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The Interactions between Barn Owls and Major Roads: Informing Management and Mitigation

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Executive Summary

The development and expansion of road infrastructures represents one of the most widespread forms of modification of the natural landscape over the past century. Roads have altered ecosystems and directly and indirectly effect a wide range of wildlife species. One of the most obvious effects of roads on wildlife is mortality caused by vehicle collisions. Barn Owls *Tyto alba*, due to their low flight and hunting behaviour, are particularly susceptible. Vehicle collisions are a major cause of death for Barn Owls and have been implicated as a contributing factor in the decline of their populations in Europe. The extent of road mortality and the route and landscape characteristics which influence risk of collision have been reported for specific road systems; however, the implementation of effective and evaluated mitigation solutions to minimise negative effects of roads on Barn Owl populations remains a significant challenge. In addition to knowledge on the nature and effects of road mortality, an understanding of the individual behaviour response and interactions of Barn Owls to road networks is necessary to identify potential for evidence-based mitigation solutions. In this context, to determine Barn Owl interactions with roads in relation to mortality patterns, we investigated: (i) the extent of road mortality and factors which influence Barn Owl vehicle collisions, (ii) the suitability of roadside verges for foraging Barn Owls, (iii) the spatial distribution, occupancy and breeding performance of Barn Owls in relation to road networks, and (iv) the foraging behaviour and movement patterns of individuals in relation to major roads.

We collated data on Barn Owl mortality incidents in the Republic of Ireland (2008–2017), which showed the species to be vulnerable to a wide range of natural and human-related pressures on a national scale. Of 423 recorded mortalities (2008–2017), 312 (73.7%) were attributed to vehicle collisions, of which the majority were on motorways (60.2%). The number of Barn Owl road casualties recorded were 15 times higher on motorways than on national roads, relative to route length. Juveniles were killed with greater frequency (n=79; 67.5%) than adults (n=39; 33.3%), with peaks in road fatalities in late autumn and winter, coinciding with the post-breeding dispersal period. One third (n=75; 34%) of road mortalities were recovered during the breeding season (March-July), which is a higher proportion than reported for other Barn Owl populations.

A road casualty survey on the M8 Motorway (96km) and the Tralee Bypass (13.5km), carried out once per day over two years (2016–2017) and once weekly over 144 weeks respectively (2014–2017), provided the first evidence of the extent of Barn Owl mortality on major roads in Ireland. We estimated a mortality rate of 51 and 60 Barn Owls per 100km per year on the M8 Motorway and Tralee Bypass respectively, when the number of carcasses recovered were adjusted for search and removal bias. These figures are within the mid or higher range of estimates for Barn Owl mortality on major roads in Europe. Road mortality locations on the M8 Motorway were clustered and significantly influenced by the proportion of grass and herbaceous cover in the roadside verge (p=0.03). This indicates that birds were attracted to suitable foraging conditions in the verge, which resulted in increased risk of collision. In contrast, we did not observe clustering of road mortalities on the Tralee Bypass. Analyses of spatial patterns of road fatalities on the M8 Motorway showed that more Barn Owls were killed in close proximity to junctions (p=0.03) and road lighting (p=0.03) than expected. There was no significant relationship between the distribution of Barn Owl road mortalities and road height, altitude and distance to linear features or traffic volumes, all of which have been previously reported to be important in determining occurrence of Barn Owl mortality on European roads. We modelled the probability of use for Barn Owls in the wider landscape and showed that high elevation areas influence movement patterns which may cause increased encounter rates and mortality on roads which traverse areas of high probability of use. This predictive tool can be used alongside data on the route and habitat conditions close to the road to identify potential hotspots for road mortality on new and existing road schemes.

To investigate the potential importance of motorway verge habitats as a foraging resource for Barn Owls, we assessed small mammal populations in roadside verges and in hedgerows in the surrounding landscape. We recorded 1,912 small mammal captures of four species.

The Bank Vole *Myodes glareolus* represented nearly half of all captures (47.6%), followed by Greater White-toothed Shrew *Crocidura russula* (29.1%) and Wood Mouse *Apodemus sylvaticus* (19.8%). The overall number of individual small mammals trapped in motorways (n=727) and hedgerows (n=663) were comparable. Small mammal abundance was similar between motorway and hedgerow sites (p=0.276), although species richness was higher on motorways (p<0.001). Our data indicates that motorway verges provide biodiversity benefits as they support a similar abundance and greater diversity of small mammal species as hedgerows in the surrounding countryside and represent a potentially important foraging resource for Barn Owls.

We showed no significant effects of major roads on Barn Owl breeding densities and distribution, which differs to the reported negative effects of roads on Barn Owl distribution and densities in Great Britain. Barn Owl breeding densities were comparable in an area surrounding the M8 Motorway (1–1.3 pairs per 100km^2) to an area of similar size, habitat and landscape conditions where there were no major roads (1.3–1.7 pairs per 100km^2). The breeding population size surrounding the M8 Motorway and the Tralee Bypass (1.5–2.2 pairs per 100km^2) were above the average breeding density recorded in Ireland (0.8–1 pairs per 100km^2). There was no significant difference in the distribution of Barn Owl breeding sites relative to the M8 Motorway (p=0.38) and the Tralee Bypass (p=0.49) compared to the expected distribution. This was also the case on a national scale, as we showed that the known national distribution of Barn Owl breeding sites (n=259) was not influenced by the motorway network (p=0.6). Within 5km of the M8 Motorway and Tralee Bypass, the average distance of Barn Owl breeding sites to the road was 2.2km and 2.4km respectively, with pairs nesting as close as 400m to a major road. As the majority of nest sites close to major roads remained active over the survey period, our findings confirm that Barn Owls can successfully nest in close proximity to major roads over consecutive years and that distribution of the population is not significantly affected by major road networks. However, uncertainty over individual survival and turn-over at breeding sites remains.

GPS dataloggers were successfully fitted (under licence to NPWS and the BTO) to 11 adult breeding Barn Owls in 2016 and 2017, which facilitated the collection of high-resolution data on Barn Owl movements and behaviour in relation to major roads for the first time. We showed that GPS technology can be successfully employed to collect extensive and high quality data on Barn Owls without negative impacts to individual birds or breeding performance. The minimum convex polygon (MCP) home range size for Barn Owls was on average 3,059ha (n=10, range=991-9, 259ha), which is considerably larger than reported for Barn Owls elsewhere in Europe. We showed that there was no avoidance effect of major roads in terms of the establishment of home ranges and general movements of Barn Owls. Of six birds which nested within 5km of a major road, four included the road within their MCP home range and their 95% kernel density estimator home range. Birds frequently crossed major roads (1.4–19 times per night), showing that these infrastructures do not present a barrier to Barn Owl movements. Barn Owls spent proportionally more time close to (≤20m) major roads than expected (p< 0.001), which indicates positive selection of major roads, and proportionally more time hunting (p< 0.001) when close to major roads than expected.

Based on our findings, we propose a series of mitigation strategies to minimise mortality and the effects of major road infrastructures on Barn Owl populations in the Republic of Ireland.

1. Barn Owl Mortality on Roads

1.1 Introduction

There is growing evidence of the negative impacts of roads on wildlife and ecosystems, suggesting that these infrastructures contribute to the loss of biodiversity (Forman *et al.* 2003). One of the most obvious direct effects of roads on wildlife is mortality caused by vehicle collisions (Malo *et al.* 2004). The increases in traffic and expansions to road infrastructures which have occurred throughout the world have coincided with the continued increase in the extent of road casualties of wildlife (Newton *et al.* 1997, Seiler *et al.* 2004). Vehicle collision is now the main cause of death for a diverse range of species (Bangs *et al.* 1989, Maehr *et al.* 1991, Newton *et al.* 1991, Taylor and Goldingay 2010) and can alter population demographics and increase risk of extinction for vulnerable species (Van der Zee *et al.* 1992, Schwab *et al.* 2011, Borda-de-Água *et al.* 2014). Barn Owls are particularly susceptible to vehicle collisions (Illner 1992, De Bruin 1994, Massemin and Zorn 1998, Ramsden 2003, Boves and Belthoff 2012). Several studies to assess avian mortality on roads have recorded Barn Owls as the most frequently affected raptor (Massemin and Zorn 1998, Shawyer and Dixon 1999), or the most frequently affected bird species (Baudvin 1997, Boves and Belthoff 2012, Loss *et al.* 2014). The relative importance of road fatalities as a cause of death for Barn Owls appears to be increasing (Newton *et al.* 1997) and there are significant concerns over the impacts of this form of mortality on Barn Owl populations throughout their range. A number of mitigation measures to reduce Barn Owl vehicle collisions have been proposed (Ramsden 2003, Highways Agency 2013). However, the implementation of evidence-based and evaluated mitigation solutions to minimise negative effects of roads on Barn Owl populations remains a significant challenge. The requirement and direction of effective mitigation solutions should be informed by an understanding of the factors which influence risk of collision and the impacts on individual populations (Clevenger *et al.* 2003), critical to which is identifying the extent of road mortality for specific populations. Accurate estimates of rates of wildlife road mortalities are difficult to obtain (Kociolek *et al.* 2011), and it is necessary to recognise the limitations and the most appropriate methods of assessing the extent of road mortality, which is required to understand the wider effects of roads on Barn Owl populations and ultimately inform mitigation action.

Road collisions are a major cause of death for Barn Owls in Europe and North America (Bunn *et al.* 1982, Baudvin 1997, Newton *et al.* 1991, de Bruin 1994, Taylor 1994, Boves and Belthoff 2012). Newton *et al.* (1997) showed that vehicle collision was the main source of mortality for Barn Owls in Britain, based on mortality incidents reported by the public, and that casualty rates have increased alongside the expansion in road infrastructures, from 6% of recorded deaths between 1910 and 1954, to 50% between 1991 and 1996. There are however numerous constraints to be considered when assessing the relative importance of road traffic accidents as a cause of mortality for Barn Owls. There is potential to overestimate vehicle collisions as a cause of death due to methodological bias (Illner 1992). The probability of finding a road casualty victim is likely to be greater than a bird which died of other causes, and therefore the ratios of recorded causes of death may not be representative (Newton 1979). To determine the extent of Barn Owl mortality on roads, many studies have employed systematic searches to record Barn Owl casualties. In Britain, an intensive search of a 50km section of single and dual carriageway over a two-year period provided an annual casualty rate of 68 Barn Owls per 100km, from which a casualty rate of 3,375 Barn Owls on the trunk and major road network of Britain was extrapolated (Shawyer and Dixon 1999). In Switzerland, seven Barn Owl casualties per 100km were estimated on an annual basis along a 36.9km stretch of motorway (Bourquin 1983). Two studies in north-eastern France estimated annual casualty rates of 65 Barn Owls per 100km along a 259km stretch of motorway (Baudvin 1997) and 25 Barn Owl casualties per 100km per year on a 150km stretch of motorway (Massemin and Zorn 1998).

Estimates of Barn Owl road casualty rates from different studies may not be directly comparable however, as sampling bias related to locating and recording Barn Owl road casualties can be influenced by search effort, removal of carcasses by scavengers, habitat conditions and other site-specific factors (Santos *et al.* 2015). Erritzoe *et al.* (2003) suggested that the manner of surveying the road can significantly affect the number of casualties detected, and that surveys conducted by car can overlook smaller birds. The timing of surveys is also important. Based on a review of road casualty studies, Erritzoe *et al.* (2003) recommended that daily or weekly surveys may be appropriate if potential sources of bias are identified and catered for to derive road casualty estimates. Boves and Belthoff (2012) showed that Barn Owl road casualties were likely to be under-recorded by standard search methods, and when the number of Barn Owl casualties recovered by standard methods were adjusted for search and removal bias, this significantly increased (2–4 times) the estimates of casualty rates on a road which was regularly surveyed in Idaho. Their findings indicate that estimates produced by road casualty surveys which do not take these forms of bias into account are likely to significantly under-represent the true casualty rates, and thus compromise assessments of the effects of such mortality on Barn Owl populations.

Regardless of the extent of road mortality, this data in isolation does not infer negative effects on a population. Road-related fatalities may have a significant impact on isolated, declining or endangered populations, but even high rates of road mortality may not impact a healthy population (Mumme *et al.* 2000, Ramsden 2003, Kofron and Chapman 2006, Glista *et al.* 2008). The time of year mortality occurs, demographics and health of individuals affected may influence the effects on a population. The majority of studies which have assessed the timing of road mortalities have shown that most Barn Owl road fatalities occur during the post-fledging period in autumn (de Bruijn 1994, Taylor 1994, Shawyer and Dixon 1999, Boves and Belthoff 2012). Several studies have reported female Barn Owls to be killed on roads with greater frequency than males. This has been attributed to the fact that females typically disperse over greater distances (Taylor 1994, Boves and Belthoff 2012). Massemin *et al.* (1998) indicated that immature Barn Owl road casualties recovered were in good body condition, based on a comparison of body weight to captive birds of similar age. An examination of body weights of carcasses which were recovered on roads in Devon also showed no indication that Barn Owl road casualties were predominantly weak or underweight individuals (Ramsden 2003). Shawyer and Dixon (1999) also reported that the majority of Barn Owl road casualties on roads in England were in good condition, with less than 15% of birds examined having lower than average body weight. Taylor (1994) however assessed body condition of adult Barn Owl road casualties and compared these to live birds, concluding that individuals in poor condition were over-represented as road casualties.

Although many studies have reported road-related mortality to be a significant factor in the context of other forms of mortality, fewer studies have attempted to assess the impact of road networks on Barn Owls populations. Illner (1992) assessed the overall effect of road casualties on Barn Owl population trends and estimated that collision with vehicles accounted for approximately 10–15% of adult Barn Owl deaths in Germany and suggested that these losses were likely to have a significant impact on the population. A study over an eighteen-year period in the Netherlands, attributed long-term Barn Owl population declines in the region to increases in major road networks (De Bruin 1994). Borda-de-Água *et al.* (2014) developed age structured simulations to model the impact of road kills on Barn Owl populations and their risk of extinction in Portugal, showing that road mortality was below the values for which there is risk of extinction, but their findings indicated that deaths on roads have the potential to affect Barn Owl populations at the local level. It is clear that the extent of mortality and the potential impacts of road networks on Barn Owl populations vary according to a range of biotic and abiotic factors and on a site-specific basis, highlighting the importance of understanding these factors for individual populations to inform conservation and mitigation action.

The objectives of this study were to determine the extent and patterns of Barn Owl mortality on roads in Ireland. We compiled the largest and longest running dataset of Barn Owl mortality incidents in the Republic of Ireland and conducted systematic surveys of selected routes to:

i. Identify spatial patterns of Barn Owl road casualties, including road types and geographic distribution
ii. Determine temporal trends of Barn Owl deaths on roads
iii. Identify the demographics and condition of Barn Owls killed on roads
iv. Determine Barn Owl road mortality rates on selected major roads, to inform the extent of road mortality on a national scale

1.2 Methods

1.2.1 Study Area

To assess spatial and temporal patterns of mortality for Barn Owls and to identify the demographics of individuals affected, we collated information on Barn Owl mortality on a national scale in the Republic of Ireland. To determine the extent of Barn Owl mortality on roads, we selected two routes to perform systematic surveys to generate estimates of Barn Owl casualty rates. The routes selected were the N22 Tralee Bypass and a section of the M8 Motorway in the south of Ireland (Figure 1.1). The N22 Tralee Bypass in County Kerry consists of a route length of 13.5km, of which 8km is a Type 2 dual carriageway and 5.5km is a standard two-lane single carriageway. The survey area on the M8 Motorway consists of a 96km section of dual-lane carriageway which runs from the border of Counties Kilkenny and Laois in the north, to Junction 14 in north County Cork at its southernmost point. The survey route predominantly runs through County Tipperary, extending into County Kilkenny in the north and Counties Limerick and Cork to the south.

