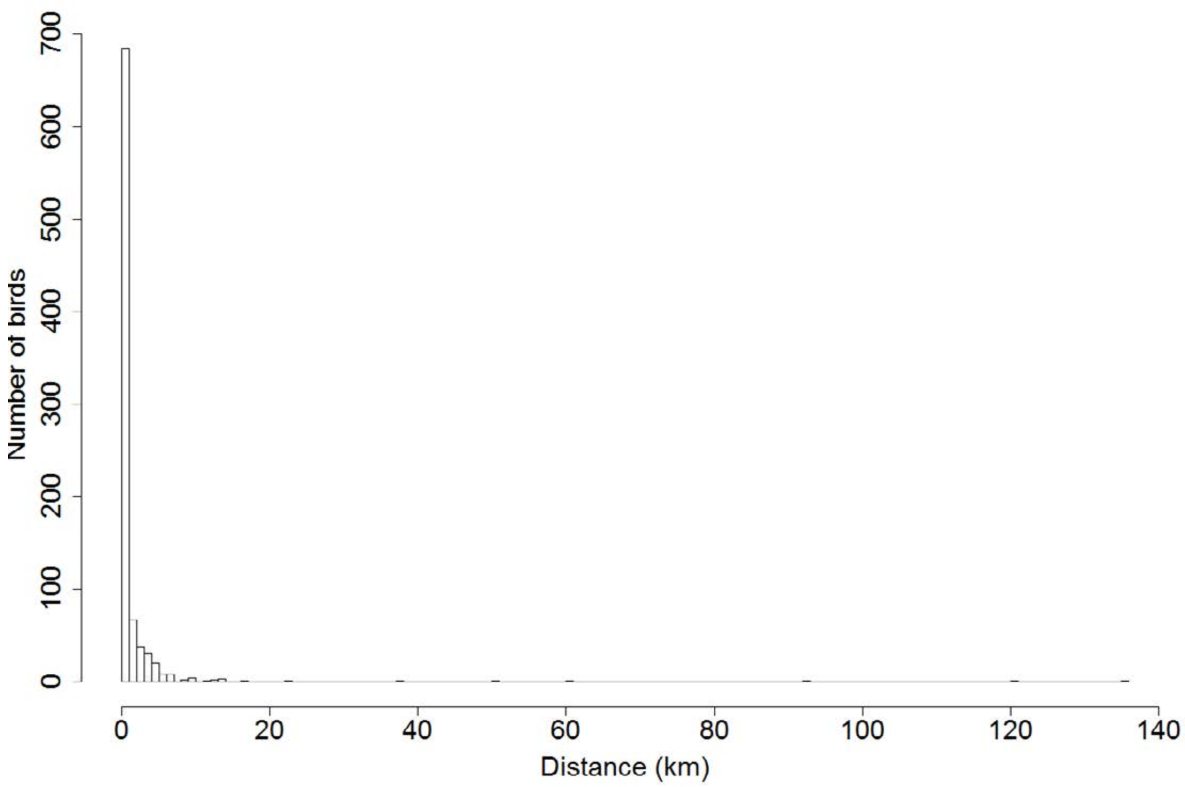


Fig. 8. Movements made by adult birds from breeding to non-breeding season and vice versa (live recaptures).

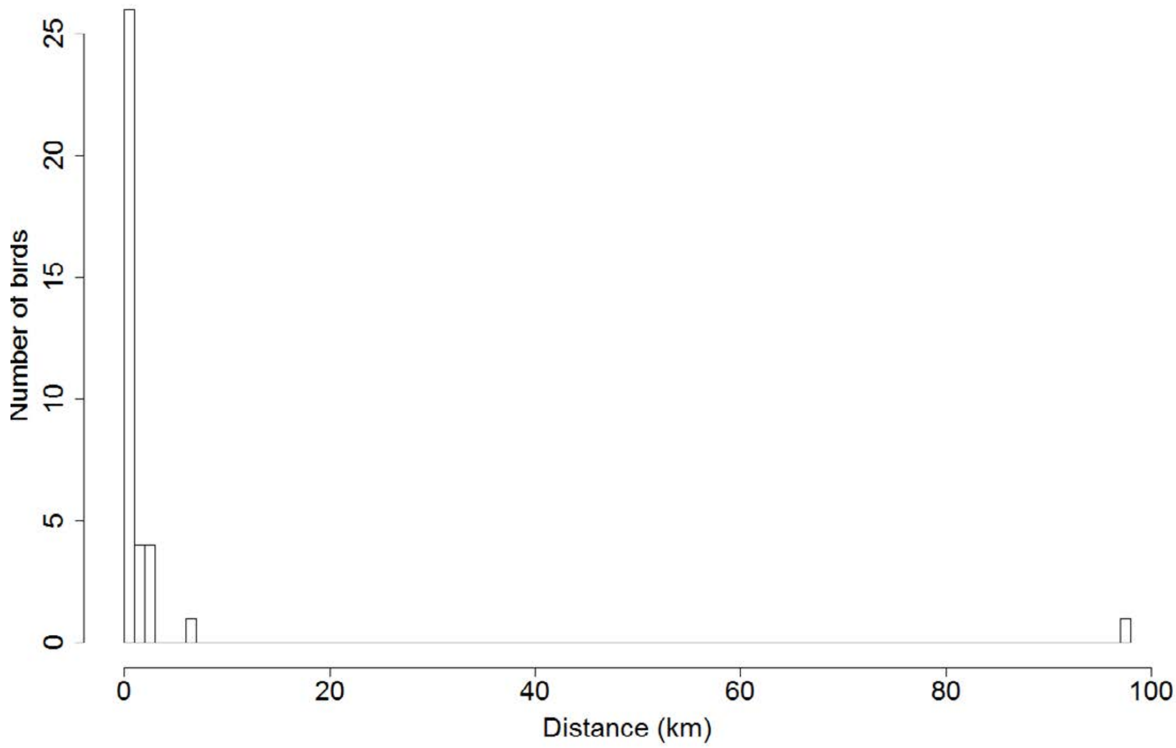


Table 11. Distances (km) travelled by males and females ringed and recaptured alive as adults. Median distances are presented with 5th and 95th percentiles (P5 and P95), means with standard errors (se). N=number of birds in each category.