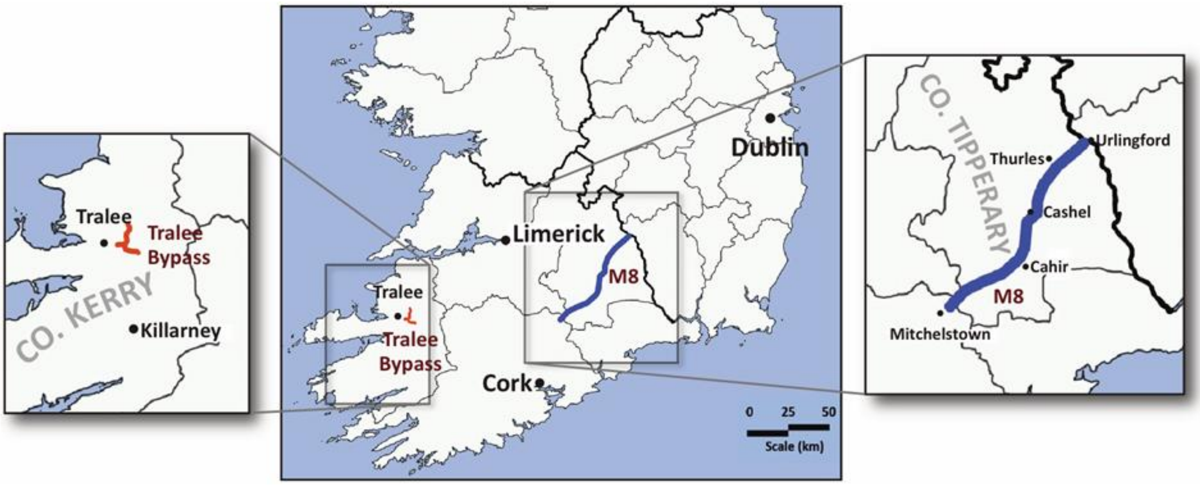


Figure 1.1 The study area selected to investigate Barn Owl mortality on major roads in Ireland, which includes two routes: a section of the M8 Motorway (96km) predominantly in County Tipperary and the Tralee Bypass (13.5km) in County Kerry.

1.2.2 Barn Owl Mortality Incidents

We compiled data on Barn Owl mortality incidents in the Republic of Ireland for the period 2008–2017. Information on Barn Owl mortalities were collated from a range of sources including monitoring studies, targeted requests via media (newspaper, magazine and website articles, social media and radio interviews) and direct requests to relevant individuals, organisations and institutes on a national basis (including ecological research institutes, conservation organisations, birdwatching groups, the National Parks and Wildlife Service (NPWS), professional ecologists, veterinarians, wildlife rehabilitators, falconers, and taxidermists). Data on Barn Owls from ringing studies in the Republic of Ireland for the period 2008–2017 were also collated. This included records of all Barn Owls ringed and recovered (Barn Owls which were ringed and subsequently recorded and reported dead) with associated information on the cause of death where available.

All reports of Barn Owl mortality incidents received were vetted by either retrieving the carcass or reviewing a photograph or description of the carcass provided by the reporter. All records which were potentially unreliable were omitted. Records of Barn Owls which had not fledged or were considered unlikely to have fledged at the time of death were also excluded.

All records of Barn Owl mortality incidents (2008–2017) were compiled in a single database using Microsoft Excel. A cause of death, where known, was attributed to each record, based on the circumstances of recovery according to one of the following categories:

- Collision with wires
- Drowned
- Fungal infection
- Human-related disturbance
- Predation
- Road casualty
- Shot
- Starvation
- Trapped in building/netting
- Unknown trauma
- Unknown cause of death

Each record was assigned to a year, month and date of recovery and to a breeding period as defined by the ‘breeding season’ (March to July) or ‘non-breeding season’ (January to February and August to December). The location of recovery was recorded using the Irish Transverse Mercator (ITM) coordinate system and assigned to a County and Province in the Republic of Ireland.

1.2.3 Barn Owl Road Mortalities

Additional criteria were recorded for all Barn Owl road mortalities. The carcasses were retrieved where possible to collate information on the age, sex and condition of individuals killed on roads. Carcasses were placed in a sealed plastic bag and labelled with the date, location (ITM coordinates) and details of the road on which they were recovered and stored in a freezer at -20°C for subsequent inspection. The road type on which the casualty was recovered was recorded using the following categories:

- Motorway
- Bypass
- National
- Regional
- Minor road

The age class of each carcass was determined by plumage characteristics, moult patterns and the development of the talon flange (Johnson 1991, Baker 1993, Taylor 1993, Shawyer 1998). All individuals were classed as ‘juveniles’ if they were in their first calendar year or recovered before March of their second calendar year, or ‘adult’ if the individuals were in their second calendar year, later than March, or older, at the time of death. This categorisation is informed by the Barn Owl breeding cycle, to distinguish between birds which were unlikely to have been recruited to the breeding population at the time of death (juveniles), and those which were likely or had potential to breed, i.e. adults (Shawyer 1998). The sex of each individual was determined, based on plumage characteristics (Baker 1993, Taylor 1993, Shawyer 1998).

To investigate the body condition of birds killed on roads, the carcasses of male road casualties which did not show signs of external haemorrhaging or decomposition were selected, defrosted for 24 hours and weighed to the nearest gram using a 600g Pesola spring balance. The body weight(g) of male road mortalities was compared to the body weight of a representative sample of live adult males which were weighed during ringing operations (2008–2017) in the Republic of Ireland. Females were not selected due to seasonal fluctuations in their body weight (Shawyer 1998).

To validate the methods employed for ageing Barn Owls, a sample of Barn Owl road mortalities were independently aged by two experienced Barn Owl researchers and the results were compared. To determine the accuracy of methods for sexing individuals, muscle samples were taken from a proportion of Barn Owl road mortalities to determine their sex by genetic analysis, and the results were compared with the sex assigned to the same individuals via visual inspection.

1.2.4 Barn Owl Road Casualty Rates

To determine the extent of Barn Owl road mortalities on major roads in the Republic of Ireland, a survey to record and retrieve Barn Owl road casualties was carried out on two selected routes: the Tralee Bypass and the M8 Motorway. These routes were selected based on prior evidence of Barn Owl vehicle collisions and existing baseline data on Barn Owl populations in their proximity. The survey methods employed for each route were broadly similar, with the differences in the survey schedule and techniques employed, detailed in the following sections for each route. All records of Barn Owl road mortalities on the survey route which were received from other sources (independent observers) over the course of the road casualty survey were checked on the same day as the report was received. All potential Barn Owl road mortalities on the survey route were inspected to confirm identification. The year, month and date of recovery was recorded for all Barn Owl mortalities and each was assigned to either the ‘breeding’ season (March to July) or ‘non-breeding’ season (January to February and August to December). The location of the road casualty was recorded with a hand-held Global Positioning System (GPS) unit using the ITM coordinate system. The position of the casualty on the route (central median, main line, hard shoulder or verge) and orientation (southbound, northbound, eastbound or westbound) were recorded. All Barn Owl carcasses were collected, placed in a sealed plastic bag and labelled with the date, location and road type and stored in a freezer at -20°C for subsequent inspection. The carcasses were aged, sexed and their body condition was assessed according to the previous methods outlined.

Tralee Bypass

The entire length of the Tralee Bypass (13.5km) was surveyed once per week over 144 weeks from the 29th of August 2014 to the 22nd of May 2017. The survey was undertaken every Thursday morning between 09:00 and 12:00hrs. The route was surveyed in both directions from a vehicle travelling at a speed of 20–35km per hour. All potential avian or mammalian road mortalities observed were visually inspected. All road casualties were identified to species level and confirmed Barn Owl mortalities were recorded and collected according to the methods previously specified. For comparison of mortality rates of Barn Owl and other species recorded on the Tralee Bypass, we used the number of Barn Owls recorded on survey visits only (i.e. excluded Barn Owls reported by independent observers) in order that these comparisons were valid.

M8 Motorway

A 96km section of the M8 Motorway (including slip roads and junctions) was surveyed once per day over a two-year period (2016–2017). The survey was carried out by road maintenance operatives who received specific training in the survey and recording methods. The survey was undertaken each day between 08:00 and 16:00hrs, commencing on the 1st of January 2016 and ending on the 31st of December 2017. Survey visits were carried out by a single road maintenance operative who drove the route (96km) in both directions at a speed of 70–90km per hour. All potential Barn Owl casualties observed were inspected and confirmed Barn Owl road mortalities were recorded and collected according to the previous methods outlined.

1.2.5 Search and Removal Bias

Trials were undertaken on the Tralee Bypass and M8 Motorway to identify the potential effect of search and removal bias and the efficiency of detecting Barn Owl road mortalities, based on the survey techniques employed. Barn Owl carcasses (hereafter referred to as trial carcasses) were placed at random locations on random dates along the Tralee Bypass between the 21st of March 2017 and the 14th of December 2017. The placement of carcasses was carried out without the knowledge of the surveyor for the road casualty survey with respect to timing and location of trial carcasses. All trial carcasses (n=26) were marked with coloured tape on the right leg so they could be distinguished from legitimate road casualties. The date, location, position on the road (central median, main line, hard shoulder or verge), and direction (southbound or northbound) was recorded for all trial carcasses. To determine detection rates of Barn Owl road mortalities, the proportion of trial carcasses recorded by the road casualty survey were determined. If trial carcasses were not recorded by the road casualty survey, then the location of each trial carcass was revisited on the same day as the survey had been carried out to ensure that the carcass was still in position at the time of the survey. On the M8 Motorway, it was not possible to replicate these trials due to health and safety reasons. Therefore, to assess search efficiency for the M8 Motorway road casualty survey, we recorded all potential Barn Owl carcasses which were reported by independent observers on the survey route (96km) over the survey period (2016–2017). The locations of reported Barn Owl carcasses were compared with the results of the road casualty survey to determine whether these potential Barn Owl carcasses had been recorded. In the event that a carcass had not been recorded by the road casualty survey, the surveyor was informed and revisited the location of the report to inspect and confirm the presence of a Barn Owl road casualty. In this way, it was possible to determine the proportion of Barn Owl road casualties known to be on the survey route which were recorded or missed by the survey and thus derive a search efficiency rate in the same way as for the Tralee Bypass.

We also assessed the rate at which Barn Owl road mortalities were removed from or alongside the road (i.e. no longer present or visible). Barn Owl trial carcasses were placed at random locations along the Tralee Bypass (on the hard shoulder or verge) between the 17th of March 2017 and the 14th of December 2017. An infrared motion sensor camera was fixed in position to focus on each trial carcass. The cameras were set to record video footage for 30 seconds when triggered, with one second intervals between events. Each carcass was checked daily over seven days to determine if it was still in position and visible. This duration of the trials was informed by the survey schedule of the road casualty survey, as seven days was the longest interval between survey visits, and thus if carcasses remained over that period, it was deemed that they were possible to record based on our survey methods. If the carcass was removed within the seven-day period, the day on which it was removed was recorded (1–7). The footage from the motion sensor camera was inspected to identify the process by which the carcass was removed or became no longer visible. For scavenging events, the species responsible, the date, day number relative to the placement of the carcass (1–7) and whether the carcass was removed in daylight or darkness was recorded. The proportion of carcasses which were removed by scavengers within seven days, and the length of time these carcasses remained visible was determined and used to calculate scavenging rates. It was not possible to conduct removal trials on the M8 Motorway and therefore the removal rates derived for the Tralee Bypass were used to inform removal bias for the M8 Motorway, on the basis that the main scavenging species are present in both survey areas (Balmer *et al*. 2013, Lysaght and Marnell 2016). The removal bias was adjusted accordingly for the difference in survey frequency between routes (survey conducted once weekly on the Tralee Bypass, and once daily on the M8 Motorway).

1.2.6 Data Analysis

All data analyses were carried out using R 3.1.2 (R Development Core Team 2015).

We used Chi Square analyses to investigate temporal patterns of Barn Owl mortality on roads to determine whether vehicle collisions occurred with greater frequency in certain months of the year than expected if road mortalities were random with respect to timing, and to determine if risk of vehicle collision is influenced by age class by comparing the number of juveniles and adults killed on roads against the null hypothesis of uniform distribution of age classes.

We used a two-sample T-test to assess whether the condition of Barn Owls (as measured by body weight) may influence their risk of collision on roads by comparison of the weight of male road mortalities with the recorded weight of live adult males, and to determine whether there was any difference in the dispersal distances travelled between males and females.

To estimate the extent of Barn Owl road mortality on the selected survey routes on the Tralee Bypass and M8 Motorway, we extrapolated the number of Barn Owl road casualties recorded to 100km per year based on the length of road surveyed and survey time period (no. road casualties recorded X 52/no. of survey weeks X 100/length of route(km)). This estimate was adjusted for search and removal bias (no. of Barn Owl road casualties per 100km per year X search efficiency rate X removal rate) to determine the estimated Barn Owl road casualty rate per 100km per year on the Tralee Bypass and M8 Motorway.

1.3 Results

1.3.1 Barn Owl Mortality Incidents

We compiled 423 records of Barn Owl mortality incidents in the Republic of Ireland between 2008 and 2017. The carcasses were retrieved for over half (n=217; 51%) of records, with species identification verified via photograph (n=18) or description (n=188) for all other records. Mortality incidents were confirmed in 21 counties in the Republic of Ireland, with most records in Counties Tipperary (n=193), Kerry (n=63) and Cork (n=46). The majority of Barn Owl mortalities were recorded in the south-west, with over two thirds of all incidents in Munster (n=346; 81%). The distribution of recorded Barn Owl mortalities per county are illustrated in Figure 1.2.

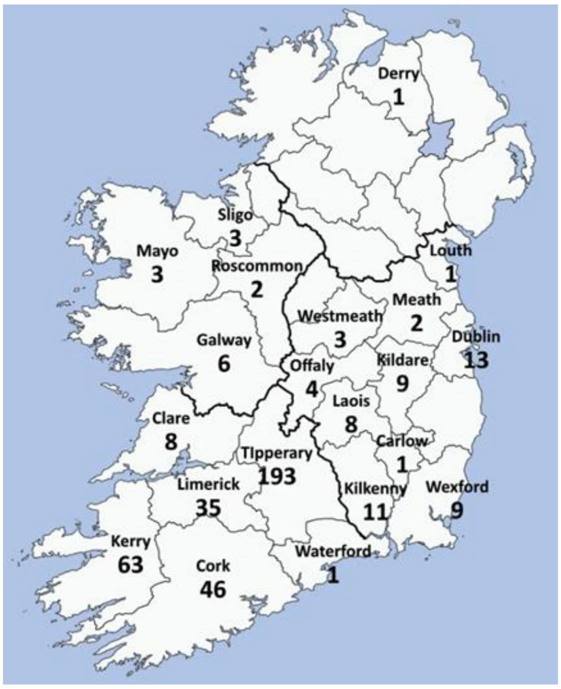


Figure 1.2 The number of Barn Owl mortality incidents (n=423) recorded per County in the Republic of Ireland (2008–2017).

**One record is omitted as the County in which it was recovered is not known. One record in County Derry in Northern Ireland is included as it originated from a nest in County Kerry and was recovered close to the border with County Donegal.*

1.3.2 Barn Owl Road Mortalities

Vehicle collision on roads (n=312) was the primary cause of death recorded for Barn Owls in Ireland between 2008 and 2017, representing just under three quarters (73.7%) of all recorded mortalities (n=423) (Figure 1.3). We recorded an average of 31 Barn Owl road mortalities per year on all road types (se=5.1, n=312, range=17–61). Barn Owl mortality on roads were confirmed in 19 counties in the Republic of Ireland, with the highest number of road casualties per county in County Tipperary (n=168), followed by Counties Kerry (n=37) and Cork (n=29). The number of road casualties recorded in each county is illustrated in Figure 1.4.

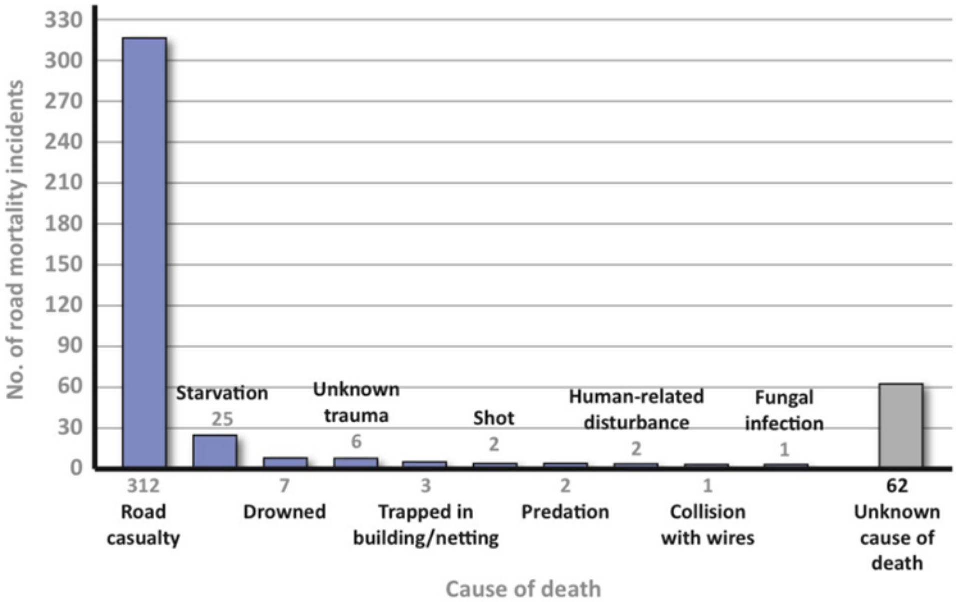


Figure 1.3 The recorded causes of mortality for Barn Owls (n=423) in the Republic of Ireland (2008–2017).

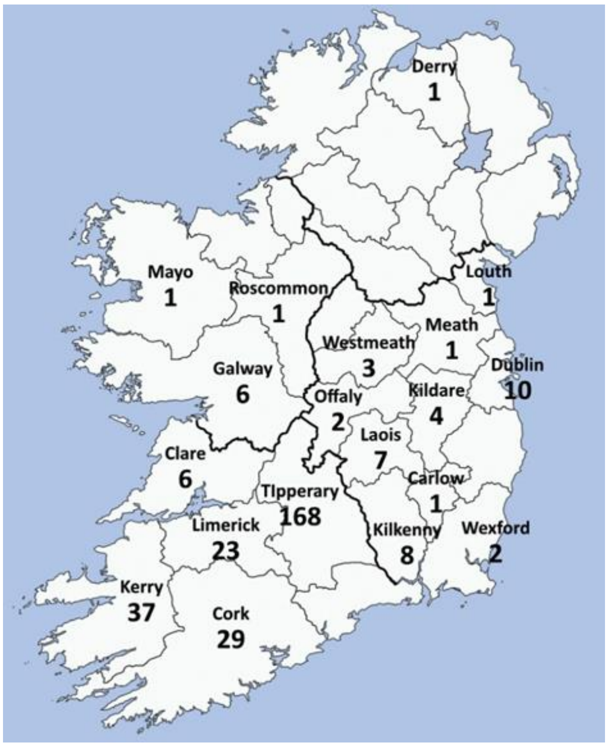


Figure 1.4 The number of Barn Owl mortality incidents (n=312) recorded per county in the Republic of Ireland (2008–2017).

A total of 979 Barn Owls were ringed in the Republic of Ireland by BirdWatch Ireland (BWI) between 2008 and 2017. Of all birds ringed (n=979), 66 (6.7%) were subsequently found dead (recovered), of which 11 were recovered in the nest site where they were ringed and were presumed not to have fledged. Of the 55 birds which had fledged, mortality on roads was the most frequent cause of mortality (n=27), representing 49% of all ringing recoveries (2008–2017) (Figure 1.5). The relative importance of vehicle collisions as a cause of mortality was lower for ringed birds (49%) than for all records of mortality causes (n=423; 73.7%). However, the cause of death was unknown (n=23; 42%) for a larger proportion of ringing recoveries compared to all records (14%).

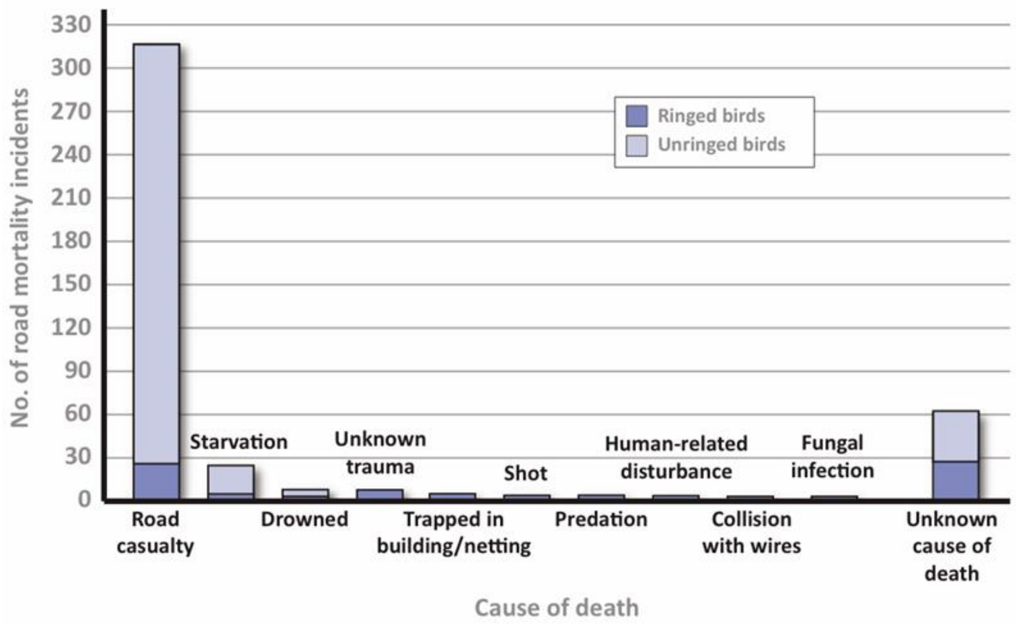


Figure 1.5 The cause of death of all Barn Owl mortality incidents (n=423) (light blue) and all ringed Barn Owls (n=55) (dark blue) in the Republic of Ireland (2008–2017).

Of 979 Barn Owls ringed in the Republic of Ireland between 2008 and 2017, 66 (6.7%) were recovered (n=55) or controlled (n=11) more than 2km from the location where they were ringed. The distance individuals dispersed ranged from 2–350km, with an average dispersal distance of 32km (se=6.5, n=64). Dispersal movements were similar between sexes (P=0.4) for the individuals for which it was possible to determine their sex (n = 44), with an average dispersal distance of 35.9km for males (se=9.3, n=23, range=3–158km) and 37.9km for females (se=16.3, n-21, range=2–350km). The dispersal patterns showing the location individuals were ringed and recovered or controlled are illustrated in Figure 1.6.

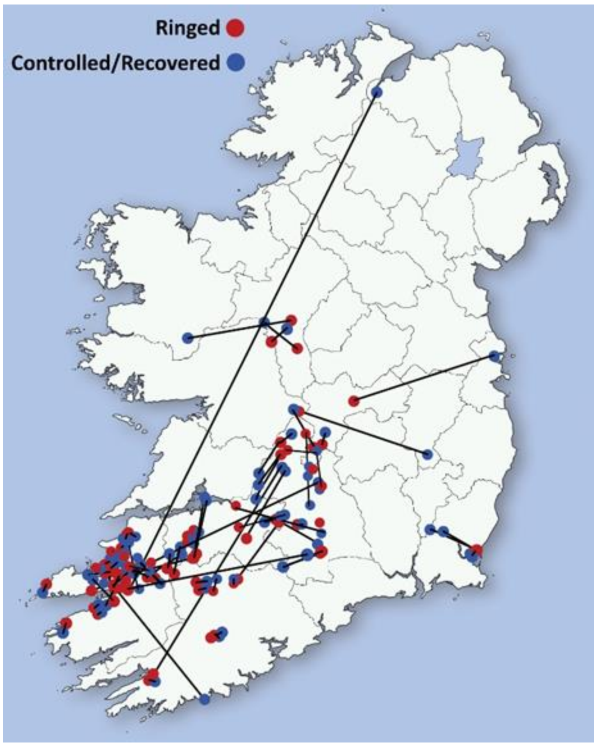


Figure 1.6 The dispersal movements (n=66) of Barn Owls ringed in the Republic of Ireland between 2008 and 2017. Only movements ≥ 2km from the origin of ringing were included. Red is the location where the bird was ringed, and blue is the location where the bird was recovered or controlled.

The majority of road mortalities (n=312) were recovered on motorways (n=188; 60%), followed by national roads (n=56; 18%) (Figure 1.7). Road mortalities were recorded in all months of the year but did not occur with the same frequency in each month (P=0.034). The highest number of road casualties were recorded in February (n=39; 12.5%), followed by September (n=37; 11.8 %), November (n=36; 11.5%) and October (n=35; 11.2%). The lowest numbers of road casualties per month were recorded in the summer months of May (n=11), July (n=14) and June (n=16). One third (n=75; 34%) of road mortalities were recovered during the 'breeding season' (March to July). The months in which Barn Owls were killed on roads are shown in Figure 1.8.

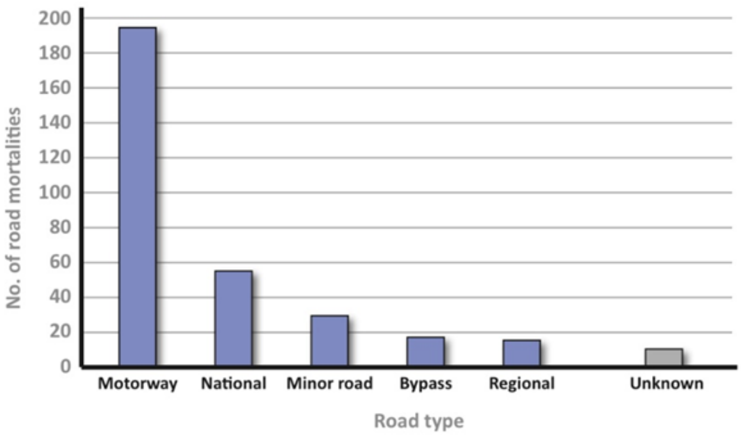


Figure 1.7 The road type on which Barn Owl road mortalities (n=312) were recovered (2008–2017).

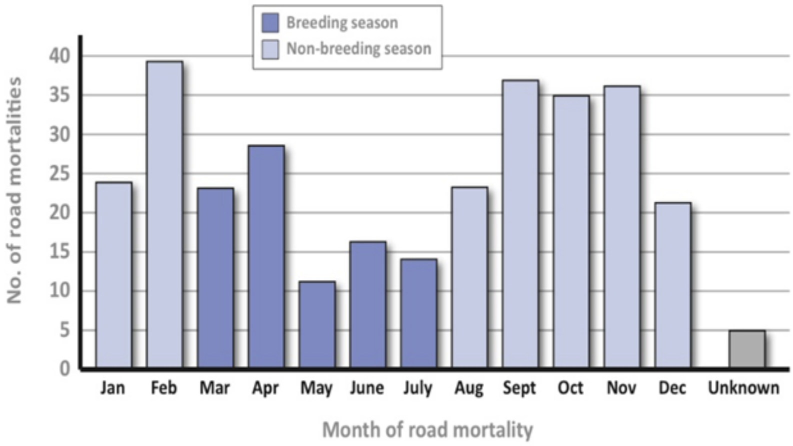


Figure 1.8 The number of Barn Owl road mortalities (n=312) recorded per month and according to breeding season (dark blue) and non-breeding season (light blue) from 2008–2017.

There were significantly more juveniles (n=79; 67.5%) killed on roads compared to adults (n=39; 33.3%) (P=0.008). A greater proportion of road casualties were male (n=62; 59%) than female (n=43; 41%). There was a significant difference in the body weight of male road casualties (n=34) and live adult males (n=54) (P=0.07), with road casualties being lighter (se=6.4, n=34, range 204–396g, mean=305g) than live males (se=3.1, n=54, range 265–385g, average=315g).

Assessing the sex of carcasses by visual assessment proved to be predominantly accurate, with 86% of carcasses (n=44) correctly sexed. A higher proportion of females were accurately sexed (94%) compared with males (81%). Validation of ageing methods indicated that of the sample of carcasses which were aged independently by two researchers (n=32), 87.5% of birds were assigned to the same age class.

1.3.3 Barn Owl Road Casualty Rates

A total of 13 Barn Owl road casualties were recorded by the road casualty survey on the Tralee Bypass (13.5km) over 144 weeks between August 2014 and December 2015. Of these, six road casualties were recorded on dedicated survey visits, seven were reported by independent observers, and subsequently inspected and confirmed. This equates to a minimum casualty rate of 34.8 Barn Owls per 100km per year on the Tralee Bypass during the study period.

In total, 79 wildlife road casualties were recorded on the Tralee Bypass on the road casualty survey, of which 65 (82%) were birds and 14 (18%) were mammals. Barn Owl (n=6) were the fifth most frequent species of all wildlife road casualties, and the third most frequently recorded bird species alongside Blackbird *Turdus merula* (n=6), and after Rook *Corvus frugilegus* (n=29) and Jackdaw *Corvus monedula* (n=9).

A total of 52 Barn Owl casualties were recorded by the road casualty survey on the M8 Motorway (96km survey route) in 2016 and 2017. Of these, 39 road mortalities were recorded on dedicated survey visits, nine road mortalities were reported by independent observers and subsequently confirmed, and the remaining four were recorded independently on both the road casualty survey and independent observers. This equates to a minimum casualty rate of 27.1 Barn Owls per 100km per year on the survey route of the M8 Motorway (96km) during the study period.