	Breeding dispersal					Inter-seasonal movements				
Sex	**N**	**Median dispersal distance**	**P5**	**P95**	**Mean ± se**	**N**	**Median distance moved**	**P5**	**P95**	**Mean ± se**
M	213	0.00	0.00	4.00	0.65 ± 0.10	11	0.00	0.00	1.41	0.13 ± 0.13
F	635	0.00	0.00	5.00	1.71 ± 0.36	25	0.00	0.00	6.09	4.8 ± 3.86

Breeding dispersal is movement from breeding season to breeding season, inter-seasonal movement is movement from breeding season to non-breeding season or vice-versa.

Table 12. Regional variation in dispersal distance of adult birds recaptured alive. Median distances are presented with 5th and 95th percentiles (P5 and P95), means with standard errors (se). N=number of birds in each category.

	Breeding dispersal					Inter-seasonal movements				
Ringing region	**N**	**Median dispersal distance**	**P5**	**P95**	**Mean ± se**	**N**	**Median distance moved**	**P5**	**P95**	**Mean ± se**
NE	36	0.00	0.00	1.00	2.66 ± 2.58	11	0.00	0.00	2.24	0.59 ± 0.26
NW	109	0.00	0.00	12.04	2.81 ± 1.33	10	0.00	0.00	2.24	0.37 ± 0.25
SE	633	0.00	0.00	4.24	1.09 ± 0.22	12	0.00	0.00	97.25	9.03 ± 8.04
SW	97	0.00	0.00	5.39	1.56 ± 0.43	3	0.00	0.00	3.00	1.00 ± 1.00

Breeding dispersal is movement from breeding season to breeding season, inter-seasonal movement is movement from breeding season to non-breeding season or vice-versa.

4.3 Associations with habitat

The associations between distance moved and the proportion of different habitat types within ringing buffers or route buffers are given in Tables 13–18. Habitat influences on dispersal of live recaptures were examined only for natal dispersal (Table 16). Tests of habitat influences by sex were only possible for natal dispersal (Tables 17 and 18).

4.3.1 Breeding dispersal and inter-seasonal movements

Breeding dispersal distances of birds recovered dead were not associated with quantities of suitable, unsuitable, or barrier habitat within 5 km of the ringing location (Table 13). There were, however, quadratic associations with the proportion of the three habitat types within the route buffers, albeit with a great deal of scatter around the relationship (Fig. 9).

On closer inspection of the suitable habitat, however, removal of three outlying data points where over 30% of the buffer contained suitable habitat removed this quadratic relationship. A significant positive relationship remained between the proportion of suitable habitat within the route buffer and the distance dispersed (estimate=0.02, t=2.13, p=0.04, Fig. 9). Similarly, removing the two outlying points where barrier habitat accounted for more than 40% of habitat within the buffer left only a significant positive effect (estimate=0.02, t=4.24, p<0.001; Fig.10). The proportion of unsuitable habitat making up the buffer was distributed more evenly, thus the quadratic relationship remained for this variable (Fig. 11).

The distance travelled by adults from breeding to non-breeding and non-breeding to breeding seasons was not associated with the proportion of any of the three habitat types within 6 km of the ringing location, or within the 1 km of the route travelled (Table 14).

Table 13. Effects of habitat on breeding dispersal distances of birds recovered dead. Results are associations between the proportions of suitable, unsuitable and barrier habitats within 5 km of ringing location (ringing buffer) and 1 km either side of the straight-line route between ringing and recovery location (route buffer).
See Table 2 for description of habitat types.

Buffer type	Habitat type	Estimate	Std. Error	t value	Pr(>|t|)
Ringing buffer	Suitable	-0.009	0.008	-1.09	0.28
(96)*	Unsuitable	0.003	0.003	0.84	0.41
	Barrier	-0.002	0.005	-0.37	0.71
Route buffer	Suitable	0.02	0.01	1.8	0.07
(71)*	Suitable^2	-0.0004	0.0002	-2.27	**0.03**
	Unsuitable	0.02	0.01	1.91	0.06
	Unsuitable^2	-0.0002	0.00009	-2.23	**0.03**
	Barrier	0.04	0.009	3.90	**0.0002**
	Barrier^2	-0.0004	0.0001	-2.82	**0.006**

**Sample size is shown in brackets. Removal of outliers removed the significant quadratic terms in the suitable and unsuitable habitat models.*

Fig. 9. Relationship between proportions of suitable habitat in the route buffer and breeding dispersal distance of birds recovered dead. A quadratic term was initially retained in the model, indicating a non-linear relationship (left). Removal of the three outliers where over 27% of the habitat was suitable removed this non-linear relationship to leave a linear one (on the log scale) only (right).

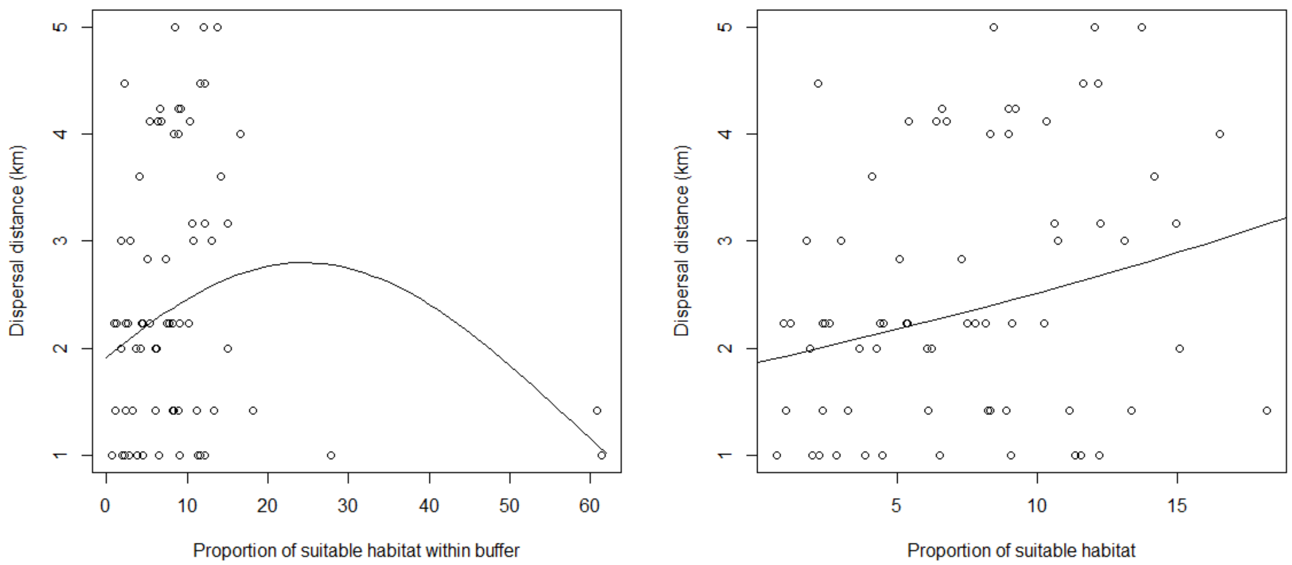


Fig. 10. Relationship between proportions of barrier habitat in the route buffer and breeding dispersal distance of birds recovered dead, after removal of outliers.

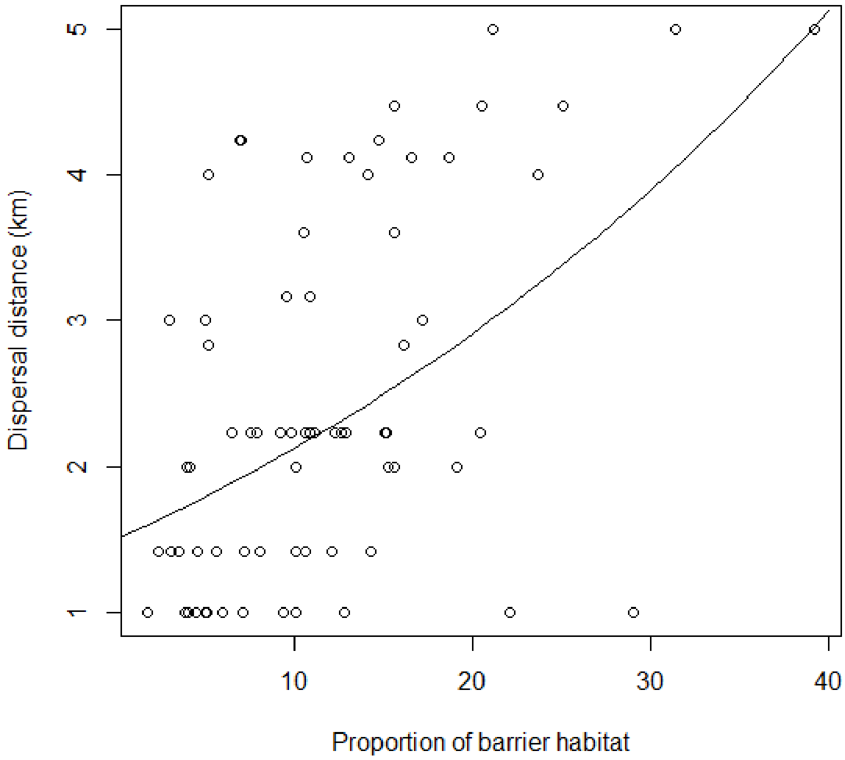


Fig. 11. Relationship between proportions of unsuitable habitat in the route buffer and breeding dispersal distance of birds recovered dead.

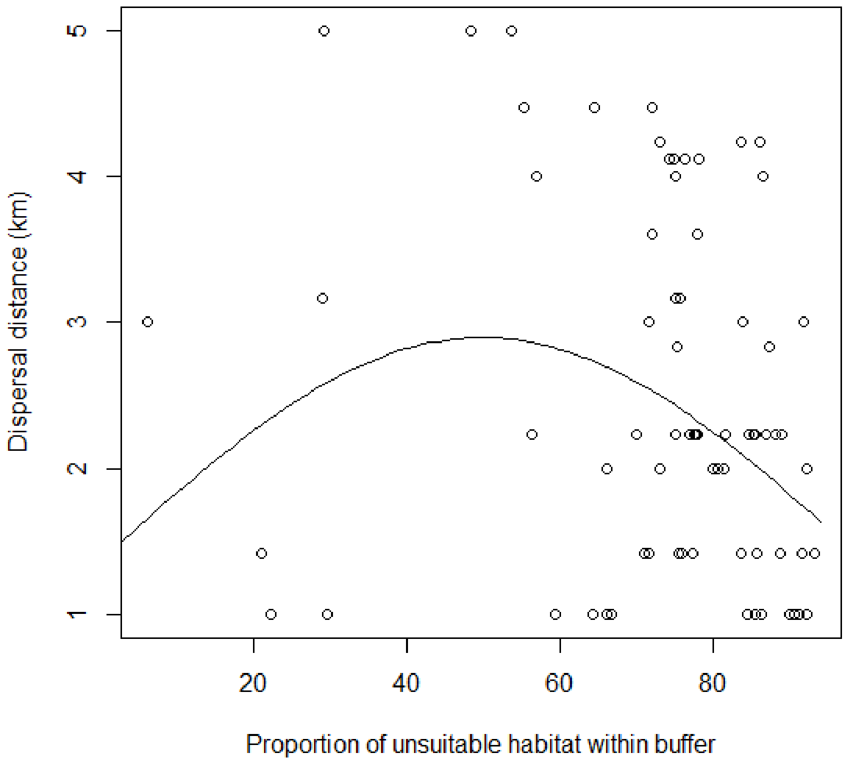


Table 14. Effects of habitat on inter-seasonal movements of birds recovered dead. Results are associations between the proportions of suitable, unsuitable and barrier habitats within 6 km of ringing location (ringing buffer) and 1 km either side of the straight-line route between ringing and recovery location (route buffer).