The survey efficiency trials showed that the road casualty survey recorded 19 (73%) of the possible 26 Barn Owl carcasses which were placed on the Tralee Bypass survey route. Of the seven trial carcasses which were not recorded, all were confirmed to have been in position at the time of the survey visit (and thus possible to record). Of 10 Barn Owl carcasses on the M8 survey route reported by independent observers, four were recorded by the road casualty survey, with the remaining six carcasses subsequently confirmed on follow up inspection.

Of the carcasses (n=18) used for the removal trials on the Tralee Bypass, one was recorded and collected by an independent observer, and therefore omitted from this trial. Of 17 trial carcasses, 11 (65%) were confirmed to be still in position and visible after a period of seven days. Of the six carcasses which were removed and/or no longer visible, three were removed on day 1, and one each on days 3, 4 and 6.

We estimated a road casualty rate of 59.8 Barn Owls per 100km per year on the Tralee Bypass when the number of road casualties recorded (34.8 Barn Owls per 100km per year) is adjusted for search and removal bias. When the number of road casualties recorded on the survey route of the M8 Motorway (27.1 Barn Owls per 100km per year) was adjusted for search and removal bias, this provides an estimate of 51 Barn Owl road mortalities per 100km per year on the M8 Motorway.

1.3.4 Road Mortality in Relation to Dispersal Movements

Three individual Barn Owls which had been fitted with a ring were recovered on the Tralee Bypass, which included two juveniles and one adult. The juveniles had dispersed from nest sites within 20km to the east and south of the Tralee Bypass. The adult Barn Owl recovered on the Tralee Bypass was a male associated with a nest site 2.6km to the east of the bypass. On the M8 Motorway, six juveniles which were ringed were recovered as road casualties. These birds had dispersed from nests located to the east and west of the motorway, within County Tipperary, as well as Counties Limerick and Kerry. Figure 1.9 illustrates the dispersal patterns of ringed individuals which were recovered on the Tralee Bypass and the M8 Motorway.

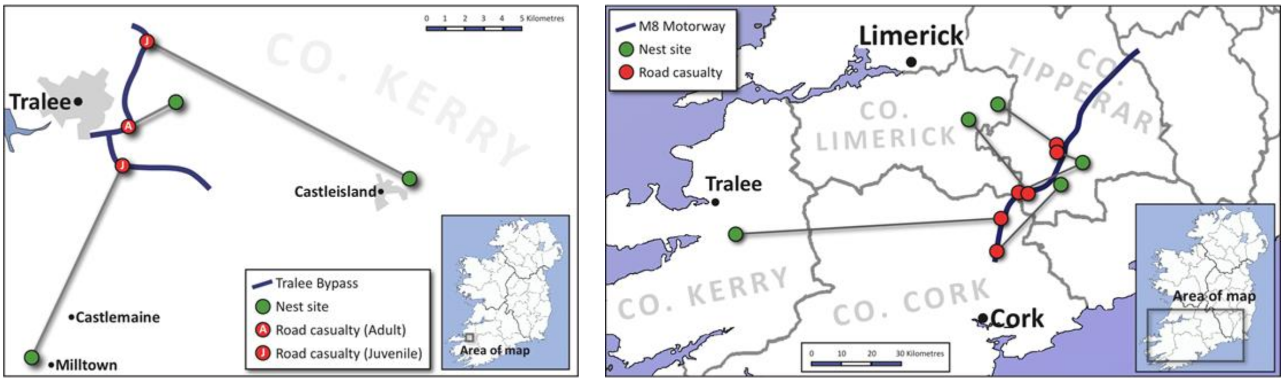


Figure 1.9 Map showing the Barn Owls which were ringed and subsequently recovered as road casualties on the Tralee Bypass (left) and M8 Motorway (right) showing the nest site, distance travelled and location of recovery on both roads.

1.4 Discussion

We collated the most extensive and longest running dataset on Barn Owl mortality in the Republic of Ireland. Our data shows that Barn Owls are vulnerable to a wide range of natural and human-related pressures on a national scale. Barn Owl mortality incidents were recorded throughout the country, reflecting the widespread distribution and dispersal behaviour of the species (Balmer *et al.* 2013). The majority of mortality incidents were recorded in the south west, with 81% of records in Munster. The bias in recorded mortality incidents towards the south west can be partly explained by the distribution and densities of Barn Owls in Ireland, with the majority of the breeding population located in the south west (Balmer *et al.* 2013). It therefore follows that mortality rates and thus likelihood of recording mortality incidents will be higher in areas with higher population densities. Mortality on roads (n=312) was the main cause of death for Barn Owls recorded in our study, representing nearly two thirds of all mortality incidents (73.7%). This is consistent with assessments of Barn Owl mortality causes throughout their range (Taylor 1994, Newton *et al.* 1997). Although the proportion of mortality on roads appears high in the context of other recorded forms of mortality, it is not possible to infer the relative importance of vehicle collisions as a cause of death for Barn Owls, based on our data, due to the potential to over-represent road mortality as a cause of death (Newton 1979).

However, our data undoubtedly shows that vehicle collision is an important source of mortality for Barn Owls in Ireland and based on our methods, the rates of road mortality recorded on a national scale should be treated as an absolute minimum.

The volume and speed of traffic on roads has been implicated as a factor which influences risk of collision for Barn Owls. Illner (1992) suggested that there were approximately 21 times more Barn Owls killed on roads with car speeds of greater than 80km per hour in the Netherlands than on roads with slower traffic. Our data indicates a similar trend, as the majority of road mortalities were recovered on motorways (n=188; 60%), despite the fact that the length of motorway in Ireland (916km) represented less than 1% of the total road network (approximately 100,639km) during the study period (TII 2016, McCarthy 2018). Barn Owl road mortality occurred disproportionately on motorways; the minimum number of Barn Owl road casualties recorded per 100km per year was 15 times higher on motorways (minimum of two Barn Owl road mortalities per 100km per year) than on national roads (0.1 Barn Owls per 100km per year) and over 500 times higher than on secondary routes (0.004 Barn Owl casualties per 100km per year) (TII 2016, McCarthy 2018). In addition to the volume and speed of traffic, there are other factors which may influence the risk of mortality for Barn Owls on motorways compared to other road types. Roadside verges of motorways may be particularly important for small mammal populations (Peter *et al.* 2013). In intensely modified landscapes, it has been shown that motorway roadside verges can support a greater abundance of small mammals than the wider countryside (Meunier 1999, Ruiz-Capillas *et al.* 2013), indicating that roads can provide an important refuge for these species. As a consequence, avian predators may be attracted to roadside verges, and use these in preference to surrounding habitats in intensive agricultural areas (Meunier *et al.* 2000). The presence of suitable perches for hunting along roadside verges may also prove attractive for foraging raptors (Nero and Copland 1981, Borquin 1983). The fact that the majority of road mortalities occur on motorways, which represents a relatively small proportion of the national road network, indicates that mitigation could be effectively targeted to motorways to achieve the maximum benefit.

Barn Owl mortality on Irish roads did not occur at the same frequency in all months of the year, with most road fatalities recovered in the early autumn to late winter. The timing of mortality on roads in Ireland is consistent with the findings of several studies in Europe (Massemin *et. al* 1998, Taylor 1994, de Bruin 1994, Shawyer and Dixon 1999, Ramsden 2003, Sousa *et al.* 2010) and North America (Boves and Belthoff 2012). The post-breeding season period in early autumn to late winter coincides with the juvenile dispersal phase (Shawyer 1998). Juvenile birds typically travel from their natal sites, often long distances, and therefore the likelihood of birds encountering roads is higher at this time of year (Shawyer 1998). For example, we showed that the average dispersal distance of juvenile Barn Owls in Ireland is 32km, with individuals dispersing as far as 350km. The post-breeding season period also coincides with peak numbers for the Barn Owl population. Shawyer and Dixon (1999) reported increased rates of road mortality following productive breeding seasons for Barn Owls, as there will be higher mortality rates when numbers are higher. Massemin *et al.* (1998) provided an additional explanation for higher road mortality rates in autumn and winter, indicating that road casualty rates followed a pattern similar to that of the temporal difference between sunset, which varies with day length, and peak of traffic. Their study concluded that the mortality of Barn Owls on motorways in autumn and winter was probably related to the peak of traffic and the onset of hunting activity and the large number and dispersal of immature individuals during the same period.

One third (34%) of Barn Owl road casualties were recovered on roads in the Republic of Ireland during the breeding season months (March to July). A higher proportion of birds were killed on roads during the nesting season in our study compared to the timing of road deaths recorded by other studies which typically show that approximately 90% or more of road casualties are recovered between September and March (Glue 1973, Shawyer 1987, Newton *et al.* 1997, Percival 1990, de Bruijn 1994, Sousa *et al.* 2010). It is generally accepted that the potential for impacts on populations is greater when birds are killed during the nesting season as opposed to outside of the breeding period. Barn Owls can breed in their second calendar year and therefore all birds killed during the breeding season would have had the potential to breed (Shawyer 1998).

Possible reasons for a higher rate of adult mortality on roads in Ireland may be related to the larger home range sizes of Irish birds compared to their counterparts in Europe and elsewhere (refer to Section 5). The reduced prey species base in Ireland compared to elsewhere in Europe, combined with the effects of habitat suitability, may also influence the use of roadside verges by adult Barn Owls in Ireland and thus increase their vulnerability to collision (refer to Section 5).

We showed a significant difference in the body weight of male road casualties recovered on Irish roads compared to the weight of live adult males, which indicates that road casualties were in a poorer body condition at the time of death. However, the average weight of road casualties (305g) in our sample was higher than the average weight described for live male Barn Owls in the UK (288g in Shawyer 1998) and was well above the weight which is attributed to starvation (below 240g), with only a single road casualty having a body weight below this threshold. The average weight of male road casualties in our study is also higher than reported by Shaywer and Dixon (1999) who conducted a similar assessment in the UK and showed that male road casualties had an average weight of 300g (range 256–366g). In the same study, Shawyer and Dixon (1999) concluded that road casualties were in good body condition. Based on the recorded weights of male road casualties, we can also ascertain that birds killed on roads were generally in good condition, which is consistent with the findings of most studies (Shawyer and Dixon 1999, Ramsden 2003).

Males and females were equally represented in our sample of birds killed on roads. This differs from other studies, which report females to be at greater risk of vehicle collision due to the fact they disperse over longer distances than males (Taylor 1994, Boves and Belthoff 2012). Our data on dispersal movements for males and females shows no significant difference, and therefore it makes sense that the likelihood of encountering major roads and the associated risk of collision is similar for both sexes in Ireland.

The findings of the road casualty survey on the Tralee Bypass further highlights the susceptibility of Barn Owls to vehicle collisions. Barn Owls were the third most frequent bird species recovered on the survey route, despite the fact that they occur at lower densities in the general proximity of the survey route compared to most of the other bird species recorded as road casualties (Balmer *et al.* 2013, Cummins and Colhoun 2013). Surveys to identify wildlife road casualties elsewhere have shown similar findings, with Barn Owls recorded as the most frequently affected raptor (Massemin and Zorn 1998, Shawyer and Dixon 1999), or the most frequently affected bird species (Baudvin 1997, Boves and Belthoff 2012, Loss *et al*. 2014). This study also provides the first evidence of the extent of mortality for Barn Owls on major roads in Ireland. Although direct comparisons between studies are difficult due to variation in methodologies, it is nonetheless interesting that our estimated annual casualty rate of 27–35 Barn Owls per 100km on major roads in Ireland (before our figures were adjusted for search and removal bias) is within the mid or higher range of estimates of the rate of Barn Owl mortality on major roads in Europe. For comparison, mortality of Barn Owls was estimated at seven Barn Owls per 100km per year on roads in Germany (Illner 1992), and similarly seven Barn Owls per 100km per year in Switzerland (Bourquin 1983), 25 Barn Owls per 100km per year in north-eastern France (Massemin and Zorn 1998), 30 Barn Owls per 100km per year on national roads in Portugal (Sousa *et al.* 2010), with estimates of 64 Barn Owls per 100km per year (Taylor 1994) and 68 Barn Owls per 100km per year in Great Britain (Shawyer and Dixon 1999). There are several reasons which may explain the similar or higher Barn Owl mortality rates recorded on Irish roads compared to elsewhere in Europe, despite the fact that Barn Owls occur in relatively low densities in Ireland. Firstly, Barn Owls in Ireland have a larger home range than their counterparts in Britain and continental Europe (refer to Section 5). Juveniles also tend to disperse further from their natal sites in Ireland (mean distance of 32km), compared to Britain where a median natal dispersal distance of 12km was reported by Wernham *et al.* (2002). As birds in Ireland move greater distances both within their home range and during dispersal, the probability of encountering a major road increases, which in turn is likely to increase risk of collision. The extent and quality of foraging habitat available in the landscape may also influence road casualty rates, as birds are more likely to be attracted to major roads to exploit foraging opportunities where there is less availability of suitable foraging habitat, and this may be a factor which affects vehicle collision rates in Ireland.

In the US, Boves and Belthoff (2012) estimated a mortality rate of 164 Barn Owls per 100km per year on a highway in Idaho before adjusting for search and removal bias. This is the only other study on Barn Owl road mortality rates that we are aware of that catered for search and removal bias, which significantly increased their estimates of Barn Owl mortality rate to 599 Barn Owls per 100km per year. We applied the same methods based on the effects of search and removal bias specific to our study area, which provides an estimate of 51 Barn Owls per 100km per year on the M8 Motorway and 60 Barn Owls per 100km per year on the Tralee Bypass. Based on these findings, if we extrapolate these figures to the motorway (916km) and dual carriageway (294km) network nationwide (TII 2016), this provides an estimate of 467 Barn Owls killed on motorways and 176 Barn Owls on dual carriageways on an annual basis in the Republic of Ireland. We must consider however that Barn Owl casualty rates on the M8 Motorway and Tralee Bypass may be higher than for other similar route types elsewhere in the country, which is likely influenced by their geographic location and Barn Owl distribution (Balmer *et al.* 2013), as well as several other factors which include the distribution of introduced small mammal species, route characteristics and verge management, which we explore in subsequent sections. There are however additional sources of potential bias which should be considered, and which may affect detection rates of Barn Owl road mortalities. Specifically, vehicle collision may not result in immediate death, particularly for larger birds (Slater 1994), which may move away from the road and therefore would not be possible to count as part of a road casualty survey. Carcasses can also be thrown into adjacent fields by high-speed vehicles, making them unavailable for recording. Nankinov and Todorov (1983) showed that at high speeds, 5% of bird species hit by vehicles were thrown into a ditch, while at low speeds only 0.5% were thus thrown. It was not possible to assess these potential sources of bias in our study, and therefore our estimates for Barn Owl mortality rates should be considered to be minimum estimates.

2. The Factors which Influence Risk of Collision for Barn Owls on Major Roads

2.1 Introduction

Mortality on roads is the main cause of death for a diverse range of wildlife (Bangs *et al.* 1989, Maehr *et al.* 1991, Newton *et al.* 1991, Trombulak and Frissell 2000) and has been implicated as a contributing factor in the population declines of individual species (Langton 1989, Van der Zee *et al.* 1992, Schwab *et al.* 2011, Borda-de-Água *et al.* 2014). A range of mitigation measures have been developed to reduce wildlife vehicle collisions, which primarily focus on altering motorist behaviour or altering the behaviour of wildlife which encounter roads (Glista *et al.* 2009, Santos *et al.* 2015). Unfortunately, effective mitigation solutions which are successful in minimising the negative effects of roads on sensitive wildlife species are often complicated, and difficult to implement (Forman *et al.* 2003). Limited evidence of the behaviour response and the factors which influence collision risk for individual species often compromise the design of effective evidence-based mitigation strategies. Many wildlife populations which are vulnerable to vehicle collisions are endangered or elusive and thus it is difficult to gather information on their response to roads to inform mitigation requirements. This is the case with the Barn Owl, which is particularly susceptible to vehicle collisions (Illner 1992, De Bruin 1994, Massemin and Zorn 1998, Ramsden 2003, Boves and Belthoff 2012). To investigate the factors which influence risk of collision for Barn Owls on roads, many studies have focused on assessing vehicle collision locations to identify mortality hotspots to determine the associated route and landscape characteristics. Understanding the factors that influence roadway mortality for Barn Owls in combination with information on individual behaviour response to roads is necessary to inform appropriate management recommendations (Clevenger *et al.* 2003) and determine the potential for and direction of practical, evidence-based mitigation solutions to reduce the impacts of roads on Barn Owl populations.

Many studies to investigate Barn Owl mortality on roads have indicated that vehicle collisions do not occur at random, but rather are influenced by a wide range of biotic and abiotic factors (Boves and Belthoff 2012). The road type including the design and structure of roads seem to be important in determining the occurrence of Barn Owl road fatalities (Baudvin 1997, Shawyer and Dixon 1999). For example, Barn Owls seem to be at greater risk of collision on roads with higher vehicle volumes and speeds than on lower class roads. Illner (1992) showed that the likelihood of Barn Owl deaths on roads with speed limits over 80km per hour were 20 times greater than on roads with slower vehicle speeds. Ramsden (2003) compared the reported mortality rates of Barn Owls on different road types in Devon, indicating that 3.6 Barn Owl road casualties per 100km were reported on motorways each year compared to 0.008 road casualties per year on country lanes. The physical characteristics, design and location of the road may also be important in dictating the extent of road mortalities. Sousa *et al.* 2010 recorded more road casualties at lower altitudes along a road in Portugal. Pons (2000) showed that the relative probability of bird collision on roads increases with embankment height of the road. Several studies have reported this to be the case for Barn Owls. It is suggested that Barn Owls are more likely to fly above the height of passing vehicles when crossing excavated sections of road, compared to level or raised sections of the road where their flight height is predicted to be lower, relative to the height of the road, thus increasing collision risk. Shawyer and Dixon (1999) indicated that areas with high mortality rates on a major road in the UK corresponded with sections of the route which were embanked or level, with fewer casualties found along excavated sections of the same road. Baudvin (1997) also reported fewer Barn Owl road casualties where the surface of the road was set below that of the surrounding terrain. Similarly, Massessmin and Zorn (1998) found that most Barn Owls were killed along embanked sections of highway that lacked roadside hedges. Based on these findings, the use of natural or artificial screens to deflect the flight path of Barn Owls above the height of traffic has been proposed as a measure to reduce Barn Owl mortality on major roads (Shawyer and Dixon 1998, Ramsden 2003).

These mitigation recommendations seem to be primarily targeted towards reducing collision risk for birds which are crossing the road; however, the behaviour and response of Barn Owls to road features is not well known, and as these measures have rarely been applied and not evaluated, it is not possible to ascertain their effectiveness.

It has also been suggested that risk of collision for Barn Owls may also be linked to the availability of suitable foraging conditions in proximity to roads. Baudvin (1997) suggested that Barn Owls were not just killed when crossing a motorway, but also when attracted to forage close to the road surface. Shawyer and Dixon (1999) reported that Barn Owl road casualties on a major road in southern England were more likely to occur where the road traversed linear habitat features, suspected to be important for Barn Owls when foraging. Similarly, mortality hotspots have been identified along sections of road which are adjacent to habitats or land-uses considered to be suitable for foraging Barn Owls (Baudvin 1997, *Sousa et al*. 2010). In addition to the influence of land uses adjacent to the road, the roadside verges may also provide foraging opportunities for Barn Owls. The verges of major roads can provide an important refuge for small mammal populations and can support a greater abundance of these species compared to the wider countryside (Meunier 1999, Ruiz-Capillas *et al.* 2013). As a consequence, avian predators can be attracted to roadside verges, and can use these in preference to surrounding habitats, particularly in intensive agricultural areas (Meunier *et al.* 2000). Many studies to assess wildlife mortality on roads have shown that predators of small mammals are disproportionately represented (Baudvin 1997), indicating that collision risk may be associated with foraging behaviour of small mammal specialists. Several studies have linked areas of high Barn Owl road casualties to sections of dual-carriageway and motorway where wide verges of open grassland habitat occur (Baudvin 1997, Shawyer and Dixon 1999, Taylor 1994). In contrast, Barn Owls were often recorded crossing minor roads in Devon in the UK, however, were rarely observed hunting along them, which was attributed to the lack of suitable wide verges of grassland habitat (Ramsden 2003). The habitat composition of roadside verges may also prove attractive for Barn Owls, as roadside verges are typically long, linear and open with a good availability of perches and therefore may represent a less energy-demanding and more profitable habitat for foraging compared to the surrounding landscape (Nero and Copland 1981, Borquin 1983, Meuiner *et al.* 2000).

Although many studies have assessed the factors which can influence risk of collision for Barn Owls related to the road infrastructure and habitat conditions in close proximity to the road, less attention has been given to the potential influence of landscape features on a larger scale. Features in the wider landscape are likely to influence the distribution and movements of Barn Owls. Avoidance of, or attraction to certain features or conditions will influence population distributions and densities and may also create a funnelling effect for the dispersal of juveniles which would influence the locations where birds encounter major roads. The ability to detect the influence of wider landscape conditions and to predict potentially problematic areas, based on the geographic location of roads in relation to the landscape suitability and probability of use by Barn Owls would be beneficial and facilitate a greater understanding of factors which determine the occurrence of Barn Owl mortalities and enhance the detection of high-risk areas.

The objectives of this study were to identify spatial patterns of Barn Owl road mortalities and the factors which influence risk of collision for Barn Owls on major roads in the Republic of Ireland. We compiled data on Barn Owl vehicle collisions on two major roads in the south of Ireland over a three-year period (2014–2017) to:

i. Determine whether there were clustering effects of Barn Owl road mortalities and to identify mortality hotspots
ii. Identify route and habitat features which influence the occurrence of Barn Owl fatalities on major roads
iii. Identify wider landscape features which may influence the occurrence of Barn Owl fatalities on major roads

2.2 Methods

2.2.1 Study Area

Spatial patterns of road mortality of Barn Owls were investigated on the Tralee Bypass and the M8 Motorway in the south of Ireland. These routes are considered representative of the major road networks in Ireland and were selected on the basis of the known occurrence of Barn Owl road mortalities on these routes. The N22 Tralee Bypass in County Kerry consists of a route length of 13.5km, of which 8km is a Type 2 Dual Carriageway and 5.5km is a standard two-lane single carriageway. The survey area on the M8 Motorway consists of a 96km section of dual-lane carriageway which runs from the border of Counties Kilkenny and Laois in the north, to Junction 14 in north County Cork at its southern most point. The survey route predominantly runs through County Tipperary, extending into County Kilkenny in the north and Counties Limerick and Cork to the south.

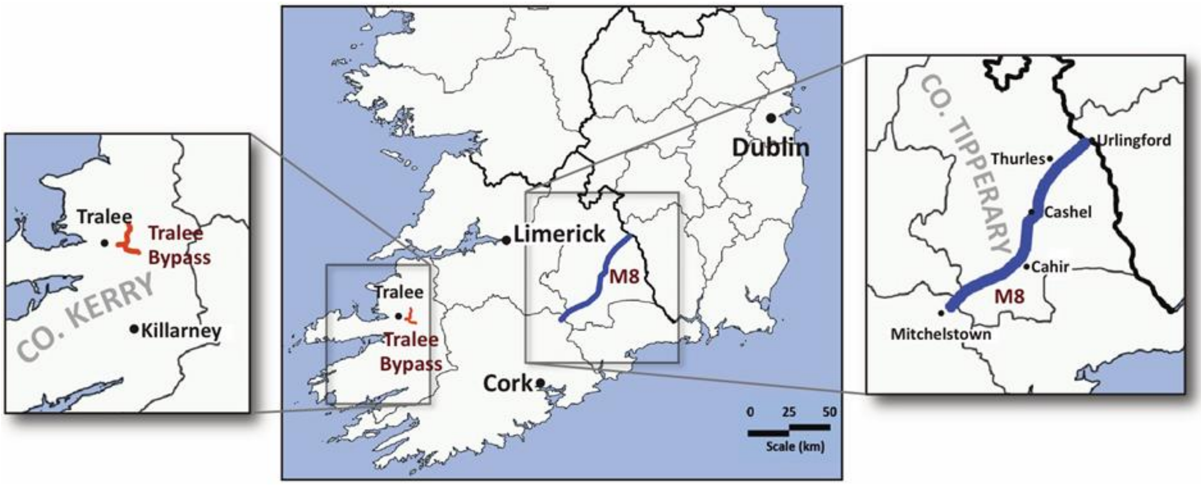


Figure 2.1 The survey areas on the M8 Motorway and Tralee Bypass which were used to investigate spatial patterns of Barn Owl road mortality.

2.2.2 Barn Owl Road Mortalities

We carried out a survey to record Barn Owl road casualties on the Tralee Bypass and the M8 Motorway in the south of Ireland. On the Tralee Bypass (13.5km), a survey was undertaken once per week over 144 weeks from the 29th of August 2014 to the 22nd of May 2017. The M8 Motorway (96km, including slip roads and junctions) was surveyed once per day over a two-year period (2016–2017). Survey visits were carried out by a single surveyor who drove the route in both directions at a speed of 20–35km per hour (Tralee Bypass) and 70–90km per hour (M8 Motorway). All records of Barn Owl road mortalities on the survey route received from other sources (independent observers) over the course of the road casualty survey were checked on the same day as the report was received. All potential Barn Owl road mortalities on the survey route were inspected to confirm identification. The location of the road casualty was recorded with a hand-held GPS unit using the ITM coordinate system. The position of the casualty on the route (central median, main line, hard shoulder, or verge) and orientation (southbound, northbound, eastbound or westbound) were recorded. Once recorded, Barn Owl carcasses were removed from the route to avoid double-counting. The purpose of this survey was to record vehicle collision locations, representative of the occurrence of road fatalities on the selected routes, and therefore only road casualties which were recorded to the required resolution (as outlined previously) were used for this study. All Barn Owl mortality locations were mapped using ArcGIS ArcMap 10.2 (ESRI Inc., Redlands, CA).

2.2.3 Influence of Road And Habitat Features on Barn Owl Mortality Occurrence

We selected 15 ecogeographical variables to describe the relevant habitat, land use and route features at Barn Owl mortality locations; hereafter referred to as ‘collision points’.

All variables selected have been reported as important in Barn Owl road mortality occurrence (Taylor 1994, Baudvin 1997, Massessmin and Zorn 1998, Shawyer and Dixon 1999, Meunier *et al.* 2000, Ramsden 2003, Gomes *et al.* 2008, Boves and Belthoff 2013), or considered potentially important in influencing risk of collision for Barn Owls in our study area. To allow comparison of ecological and geographic variables at collision points (observed) to the availability of these features on the route (expected), we generated random points on the M8 Motorway (n=100) using the Random Point Generator in ArcMap. The distribution of random points was interrogated with respect to proximity to collision points, and all random points which were within 100m of a collision point were excluded to ensure independence, which left a total of 96 random points. Values were assigned for all 15 variables to each collision and random point. In a small number of cases, it was not possible to assign a specific value, in which case the mode was calculated and assigned to ensure there were no missing data. Table 2.1 presents information derived for all variables including a description and source.

Table 2.1 Details of all variables recorded for collision and random points on the M8 Motorway and Tralee Bypass, including a description of each variable and the source from which they were derived.

Variable	Code	Description	Unit	Source
Elevation	Rd_Elev	The altitude above sea level (asl) of the road	Metres	Lidar maps
Verge height	Vrg_height	The verge slope (verge top - verge bottom)	Metres	Lidar maps
Verge width	Vrg_width	Width of the verge (road surface to barrier with adjacent land)1	Metres	Google Maps and ArcGIS Arc Map 10.2
Verge grass and herbaceous cover	Vrg_grass_herb	Proportion of open grass and herbaceous cover in verge	%	Google Street View & visual assessment
Adjacent land use	J_Adjac_land	Adjacent land use to the roadside verge	1-22 CLC categories	CLC
Distance to river	Dist_river	Distance to nearest river	Metres	ArcGIS ArcMap 10.2
Distance to hedgerow	Dist_hedgr	Distance to nearest hedgerow/tree line	Metres	ArcGIS ArcMap 10.2
Distance to junction	Dist_junct	Distance to nearest junction	Metres	ArcGIS ArcMap 10.2
Distance to flyover	Dist_flyov	Distance to nearest flyover	Metres	ArcGIS ArcMap 10.2
Distance to marker	Dist_mark	Distance to nearest marker plate (sign)	Metres	ArcGIS ArcMap 10.2 &TII data
Distance to barrier	Dist_noiseB	Distance to nearest noise barrier	Metres	ArcGIS ArcMap 10.2 & TII data
Distance to public lighting	Dist_PubLight	Distance to nearest public lighting	Metres	ArcGIS ArcMap 10.2 & TII data
Distance to road lighting	Dist_RdLight	Distance to nearest road lighting	Metres	ArcGIS ArcMap 10.2 & TII data
Traffic volumes	AADT_2017	Annual Average Density Traffic per year (M8 only)	Average no. vehicles/yr.	TII data
HGV[1] volumes	PERC_HGV	Percentage of Heavy Goods Vehicles (M8 only)	% of AADT[2] which are HGV	TII data

[1] HGV = Heavy Goods Vehicles, [2] AADT = Annual Average Density Traffic

For each variable (n=15), we inspected the variation in values (mean, minimum and maximum) for collision and random points to identify the variables which clearly did not influence collision, based on an understanding of Barn Owl ecology. These variables are reported in the following sections and were excluded from further analysis.