Buffer type	Habitat type	Estimate	Std. Error	t value	Pr(>|t|)
Ringing buffer	Suitable	0.0105	0.01	0.75	0.45
(71)	Unsuitable	-0.0066	0.004	-1.79	0.08
	Barrier	0.005823	0.005	1.18	0.24
Route buffer	Suitable	-0.065	0.06	-1.06	0.29
(51)	Unsuitable	-0.002	0.003	-0.62	0.54
	Barrier	0.005	0.003	1.34	0.19

**Sample size is shown in brackets. See Table 2 for description of habitat types.*

4.3.2 Natal dispersal

The proportion of suitable, unsuitable and barrier habitats within 15.8 km of the ringing location of chicks was not associated with the distance moved by these birds recovered dead in any subsequent breeding season (Table 15). The proportion of unsuitable habitat in the route buffers between ringing and recovery locations was negatively associated with the distance between locations. In contrast, dispersal distance was positively associated with the proportion of barrier habitat around the route. There was also a significant association with the proportion of suitable habitat within these route buffers, with the retention of a quadratic term in the model indicating a humped relationship. However, removal of outliers (three points greater than 60% suitable habitat resulted in no significant effect of suitable habitat (estimate=0.03, t=1.13, p=0.26)).

There were no significant relationships between natal dispersal distance and the proportion of different habitat types within 10.8 km of the ringing location for birds recaptured alive (Table 16, Fig. 12).

Table 15. Effects of habitat on natal dispersal distances of birds recovered dead. Results are associations between the proportions of suitable, unsuitable and barrier habitats within 15.8 km of ringing location (ringing buffer) and 1 km either side of the straight-line route between ringing and recovery location (route buffer).

Buffer type	Habitat type	Estimate	Std. Error	t value	Pr(>|t|)
Ringing buffer	Suitable	0.009	0.005	1.60	0.11
(1,006)*	Unsuitable	-0.001	0.001	-1.13	0.26
	Barrier	0.003	0.002	1.46	0.14
Route buffer	Suitable	0.14	0.04	3.44	**0.0006**
(929)*	Suitable^2	-0.03	0.01	-2.66	**0.008**
	Unsuitable	-0.004	0.0009	-3.90	**0.0001**
	Barrier	0.005	0.001	3.52	**0.0004**

**Sample size is shown in brackets. See Table 2 for description of habitat types.*

Table 16. Effects of habitat on natal dispersal distances of birds recaptured alive. Results are associations between the proportions of suitable, unsuitable and barrier habitats within 15.8 km of ringing location (ringing buffer) and 1km either side of the straight-line route between ringing and recovery location (route buffer).
See Table 2 for description of habitat types.

Buffer type	Habitat type	Estimate	Std. Error	t value	Pr(>|t|)
Ringing buffer	Suitable	0.003	0.004	0.90	0.37
(1062)	Unsuitable	-0.001	0.002	-0.87	0.39
	Barrier	0.0009	0.002	0.40	0.69
Route buffer	Suitable	0.03	0.02	1.34	0.18
(801)	Unsuitable	-0.001	0.0008	-1.61	0.11
	Barrier	0.003	0.001	1.92	0.06

**Sample size is shown in brackets.*

The relationship between habitat and dispersal distance of males and females was examined where sample size allowed, which was only for natal dispersal of each of dead recoveries and live recaptures. There were no associations with habitat or dispersal distance of male chicks (Table 17). For female chicks, however, there was a positive relationship between dispersal distance and the proportion of suitable habitat within 15.8 km of the ringing location (Table 17). Quadratic terms for the proportion of unsuitable and barrier habitats within this buffer were retained in models, indicating a non-linear response to these variables (Fig. 13 and 14). The proportion of unsuitable habitat in the route buffer between ringing and recovery locations was also a significant influence (Table 17). The lack of associations found between natal dispersal distance of live recaptures and proportion of habitat remained true when birds were split into males and females (see Table 18).

Fig. 12. Natal dispersal distance of chicks recaptured live with respect to the proportion of suitable (left) and unsuitable (right) habitat in the route buffer. No significant associations were detected.