2.2.4 Influence of Landscape Features on Barn Owl Mortality Occurrence

To assess landscape scale influences on the occurrence of Barn Owl mortality on the M8 Motorway and the Tralee Bypass, we collated data on Barn Owl movement patterns, space and landscape use in the regions surrounding both routes to identify areas of overlap between mortality hotspots on the roads and areas of high probability of use for Barn Owls. We reviewed fine scale resolution data on Barn Owl movements collated via GPS dataloggers fitted to 11 adult breeding Barn Owls which nested within 70km of the M8 Motorway and the Tralee Bypass (refer to Section 5 for further details). The data illustrated that the movement of Barn Owls is strongly influenced by elevation. Accordingly, we evaluated the range of elevations used by each individual by extracting elevation data from the Digital Elevation Model (DEM) at each GPS fix for each individual using ArcView. We removed the GPS fixes from the vicinity of the nest (taken as all fixes within 100m of the nest) to avoid bias. For the majority of individuals, the GPS fixes were largely ranging from 10–70m (Figure 2.2) which were consistent with the elevations of the nest site of each individual (Figure 2.3.). One individual (MEL6F/MEL7F) was a notable exception, with a nest at a higher elevation (143m) compared with other individuals (which nested from 9–56m), and with GPS fixes ranging mostly from 150–180m.

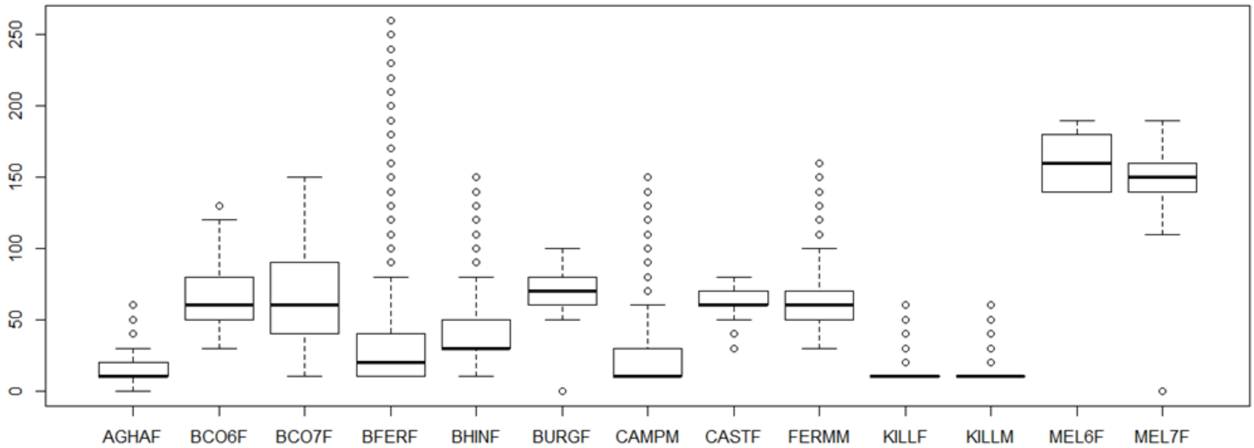


Figure 2.2 The elevation of GPS fixes (movements) of Barn Owls (n=11) fitted with GPS dataloggers in 2016 and 2017.

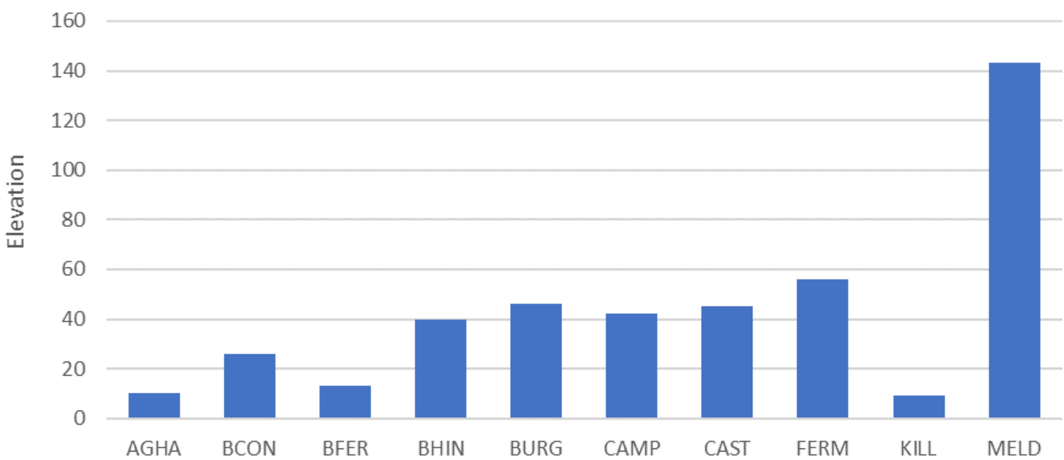


Figure 2.3 The elevation of the nest site (n=10) of all individual Barn Owls (n=11) which were fitted with GPS dataloggers in 2016 and 2017.

Using the programme Maxent (Phillips *et al.* 2019), we created a map of probability of use of Barn Owls for the regions surrounding the M8 Motorway and the Tralee Bypass. The Maxent software is based on the maximum-entropy approach for modelling species niches and distributions. It generates a probability of distribution or movements from a set of environmental (in this case DEM) and georeferenced occurrence (GPS fixes), where each grid cell is assigned a predicted suitability of conditions for the species. The fixes from two individuals (FERMM and BURGF) with nests sites located within 5km of the M8 Motorway were combined to generate the map for the M8 Motorway region, and data from two individuals (BCO6F/BCO7F and BHINF) which nested within 5km of the Tralee Bypass were used to generate the map for the Tralee Bypass region. A high value of the function at a particular grid cell indicates that the grid cell is predicted to have suitable conditions for Barn Owls. The computed model is a probability distribution over all the grid cells.

2.2.5 Data Analysis

Data analyses were carried out using R 3.1.2 (R Development Core Team 2015). Barn Owl vehicle collision data for the M8 Motorway and Tralee Bypass were treated separately.

We investigated clustering in the spatial arrangement of Barn Owl mortality locations using Ripley’s K-function in ArcGIS ArcMap 10.2 (ESRI Inc., Redlands, CA). The values of the network K-function for observed data were compared with an approximation of expected values of network K-function for a random situation, which was generated by 1,000 Monte Carlo simulations.

To identify potential variables which influence risk of collision for Barn Owls, we performed logistic regression using multiple variables, simplified through stepwise backward elimination using the Wald statistic (α=0.5) to remove non-correlated determinants. The power of the model and the predictive accuracy was tested using the Hosmer-Lemeshow test, and the adjusted Akaike’s information criteria (AIC) tested the parsimony of resultant models. We also performed a Welch Two Sample t-test on seven specific variables (*verge width, verge grass and herbaceous cover, distance to junction, distance to flyover, distance to marker, distance to road lighting and HGV volumes*) to determine variation in values for collision points (observed) and random points (expected).

To assess the potential influence of landscape suitability and features on the occurrence of Barn Owl mortality on the M8 Motorway and the Tralee Bypass, we used Maxent software (Phillips *et al.* 2019) to create a map of probability of distribution and movement patterns of Barn Owls and compared this with the known locations of Barn Owl mortalities on both routes.

2.3 Results

We recorded 78 Barn Owl road mortalities on the M8 Motorway and 13 on the Tralee Bypass for which accurate location information was available, and which are used in our model.

2.3.1 Spatial Pattern of Road Mortalities

We observed significant clustering in the distribution of Barn Owl mortalities on the M8 Motorway. There was strong clustering of Barn Owl road mortalities at low distances and strongly significant homogeneity in vehicle collision locations at longer distances which show that Barn Owl mortality occurred in specific locations, rather than being randomly distributed along the motorway. We did not observe significant spatial autocorrelation of Barn Owl mortality locations on the Tralee Bypass, indicating that vehicle collisions were not clustered and occurred at random along the road, although the sample size of these collision points was too low for significant results to be obtained.

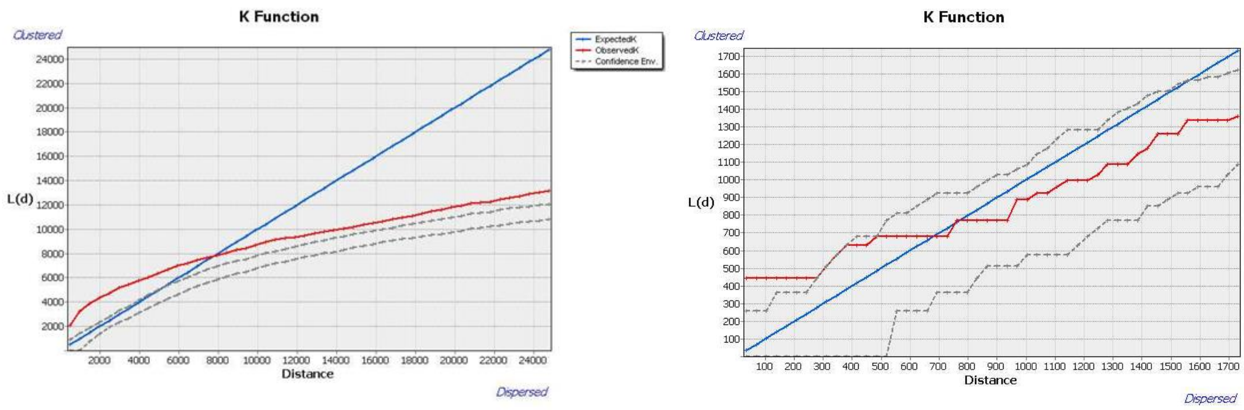


Figure 2.4 Output of the Ripley's K-function which shows the location of observed Barn Owl mortality locations compared to expected on the M8 Motorway (left) and Tralee Bypass (right).

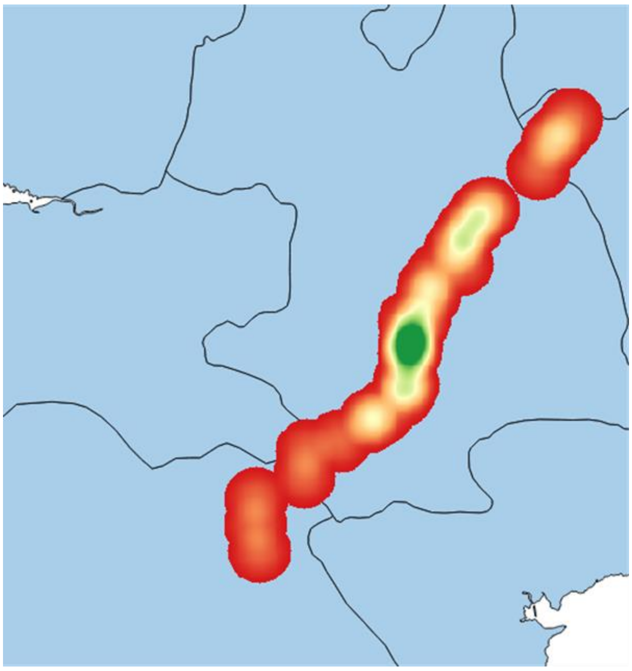


Figure 2.5 Heat map showing the distribution of Barn Owl mortality locations (n=63) along the M8 Motorway, areas with limited or no Barn Owl mortalities are red, areas where there was clustering of Barn Owl mortalities are shown in light yellow (low clustering) to green (high clustering).

2.3.2 Influence of Road and Habitat Features on Barn Owl Mortality Occurrence

Inspection of the data revealed seven variables as non-influential in determining Barn Owl collision on the M8 Motorway. The elevation (m) asl of the M8 Motorway did not vary considerably in our study area, with similar values recorded for collision points (SD=22, mean=101.4m, range=44–155m, n=78) and random points (SD=27, mean=100.1m, range=36–172, n=96). Verge height was comparable between collision points (SD=4.1, mean=1.7m, range=-7–12m, n=63) and random points (SD=5, mean=1.3m, range=-9–13m, n=96), with 63% of collision points located where the road was level or above grade compared with 57% of random points located in sections of the road which were level or above grade. The distance to hedgerow was similar between collision points (SD=49.1m, mean=61.2, range=8–280m, n=63) and random points (SD=60.6, mean=68.4m, range=3–330m, n=96). Traffic volumes calculated as the AADT were also similar but lower at collision points (SD=975, mean=7,009, range=5,100–9,800, n=63) compared to random points (SD=1613, mean=7,433, range=4,500–12,800, n=96). Only one collision point was located within 100m of a river and public lighting.

Noise barriers are not frequently distributed on the M8 Motorway and were not considered to influence mortality locations, based on visual inspection. These variables (n=7) were therefore not considered important in determining the occurrence of Barn Owl vehicle collisions and were excluded from further analysis, leaving eight explanatory variables which we used in our model.

To fit the model, we refined the values for four explanatory variables (distance to junctions, flyovers, marker plates and road lighting), which was informed by a high degree of variation in distance values to collision and random points. From an ecological perspective, these features are only likely to affect risk of collision for Barn Owls at specific distances, and therefore we assigned a (1) if collision points and random points were located within 50m of marker plates, 100m of junctions and flyovers and 150m of road lighting, and (0) if points were located further than specified.

We used backward elimination of variables (8) using the Wald statistic which identified the best fitting model to retain six explanatory variables (Table 2.2). Goodness-of-fit testing using AIC showed a value of 235.83. A Hosmer-Lemeshow test indicated that the model is likely to accurately predict the deterministic variables for Barn Owl road mortality on the M8 Motorway, given the set of criteria include in our model (X2 =8.181, df=8, P=0.416). Our model showed one variable to significantly influence the occurrence of vehicle collisions for Barn Owls on the M8 Motorway which was the proportion of grass and herbaceous cover in the verge (P=0.03).

Table 2.2 Outputs of the model showing the variables used (n=6) and significance values for each.

Coefficients	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-3.056830	1.24	-2.45	0.0142 *
Vrg_grass_herb	0.027303	0.01	2.08	0.0373 *
Vrg_width	0.016653	0.01	0.98	0.3236
Flyov_100m	0.008786	0.452744	0.019	0.9845
Mark_50m	0.002507	0.430067	0.006	0.9953
RdLight_150m	0.363742	0.649531	0.560	0.5755
Junct_100m	1.186595	0.958690	1.238	0.2158

A Welch Two Sample t-test also showed a significantly greater proportion of grass and herbaceous cover at collision points compared to expected (df=146.16, P=0.01). There were also significantly more collision points within 100m of a junction (df=104.94, P=0.03), and within 150m of road lighting (df=122.98, P=0.03) than expected if distribution were random on the motorway. None of the other variables showed a significant relationship with collision points (Welch Two Sample t-tests).

2.3.3 Influence of Landscape Features on Barn Owl Mortality Occurrence

The map of probability of use illustrated in Figure 2.6 highlights the areas most likely to be used (blue) and those which will most likely be avoided (red) by Barn Owls. The probability of movement illustrates the lowland areas that would be favoured by birds undergoing localised as well as wider dispersal movements, as well as those that would be avoided (upland regions).