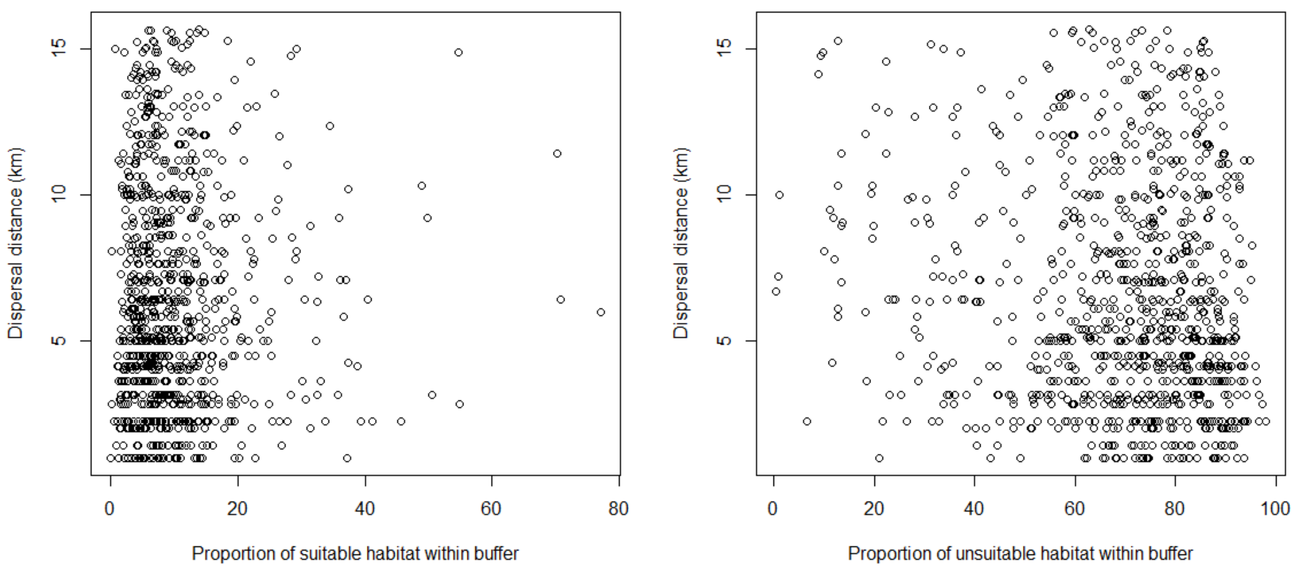


Table 17. Effects of habitat on natal dispersal distances of birds recovered dead. Results are associations between the proportions of suitable, unsuitable and barrier habitats within 15.8 km of ringing location (ringing buffer) and 1km either side of the straight-line route between ringing and recovery location (route buffer).

		Male				Female			
Buffer type	**Habitat**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Ringing buffer	Suitable	0.31	0.19	1.64	0.10	0.42	0.18	2.29	**0.02**
(M=118,F=104)	Unsuitable	-0.0009	0.004	-2.09	**0.04**	0.04	0.02	2.18	**0.03**
	Unsuitable2					-0.0004	0.0002	-2.71	**0.008**
	Barrier	0.009	0.007	1.43	0.16	0.06	0.02	2.49	**0.01**
	Barrier2					-0.0008	0.0004	-2.23	**0.023**
Route buffer	Suitable	0.12	0.08	1.57	0.12	0.14	0.09	1.63	0.11
(M=112,F=99)	Unsuitable	-0.008	0.003	-2.87	**0.005**	-0.007	0.003	-2.56	**0.01**
	Barrier	0.006	0.005	1.39	0.17	0.006	0.004	1.41	0.16

Sample size is shown in brackets (M=male; F=female).

Table 18. Effects of habitat on natal dispersal distances of birds recaptured alive. Results are associations between the proportions of suitable, unsuitable and barrier habitats within 15.8 km of ringing location (ringing buffer) and 1km either side of the straight-line route between ringing and recovery location (route buffer).

		Male				Female			
Buffer type	**Habitat**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Ringing buffer	Suitable	0.09	0.10	0.87	0.39	0.01	0.07	0.20	0.84
(M=139,F=259)	Unsuitable	-0.0005	0.003	-0.13	0.90	-0.002	0.003	-0.63	0.53
	Barrier	0.0005	0.004	0.11	0.91	-0.0003	0.004	-0.09	0.93
Route buffer	Suitable	0.03	0.04	0.78	0.44	0.02	0.03	0.67	0.51
(M=174,F=329)	Unsuitable	-0.003	0.002	-1.78	0.08	0.0003	0.001	0.28	0.78
	Barrier	0.007	0.003	2.38	**0.02**	-0.0005	0.002	-0.27	0.79

Sample size is shown in brackets (M=male; F=female).

Fig. 13. Relationship between proportion of unsuitable habitat within 15.8 km of ringing location and natal dispersal distance of female birds recovered dead.

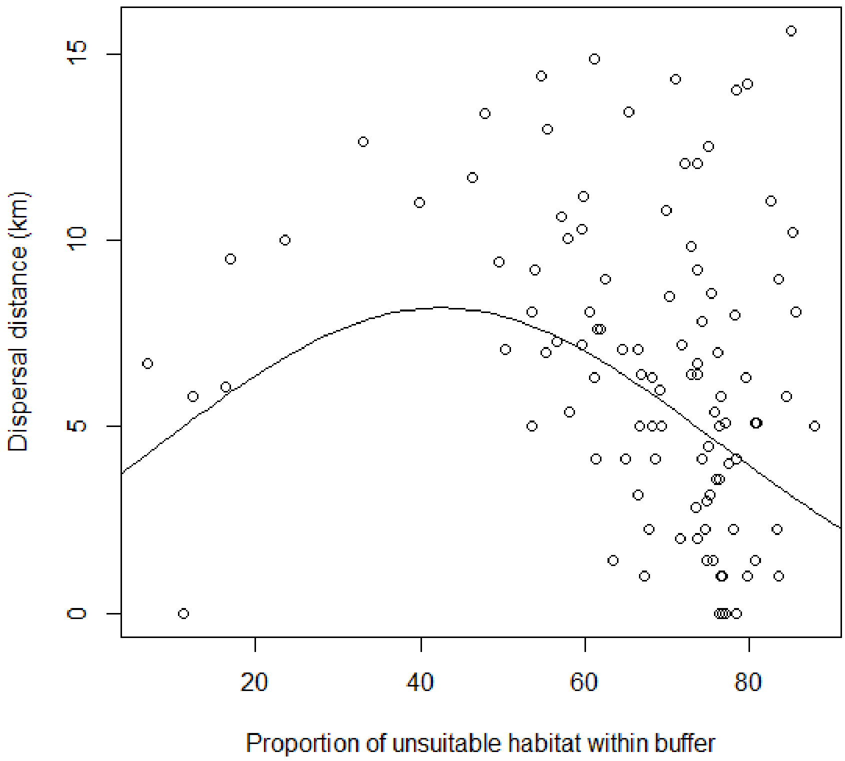
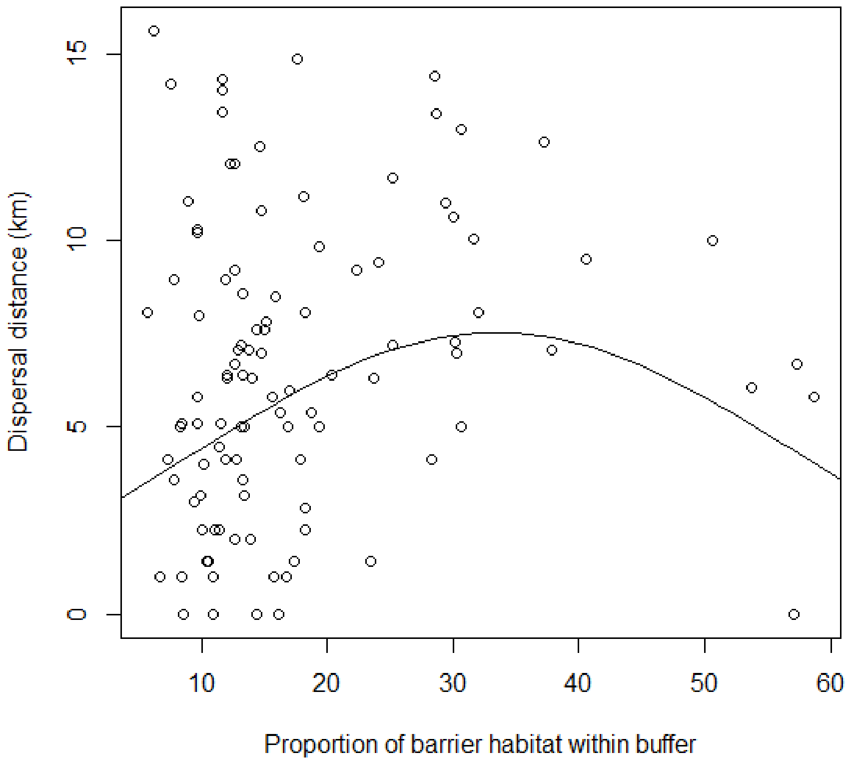


Fig. 14. Relationship between proportion of barrier habitat within 15.8 km of ringing location and natal dispersal distance of female birds recovered dead.



4.4 SUMMARY OF KEY RESULTS

Dispersal distance varied with type of movement; chicks moving away from the natal site moved further than adults moving breeding season to breeding season or between breeding and non-breeding seasons.

Chicks moving from the nests did so within the first nine fortnights of ringing, during which time dispersal distance increased. After this point, dispersal distance decreased slightly before reaching a plateau.

Female chicks dispersed further than males and dispersal distances were subject to regional variation.

There was significant evidence of habitat influencing dispersal distance; breeding and natal dispersal distance were positively associated with suitable and barrier habitats, i.e. those habitats where Barn Owls might forage, such as semi-natural grass, and those expected to restrict movement, such as montane, urban and woodland habitats. Those habitats classed as unsuitable for Barn Owls (arable and improved grass) were negatively associated with dispersal distance

5. DISCUSSION

Barn Owl, by Paul Newton/BTO

Analysis of the BTO ring-recovery database allows examination of dispersal patterns across Great Britain. The work here represents a significant update of that by Wernham *et al.* (2002), allowing analysis of records post-1998 and the inclusion of live recaptures.

The avoidance of in-breeding is a powerful evolutionary driver behind the dispersal of chicks from their natal areas, and this is reflected in the results of this study, as well as in previous research (Wernham *et al.* 2002, Bunn *et al*. 1982). The median natal dispersal distance of chicks recovered dead was lower than that reported in the *Migration Atlas*, but this earlier work was based on a sample of 384 chicks, compared to (and included in) the 1,439 records analysed here.

The larger dataset allowed analysis of movements within the first 12 months of ringing at a finer temporal scale than in the *Migration Atlas*, revealing a peak in dispersal in birds recovered nine fortnights after ringing. This peak is higher than distances dispersed by chicks recovered later in the year, and higher than the median dispersal distance of chicks, both within the first year and to recovery locations in subsequent breeding seasons. This could indicate that after initial exploratory movements further afield, chicks return to locations slightly closer to the natal site to settle, as has been observed in Buzzard (*Buteo buteo*) chicks (Walls & Kenward 1998).

Alternatively, the result may be a product of mortality rates; dispersal distances of birds recovered later in the year or in subsequent breeding seasons can only be of those that survive to that point. The daily mortality risk of chicks decreases with time after fledging (Bunn *et al.* 1982). Of course, one of the factors contributing to mortality risk could be dispersal distance itself; those wandering further from the natal site earlier may be at greater risk than those remaining close to the natal site (inexperience, being away from parents providing food, etc.). The dispersal distance of birds recaptured alive followed a similar pattern, although dispersal movements began slightly later (not starting until fortnight five) and peaked later (fortnight eleven). This may be a reflection of the distribution of recapture effort; recaptures near the natal site are unlikely, so dispersal events are biased later and towards longer movements (when small scales are considered).

Female Barn Owl chicks dispersed further than male chicks, as has been reported previously (e.g. Taylor 1994, Marti 1999), but this variation disappeared in adulthood. Some regional variation in natal dispersal distances was found, both within the first 12 months after ringing and in movements to subsequent breeding seasons (in contrast to Wernham *et al.* 2002 and Percival 1990). This variation was true of juveniles recovered either live or dead but, for birds ringed as chicks and recovered in any subsequent breeding season, the variation was only seen in dead recoveries. Similar regional variation in breeding dispersal distances of birds recaptured alive was also found.

Significant associations were found between the proportion of habitat within ringing or route buffers and movements of adults moving from breeding season to breeding season (dead recoveries), and of chicks moving from the natal site to breeding season locations (dead recoveries). For adults, breeding dispersal distance was positively associated with the proportion of all three habitat groups in route buffers

(Table 13). Models suggested significant quadratic relationships with habitat, although removal of outliers tended to remove these quadratic effects, so they were not strongly supported by the data. Using suitable habitat as an example, the model suggests an 'n'-shaped relationship, with distance increasing until a peak proportion of suitable habitat is reached, after which distance decreases (Fig. 9). This curve is likely, however to be influenced by two data points where the proportion of suitable habitat was greater than 60%. By removing these points, and therefore removing the downward pull, only the linear term remained significant (Fig. 9). The quadratic curve could be a genuine effect, but without further instances of high proportions of suitable habitat, the position of the peak in the response cannot be reasonably estimated. It does at least appear that, at low occurrence of suitable and barrier habitats (Fig. 10), a positive relationship between dispersal distance and habitat availability is observed. A negative relationship is observed at high occurrence of unsuitable habitat within the route buffer, and a nearly significant positive relationship at low proportions of unsuitable habitat (Fig. 11).