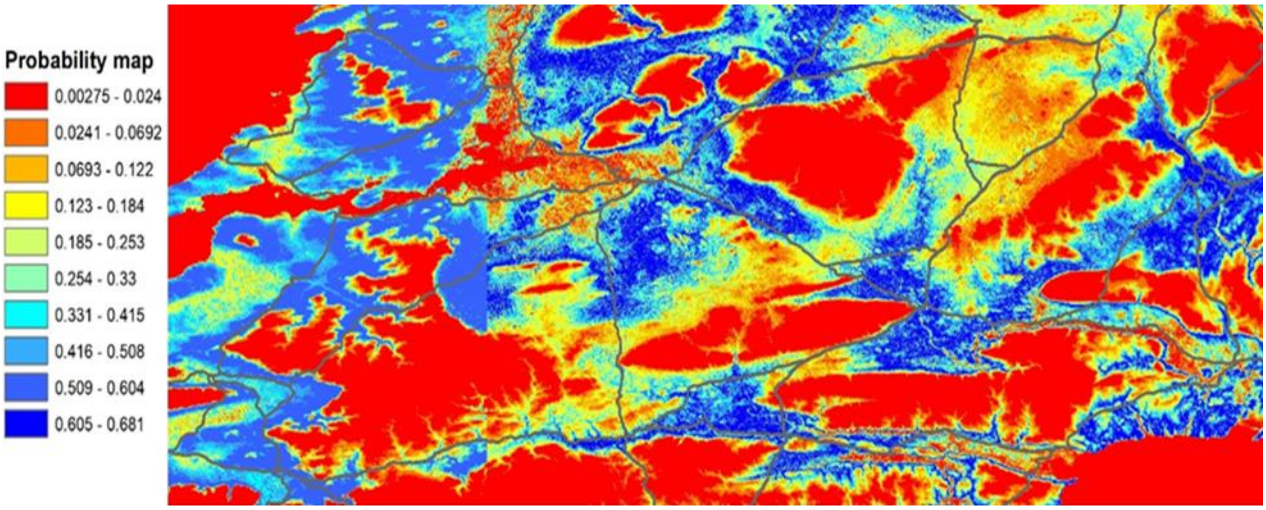


Figure 2.6 Probability distribution and movement map for Barn Owls based on the GPS tracked individuals close to the Tralee and M8 Motorway regions (left and right box respectively as illustrated) and using the Digital Elevation Model to model the predicted distribution. The range is from red (very low probability of occurrence) through to blue (very high). This figure also shows the distribution of main roads.

When the M8 Motorway collision hotspots are illustrated, it is apparent that the probability of use of Barn Owls, influenced by high elevation areas within the wider landscape, are potentially serving as a funnel, so it is perhaps not surprising that these areas are where significant clusters of casualties have been recorded.

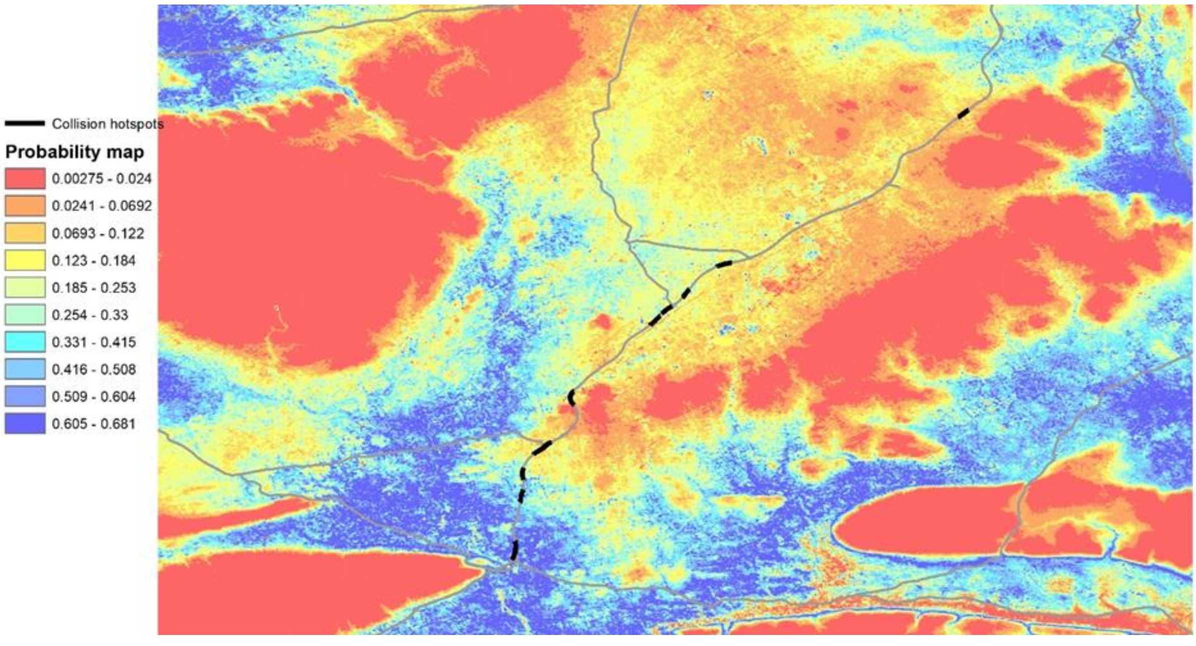


Figure 2.7 Probability distribution maps for Barn Owls in the M8 Motorway region illustrating the collision hotspots (black).

2.4 Discussion

We demonstrated clustering effects and the detection of mortality hotspots for Barn Owls on a major road in Ireland for the first time. Identification of mortality hotspots allows mitigation efforts to be targeted to the areas which will be most beneficial in minimising road fatalities while maximising resources. The clustering of vehicle collisions also indicates that road deaths do not occur at random but are driven by specific geographical or ecological factors.

Although our approach was informed by a review of methods and identification of the most appropriate procedures to characterise owl roadkill hotspots (Gomes *et al.* 2008), these methods can be adapted for other wildlife species which are vulnerable to the effects of major roads, to identify high risk areas and help inform conservation policy and targeted mitigation solutions to vehicle collisions.

We observed significant spatial clustering of Barn Owl mortalities on the M8 Motorway and identified two main mortality hotspots on this route. In contrast to the M8 Motorway, we did not observe clustering of road mortalities on the Tralee Bypass. Although the estimated Barn Owl mortality rate is slightly higher on the Tralee Bypass than on the M8 Motorway (refer to Section 1), the lack of observed clustering of Barn Owl fatalities on the bypass may have been influenced by the low number of recorded road casualties related to the short route length. The variation in observed clustering effects on the M8 Motorway and the Tralee Bypass nevertheless highlights that the nature of Barn Owl vehicle collision and factors influencing mortality can differ between roads, even over a relatively short spatial range. Applying the existing evidence-base of deterministic factors which influence Barn Owl road mortality from one road to another or across large spatial ranges may have some benefits; however, a detailed understanding of the local conditions is also necessary to identify the potential presence and location of mortality hotspots and identification of the factors most likely to influence risk of mortality, in order to inform potential mitigation requirements and strategies.

Several road features which have been identified as important in influencing risk of mortality for Barn Owls on other road systems, were not important in determining occurrence of mortality on major roads in Ireland. Analyses of spatial patterns of Barn Owl road fatalities in relation to road height (whether the road was embanked, level or cut) revealed that this route feature did not significantly influence risk of collision for Barn Owls on the M8 Motorway. Although we found more Barn Owl mortalities along embanked or level sections of the motorway (63%), this was similar to expected (57%) based on the route characteristics.

In contrast to our findings, several studies have linked Barn Owl mortality hotspots with sections of road which were embanked or level (Baudvin 1997, Massessmin and Zorn 1998, Shawyer and Dixon 1999); however, specific details of the height of the road at mortality hotspots or on these routes are generally not provided, and therefore direct comparisons with the road height conditions on the M8 Motorway is not possible. The variation in the recorded road height on the M8 Motorway ranged from excavated sections of road which were 9m below the top of the verge to embanked sections where the road was 12m raised above the verge, which suggests that there was sufficient variation for the influence of road height on the distribution of Barn Owl fatalities to be detected, if this factor was important in determining vehicle collisions. The use of natural or artificial screens on embanked and level sections of road to deflect the flight path of Barn Owls above the height of traffic has been proposed as a measure to reduce Barn Owl road mortality (Shawyer and Dixon 1998, Ramsden 2003). Based on our findings, we recommend caution in applying these mitigation measures where road height is not proven to determine the occurrence of Barn Owl vehicle collisions, as is the case on the M8 Motorway and Tralee Bypass. Emphasis on these mitigation measures in the absence of evidence of their requirement or effectiveness on specific roads could create a false sense of minimising Barn Owl road mortality rates, while also directing focus and resources from potentially more effective mitigation solutions.

Linear features such as hedgerows, tree lines and rivers which can be used by Barn Owls for foraging and have been linked with increased risk of mortality on certain major road systems. It has been proposed that there is increased risk of collision where such features which are used by Barn Owls intersect a major road (Shawyer and Dixon 1999). We did not observe this to be the case on the M8 Motorway however, as we showed linear features, at least on a localised scale, were not important in determining the spatial patterns of Barn Owl vehicle collisions. There was only a single large (>15m in width) river (the River Suir) which traversed the M8 Motorway in our study area. Barn Owl road mortalities were not recorded in the vicinity of this river, and only one Barn Owl road casualty was recovered within 100m of one of many smaller rivers which crossed the motorway.

Although we did not observe rivers to be important in determining Barn Owl mortality on the M8 Motorway, it is important to note that several Barn Owl mortalities have been recorded close to the rivers elsewhere in the country, which suggests that this factor may be important in certain areas; however, this was not the case in our study area. Similarly, the distance to hedgerows or tree lines did not appear to dictate Barn Owl mortality locations on the M8 Motorway. However, due to the density and intricate nature of hedgerow networks in the Irish landscape and specifically in the surrounds of the M8 Motorway, it was difficult to discern whether these linear features impacted Barn Owl mortality. For example, the mean distance from a Barn Owl road casualty, and random point to a hedgerow was 61m and 68m respectively. Nonetheless, it would be difficult to develop and implement mitigation related to hedgerows given their density in proximity to major roads throughout the country, at least on a large scale.

The elevation (m asl) of the road did not explain spatial patterns of Barn Owl road mortalities on the M8 Motorway, as has been shown to be the case on other routes. Sousa *et al.* (2010) revealed that mortality hotspots were strongly related to lower altitudes on a highway in Portugal. Barn Owls avoid upland areas in Ireland, demonstrated by the movements of individual GPS tracked birds (refer to Section 5) which showed a strong preference for low-lying areas and avoidance of higher ground within their home ranges. Avoidance of higher elevations is also demonstrated by the distribution of nesting pairs in the Republic of Ireland, the majority of which are below 150m asl. Therefore, the risk of mortality on roads is less at the higher elevations which are avoided by Barn Owls. However, the elevation gradient on the M8 Motorway did not vary considerably, and the majority of the route is below 150m asl. This is also the case across much of the major road network in Ireland which predominantly runs through low-lying areas. As demonstrated by our findings, road elevation is unlikely to influence risk of collision on roads where there is no significant variation in altitude, and which do not include higher altitudes (e.g. >150m asl). On a wider landscape scale however, elevation is likely to influence the distribution of Barn Owls and their movements, including juvenile dispersal patterns, and this may dictate the location and frequency with which birds encounter major roads, as discussed further on.

Our model showed a significant relationship between the proportion of open grassland and herbaceous cover in roadside verges with the distribution of Barn Owl vehicle collisions. This indicates that suitable foraging conditions in roadside verges attract Barn Owls, which are subsequently at greater risk of collision than elsewhere on the road. This concurs with several other studies which linked areas of quality foraging habitat (Taylor 1994) in roadside verges to Barn Owl mortality hotspots. Although the proportion of grass and herbaceous cover was shown to be significant, this was the only factor detected by our model which determined spatial patterns of Barn Owl road mortality on the M8 Motorway. We assessed all factors on the road or in the immediate vicinity of the road which have been reported or considered to be important in influencing Barn Owl mortality. Based on our model fit however, it is likely that there are additional factors which influence Barn Owl mortality on the M8 Motorway which were not detected, either because these are important at low levels (i.e. a multitude of factors related to deaths of a small sample of birds) or because these factors are influential at a wider geographic scale, which we did not test for in our model.

Assessment of the importance of specific factors in isolation showed a significantly higher proportion of Barn Owls killed on the motorway in close proximity to junctions and road lighting than expected. These factors may have been influential in the deaths of a low proportion of birds and thus were not detected by our model but are nonetheless important in understanding the factors which drive Barn Owl road mortality. Eight Barn Owl mortalities (10%) were recovered within 100m of a junction, which was five times more than expected. The areas surrounding junctions may be attractive for Barn Owls, as these areas are typically associated with extensive open grassland. In addition, significantly more Barn Owls were killed within 150m of road lighting than expected. Twelve Barn Owls (15%) were recovered within 150m of road lighting on the M8 Motorway, which was three times the number expected (5%), and the mean distance of random points to road lighting was over 8.7km. As road lighting on the M8 Motorway is largely restricted to junctions, it is possible there is a correlation between road lighting and junctions on the influence of Barn Owl mortality locations.

There is limited literature available on the use or avoidance of artificial lights by Barn Owls for foraging; however, in the context of a major road where the noise levels from traffic can be high, the ability to visually detect prey at night may increase the attractiveness of areas in proximity to lighting, which warrants further attention.

In addition to the influence of the proportion of open grassland and herbaceous cover in roadside verges, our map of probability of use by Barn Owls shows that features in the wider landscape, and particularly the distribution of high elevation areas, are also likely to determine spatial patterns of mortality on major roads. The movement patterns of adult Barn Owls show a clear preference for lower elevations (<170m asl) and avoidance of uplands areas (<170m asl). This suggests that the dispersal patterns of juveniles are also influenced by altitude. The avoidance of upland areas by juveniles when dispersing could lead to a funnelling effect in the landscape and thus increase the likelihood of birds encountering a road at specific locations as opposed to at random. The M8 Motorway is centrally situated within the core stronghold for Barn Owls in Ireland (Balmer *et al.* 2013), and we showed that juvenile Barn Owls, originating from nest sites to the east and west of the road, are killed on the motorway (refer to Section 1). The geographic location of the M8 Motorway, and the fact that it is likely traversed by a high proportion of dispersing juveniles, may at least partly explain the apparently high road mortality rates recorded on this route. There are also several high elevation areas above 300m asl surrounding (within 20km) the M8 Motorway, which include the Slieve Felim Mountains and the Galty Mountains, north of the motorway, and the Knockmealdown and Comeragh Mountains to the south. Dispersing juveniles which travel in the general direction of the road are likely to be funnelled into the low-lying areas to avoid these upland areas as illustrated by our map of probability of use. This is likely to result in increased encounter rates on specific sections of the motorway, which can explain the clustering effect of road fatalities on the M8 Motorway. Our findings therefore show the value of assessing factors which influence spatial patterns and rates of Barn Owl road mortality on two scales: at the scale of the road and surrounding habitat (within 100m of the road), and at a broader landscape scale (within 50km of the road). The development of probability maps provides a new method for identifying problematic or high-risk areas for vehicle collisions which can be used alongside finer-scale information on the specific route and adjacent habitat features, which can be applied on a nationwide scale.