A similar pattern could be seen for chicks dispersing from natal sites to breeding season locations, with a positive relationship between dispersal distance and barrier habitat, and a negative relationship with unsuitable habitat (Table 15). The positive relationship with barrier habitat was also indicated for natal dispersal of live recaptures, although this was not quite significant ($p=0.06$, Table 16). For dead recoveries, a quadratic relationship with the proportion of suitable habitat was indicated, although, in this instance, removing outliers removed any significant relationship with suitable habitat. Examining habitat influences on dispersal distances of male and female chicks again showed the negative relationship between the proportions of unsuitable habitat in the route buffer for female chicks, but also indicated a negative relationship with the proportion of unsuitable habitat within 15.8 km of the ringing location (Table 17). This relationship was n-shaped, again showing a negative relationship when unsuitable habitat made up a high proportion of buffer habitat (Fig. 13). A similar curve was produced for barrier habitats, with a positive association between female chick dispersal distance and proportions of barrier habitat at low proportions of barrier habitat, and the reverse relationship at high proportions of barrier habitat (Fig. 14).

The results above highlight some important caveats to the data, notably that of high variation around the relationships identified. Data points were highly scattered, indicating large variation in dispersal distances. Although some habitat effects are indicated by the models, it is clear that these alone cannot explain the variation in dispersal distance because of the enormous unexplained variance, or scatter, in the graphs shown (see, e.g., Figure 9–10). It is likely that there are numerous other factors affecting distances dispersed, such as where recovery or recapture can occur in practice, fine details of habitat quality not revealed by land cover (e.g. vegetation type or fine-scale heterogeneity) and stochastic variation (e.g. whether a bird happens to be crossing a road at the point in time that traffic is passing). In future analyses, with ever increasing datasets and thus improved sample sizes, as well as better quality habitat data, for example from more sophisticated remote sensing, it should be possible to investigate more of these potential influences. In a recent study by Hindmarch *et al.* (2012) the length of highways near nest boxes was identified as important in describing the probability of nest box occupancy while the continued occupancy over time was influenced by an increase in traffic exposure. This emphasises the importance of local influences on distribution and in turn dispersal patterns, which may only be apparent from tracking or fine-scale habitat data. It also suggests the influence the railway line itself may have on settlement patterns.

The model results reported here can therefore inform decisions to minimise risk to Barn Owls, but they cannot be used to infer absolute risk, due to the other variables involved that are currently unaccounted for.

Another important caveat to these results is the question of location accuracy. Records in the ringing database are accurate to 1 km; any birds that are recovered within the same square will be recorded as not having moved. There were many examples of 0 km dispersal distances, which could indicate either a return to the same nest box or to another location within the same square, or mortality near the nest site. Conversely, a bird recovered in a square neighbouring its ringing location will be recorded as having dispersed 1 km, when in some instances this bird will have travelled a shorter distance than the previous example. When dealing with small-scale movements, this precludes analysis of some dispersal types (inter-seasonal movements and breeding dispersal by live recoveries). The median dispersal distance of other groups was >5 km, which therefore should overcome these issues because habitat patterns at scales of less than a 1 km square are too small to be relevant. However, all analyses will potentially have been affected by the habitat data used being imprecise, i.e. informing about the 1 km square scale, and not the (much smaller) scales at which Barn Owl movement decisions must operate.

Route buffers were used to examine habitat influences on dispersal distances in tandem with buffers around ringing locations. Other than for female chicks, no significant associations between habitat and dispersal distance were found using the ringing buffers. These buffers were set using the 75th percentile dispersal distance, to include the majority of movements from ringing to recovery location but to exclude very long movements that might otherwise influence the results unduly, as buffers would then become very large. However, many dispersal movements will have occurred within a smaller core, or will have been restricted into a particular area due to habitat availability, so the circular buffer approach may be a poor representation of habitat influences and their spatial arrangement, especially when buffers are large. The alternative, route buffer, approach should give a better indication of the real habitat features that would have affected dispersal to reach the recovery location. However, the caveat with this route buffer approach is the assumption of a straight line-route between ringing and recovery locations, which of course is unlikely to reflect reality. By nature of this being a route buffer, only birds that were recorded as having moved between ringing and recovery or recapture locations could be included. Birds that did not move beyond the 1 km square in which they were ringed may have been limited by habitat availability, but this will not be indicated in the results.

Dispersal distances of birds recovered dead and those recaptured alive differed, with those recaptured alive travelling shorter distances. As mentioned in the Methods section, this is likely to reflect biases in the distribution of recapture methods, as the majority of live recaptures will be in nest boxes. The main source of dead Barn Owl recoveries is through road collisions. It is possible that some birds may be transported on vehicles between collision and recovery locations, thus artificially increasing the dispersal distance. Where a bird is suspected to have been moved to the recovery location, this is coded in the database, but it is possible that some instances of this remained undetected. One way to eliminate this problem would be to omit all roadside fatalities, but this would result in a much reduced sample size. It is likely that the number of occasions on which birds are moved significantly in this way makes up only a small proportion of the data. The bias in differences between live and dead dispersal distances appears to be constant, so future analyses could perhaps combine dead recoveries and live recaptures with the use of a correction factor to account for this bias.

6. CONCLUSIONS

In considering optimal location for mitigation and enhancement measures to avoid unacceptable mortality risk to Barn Owls from HS2, a number of factors must be considered. As adults, Barn Owls are fairly sedentary, travelling an average of 2.2 km from breeding site to breeding site or 2.8 km from breeding season to non-breeding site or vice-versa. This means that breeding populations can be considered to be stable, spatially, at scales of larger than 2–3 km, which is consistent with reported home ranges of Barn Owls (3 km^2, Bond *et al*. 2005, Taylor 1994), and that impacts of the railway on birds further than this from it will not be significant. Enhancement measures for Barn Owls should, therefore, be focused over 3 km from the track.

It is also noteworthy that the south-east region, in which the first phase of HS2 lies, is the region in which Barn Owls are most sedentary. For chicks, however, dispersal distances are longer; the highest median distance dispersed by chicks from the natal site to a subsequent breeding site was 7.8 km, but 75% of movements occurred within 15.8 km of the ringing site. These distances may vary with region and there is some evidence that habitat type influences dispersal distance. The large quartile range of dispersal distance indicates the variation in movements, thus the optimum location of mitigation measures is hard to quantify precisely. Impacts of the railway could extend to over 15 km for dispersing chicks, but the majority of chicks do not disperse so far, so considering protection at such a distance may be overly cautious. It is important to note that the post-fledging period carries the maximum daily mortality rates, thus an additional footprint of HS2 on more dispersive individuals may not be significant biologically.

There is a fairly consistent indication that unsuitable habitat is negatively related to dispersal distance (at least at higher proportions of unsuitable habitat), while suitable and barrier habitats are positively related to it. This suggests that the birds may be restricted in movements where habitats tend to offer fewer resources, but that they are motivated to move further through better habitat or where they have to travel around barriers. Appropriate action to minimise Barn Owl movements in the vicinity of the railway line would appear to be to introduce high quality habitat further from the railway line, and to be cautious with barrier habitat, which may not be effective in reducing movements. Intensive farmland was classified as unsuitable habitat in the analysis, which appeared to restrict dispersal movements, so these habitats might be effective in ensuring Barn Owls do not interact with the railway line. However, the analyses conducted here are coarse and within such 'unsuitable' habitat, fine-scale features, such as field or ditch margins, are likely to be present that might actually be suitable for Barn Owls. Thus caution must be taken in adopting such an approach. Direct observation of movement behaviour, for example via satellite tag tracking, may be required to identify such habitat influences definitively. More generally, variation in dispersal distance is high, reflecting influences of various other factors besides habitat, movement type and time between ringing and recovery events. Evidence of response to habitat varying with sex indicates the complex relationships that are at play. Variation due to factors that have not been considered explicitly here (such as fine-scale habitat, for which data were not available), could have important effects on movements and this should be borne in mind in any applications of the results.

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9. Glossary

Pullus (pl. pulli): Young chicks not yet able to fly

N: Sample size, in this case number of birds

z: Test statistic from Wilcoxon rank tests, used to test differences between two samples. The z statistic can then be used to obtain a p value to determine whether the samples are statistically different from each other.

H: Test statistic from Kruskal-Wallis test, used to test differences between more than two samples. The h statistic can then be used to obtain a p value to determine whether the samples are statistically different from each other.

D.f.: Degrees of freedom. The number of data points that are free to vary; these are used to calculate the p value of the test statistic.

p: The p value of a test is the probability that the result obtained is the same as expected if there were no difference between samples

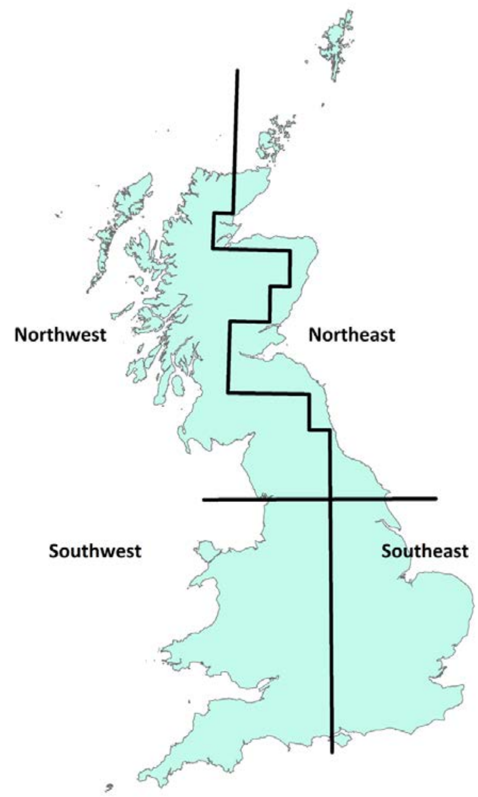
Statistically significant: Differences between samples are statistically significant if the p value obtained is lower than 0.05. In other words, there is less than a 5% chance of the difference observed being due to chance.

Quartile range: A measure of variation within the data, this is the range of values within which 25–75% of the data fall.

5th or 95th percentile: An additional method of showing variation within the data. Five percent of data points fall under the 5th and over the 95th percentile.

Stochastic variation: Unexplained or random variation in the system.

Regions: the regions used in these analyses were:





Images: Mike Toms; Paul Newton; John Harding. Cover image: Paul Newton.

Informing best practice for mitigation and enhancement measures for Barn Owls

The introduction of the High Speed Two (HS2) rail line represents a national-level impact on Barn Owls and appropriate measures have been identified as required to minimise and to mitigate the mortality risk. Examining patterns of Barn Owl movement and influences upon them can help to determine where such measures should be placed, in order to ensure that Barn Owls new measures do not have unintended negative effects from attracting birds to the vicinity of the railway line.

Using the BTO's ring-recovery database we have been able to analyse dispersal movements, with the aim of providing insight into Barn Owl movements in the UK. The results of this work suggest that new, high-quality habitat aimed at mitigating negative effects of HS2 on Barn Owls should be located between 3 km and 15 km away from the railway route, depending on the importance placed on minimizing juvenile, as opposed to adult, mortality. Further, introducing barrier habitats may not be effective at restricting movements. Instead, locating poor quality foraging habitat near the railway line (or removing high-quality habitat) could help to minimise train strikes by restricting movements. However, this conclusion must be applied with caution because the results involved considered habitat only at large spatial scales. Nominally unsuitable habitat, such as intensive farmland, may actually include significant fine-scale habitat features that attract Barn Owls.

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