3. Motorway Verges as a Habitat for Small Mammals

3.1 Introduction

Although most effects of roads on the environment are negative, there is evidence that some species respond positively to roads (Forman *et al.* 2003). As one of the most extensive functioning systems of linear habitat in the world (Forman and Alexander 1998), road infrastructure and associated verge habitats can contribute to maintaining species diversity and ecological processes, particularly in heavily-modified environments (Gelling *et al.* 2007). In such landscapes, roadside verges are often less intensely managed and have a higher plant diversity (Forman *et al.* 2003) than surrounding habitats, and therefore have the potential to provide a refuge and food source for certain wildlife (Forman and Alexander 1998, Huijser and Clevenger 2006). Roadside verges may be particularly important for small mammal populations (Peter *et al.* 2013). These species fulfil an essential role in the functioning of ecosystems as they represent an important trophic resource (Glue 1974, McDonald *et al.* 2000, Webbon *et al.* 2006), which directly influences the abundance and diversity of avian and mammalian predators (Butet and Leroux 1993, 2001, Shawyer 1998, Salamolard *et al.* 2000). Evidence of widespread declines in small mammal populations in agricultural landscapes throughout Europe has led to concerns over the potential for wider ecosystem repercussions. These declines have been attributed to reduced habitat availability due to the intensification of agricultural systems (Aschwanden *et al.* 2007), where small mammals are now largely confined to edge habitats (Gelling *et al.* 2007, Bates and Harris 2009). In agricultural ecosystems, roadside verges may therefore be particularly important for small mammal communities. In such intensely modified landscapes, it has been shown that roadside verges can support a greater abundance of small mammals compared to the wider countryside (Meunier 1999, Ruiz-Capillas *et al.* 2013).

Avian predators may be attracted to roadside verges and use these in preference to surrounding habitats in intensive agricultural areas (Meunier et al. 2000). The availability of prey-rich foraging habitat may provide benefits for certain raptor species; however, this also presents a dilemma, as risk of collision for predators is likely to increase if they are attracted to roadsides to forage for small mammals (Ramsden 2003). Barn Owls are particularly susceptible to vehicle collision (Illner 1992, De Bruin 1994, Massemin and Zorn 1998, Ramsden 2003, Boves and Belthoff 2012). Several studies to assess avian mortality on roads have showed that Barn Owls are disproportionately represented and often the most frequently affected raptor (Massemin and Zorn 1998, Shawyer and Dixon 1999), or the most frequently affected bird species (Baudvin 1997, Boves and Belthoff 2012, Loss *et al.* 2014). Gomes et al. (2008) indicated that one of the main factors influencing Barn Owl vehicle collision was the presence of suitable habitat conditions which promote hunting near roads. Similarly, roadside grass verges which support small mammal populations have been linked to mortality hotspots for Barn Owl road casualties (Baudvin 1997, Gomes *et al.* 2008). Consequently, opinion is divided on appropriate management measures of roadside verges. Some studies recommend that verge habitats should be enhanced for small mammals and their predators (Meunier *et al.* 2000, Ascensao *et al.* 2012), whereas others recommend the opposite to reduce collision risk for predators (Ramsden 2003, Gomes *et al.* 2008). There is limited data however on how Barn Owls exploit roadside verges, and in particular whether the potential benefits associated with the provision of suitable foraging habitat outweigh the increased risk of collision for Barn Owl populations. The situation is further complicated by the limited and geographically isolated data on small mammal communities on roadsides, and the fact that behaviour responses vary depending on many site and species-specific factors including local and landscape habitat conditions, and species assemblages (Bellamy *et al.* 2000, Biossonette and Rossa 2009, Peter *et al.* 2013). It is clear that an improved understanding of the importance and use of roadsides by small mammal communities and the potential implications for their predators is essential to recognise the ecological value and potential of roads in these landscapes, and to inform appropriate management of roadside verges to deliver biodiversity benefits according to local environmental conditions.

In the Republic of Ireland, the rapid modernisation of farming practices over recent decades has had a profound effect on local landscapes, which has radically impoverished the diversity of flora and fauna in agricultural ecosystems (Donald *et al.* 2001). Agriculture is the dominant form of land use in Ireland, covering 70% of the land surface area (Eaton *et al.* 2008). The majority (76%) of agricultural land is devoted to grassland, primarily for beef and dairy production (Central Statistics Office 2012). Here, small mammals are largely restricted to field margins, which are primarily linear semi-natural hedgerow habitats (Montgomery and Dowie 1993). The reduced habitat availability and consequences for small mammals has led to interest in the impacts of the expanding road network for small mammal communities and the potential implications for Barn Owl populations. Alongside the intensification of agriculture, the Irish national road network has increased substantially, particularly with the development and expansion of motorways since the early 1980s (Transport Infrastructure Ireland 2016). However, there is a lack of information regarding wildlife responses to this landscape modification, including small mammal populations. As evidence of small mammal interactions with motorways is limited and often contradictory (Rest 1992, Meunier *et al.* 1999, Ruiz-Capillas *et al.* 2013, Peter et al. 2013), there are no broad principles that can inform the implications of road expansion for small mammal populations in Ireland. These limitations are further compounded by the unique small mammal community in Ireland, lacking grassland specialists, as these typically dominate the open grassland habitats associated with motorway verges in other regions (Bellamy *et al.* 2000).

The objectives of this study were to determine the importance and use of motorway verges by small mammals in Ireland. To assess the importance of motorway verges for small mammal communities in the context of the wider landscape, we measured and compared small mammal abundance, biomass and species assemblages in motorway verges and hedgerows in the surrounding countryside. We also investigated the habitat preferences of small mammals in motorway verges to identify the factors which may influence overall and individual species abundance in roadside verges. This information should help inform the ecological value of motorway roadside verges in Ireland, and specifically help inform the potential suitability and attractiveness of motorway verge habitats as a foraging resource for Barn Owls.

3.2 Methods

3.2.1 Study Area

To investigate the effects of motorway verges on small mammal communities in Ireland, we selected an area encompassing an 80km section of the M8 Motorway and surrounding agricultural lands, in Counties Tipperary, Kilkenny and Cork in the Republic of Ireland (Figure 3.1). This study area was selected as it incorporates the known range of six small mammal species that occur on the island of Ireland: Wood Mouse Apodemus sylvaticus; House Mouse *Mus musculus*; Bank Vole *Myodes glareolus*; Pygmy Shrew *Sorex minutus*; Greater White-toothed Shrew *Crocidura russula* and Brown Rat *Rattus norvegicus*, although there is recent evidence that Pygmy Shrews may be locally extirpated due to the presence of Greater White-toothed Shrew (Tosh et al. 2008, McDevitt et al. 2014). One other small mammal, the Hazel Dormouse *Muscardinus avellanarius*, has a limited distribution in Ireland and was not present in our study area (Sheehy and Lawton 2015).

The M8 Motorway is a dual-lane carriageway which runs through predominantly improved agricultural lands comprising mostly pastoral and some arable, which is typical of the motorway network and surrounding landscape in Ireland. The roadside verges of the M8 Motorway consist of a broad unmanaged and ungrazed strip of natural vegetation which is predominantly open grassland with herbaceous vegetation and some tree and scrub cover, and a narrow-mown strip adjacent to the road surface. Field margins in the surrounding landscape are typically hedgerows, which are narrower and higher compared to motorway verges with a dense, and often continuous tree cover.

3.2.2 Small Mammal Survey

To compare small mammal communities in motorway verge habitats to hedgerows in the wider countryside, we established trap lines in both habitats.

Twenty-five trap lines were selected in motorway verge habitats, hereafter referred to as 'motorways', and twenty-four trap lines were selected in hedgerow field boundaries in the surrounding countryside, hereafter referred to as 'hedgerows'. Trap lines in hedgerows were selected along the verges of minor single carriageway roads, to allow for ease of access and these are representative of hedgerows in the wider countryside which are used by small mammals. Within the study area, trap lines were positioned at a minimum of 2km from each other to ensure independence of captures. Trap lines in hedgerows were positioned between 2km and 3km from the motorway to maintain habitat similarity between treatments (motorway and hedgerow trap lines) (Figure 3.1.). Each trap line (motorway and hedgerow) was 90m in length and consisted of 10 trap points, spaced at 10m intervals. At each trap point, two live-traps were deployed; therefore, 20 traps were used per trap line. Two trap types were used at each trap point to improve inter-species captures (Rose *et al*. 1977, Nicolais and Colyn 2006). These were a chamber trap (Longworth or Heslinga) and a plastic trip-trap. Traps were baited with oats and mealworm, and straw was provided as bedding.

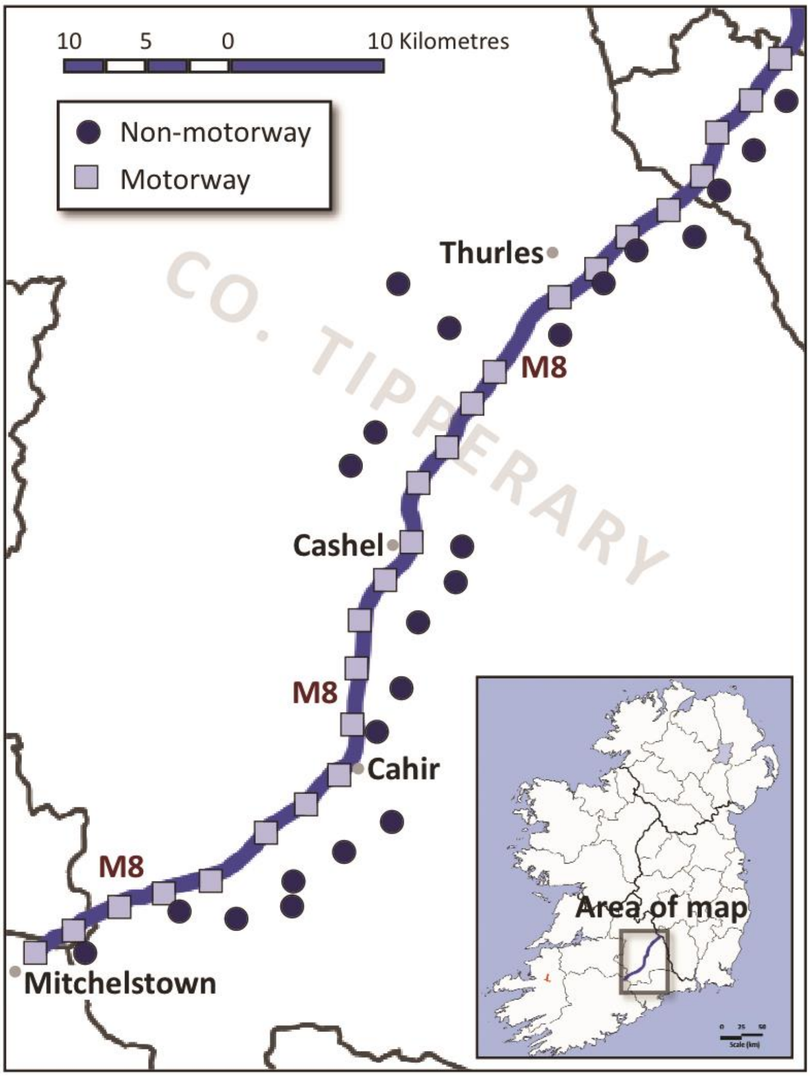


Figure 3.1 Location of study area within Ireland (inset) showing the M8 Motorway and location of motorway and hedgerow sites selected for sampling small mammal communities.

Small mammal sampling and handling procedures were carried out under licence to the NPWS in Ireland. Trapping was conducted over a six-week period in September and October 2016, to coincide with the peak in small mammal abundance in Ireland (Montgomery 1989). Traps were deployed on the first morning (Monday) of each week and were *in situ* for four trap nights, resulting in 80 trap nights per trap line.

Overall, trap effort was 3,156 trap nights with 1,636 and 1,520 trap nights undertaken on motorways and hedgerows respectively. The order of trap lines was randomly assigned to minimise bias relating to weather conditions or timing.

Traps were checked each morning from 08:00 hrs on the second day (Tuesday) to the fourth day (Thursday), and were removed on the fourth day of each week. Small mammal captures were placed in a clear plastic bag and identified to species level. All individuals were fur clipped using a unique mark specific to each trap line. For each capture, the sex (m/f), age class (juvenile/adult) (Gurnell and Flowerdew 2006), weight (to nearest 0.1g), whether the individual was marked (y/n), and the mark type if relevant, were recorded, and the animal was then released at the point of capture.

To investigate small mammal communities in motorways and hedgerows and to allow comparisons, we assessed the following attributes for each trap line on both treatments:

- Overall and individual small mammal abundance
- Recapture rate
- Biomass per trap night
- Species assemblage
- Sex and age class ratio
- Predator activity

The number of individual small mammals captured per trap night was used as the measure of small mammal abundance for each trap line. Recapture rates were the proportion of individuals trapped twice or more per trap line. Biomass (g) per trap night was calculated for each trap line using the mean weights (g) of animals trapped, as there is a relationship between abundance and body size in small mammals. Small mammal species assemblages were compared between motorway and hedgerow sites by measuring the species richness (S), Shannon-weaver index of diversity (H) and Shannon-weaver index of equitability (EH) for each trap line. The age class (juvenile or adult) of small mammals was determined for all individuals and sex ratios were also compared for three species for which the sex could be accurately determined (house mice, wood mice and Bank Voles). The sex ratios of Greater White-toothed Shrews were not determined due to the difficulty of sexing shrews in the field. We measured predator activity as the rate of trap disturbance by recording the number of traps which were disturbed or moved on each trap line.

3.2.3 Habitat survey

Habitat characteristics were recorded for each trap line to determine features of the verges which may influence small mammal communities and individual species (Montgomery & Dowie 1993, Bellamy *et al.* 2000). For each trap line, the following information was recorded:

- Verge width (1m, 25m, 6–10m, >10m)
- Tree abundance (<1, 1–5, 6–10, 11–20, >20)
- Adjacent land use (arable, improved grassland, unimproved grassland, woodland, other)

Additional variables were collected but were not comparable between treatments.

3.2.4 Data Analysis

All data analyses were carried out using R 3.1.2 (R Development Core Team 2015). Factors affecting overall small mammal abundance between motorway and hedgerow sites were examined using linear models. Small mammal abundance was the response and the treatment (motorway or hedgerow site), verge width, tree abundance, and adjacent land use were included as explanatory variables.

Generalised linear models (GLM) were used to examine differences in individual species abundance (individuals per trap night). Small mammal abundance was used as the response variable and the treatment (motorway or hedgerow site), species, verge width, tree abundance, and adjacent land use were included as explanatory variables. Species richness, diversity and equitability indices were compared between treatments using Mann-Whitney U tests.

3.3 Results

We recorded 1,912 small mammal captures of four species: Wood Mouse, House Mouse, Bank Vole and Greater White-toothed Shrew. The Bank Vole (n=910) represented nearly half of all captures (47.6%), followed by Greater White-toothed Shrew (n=556; 29.1%), Wood Mouse (n=379; 19.8%) and House Mouse (n=67; 3.5%). Of the individual small mammals trapped, 516 (26.9%) were recaptures, with 310 recaptures in motorways and 206 in hedgerow sites.

The overall number of individual small mammals (excluding recaptures) trapped in motorways (n=727) and hedgerows (n=663) were comparable (Table 3.1). Small mammal abundance was similar between motorway and hedgerow sites with an average of 0.448 individuals on motorways compared to 0.438 in hedgerows ($t=-1.102$, $p=0.276$). The abundance of Bank Vole, Greater White-toothed Shrew and House Mouse were comparable between treatments however Wood Mouse abundance was higher on motorways ($t=-2.667$, $p=0.008$) (Figure. 3.2). The abundance of Bank Vole, Greater White-toothed Shrew and House Mouse was not influenced by any of the habitat variables assessed; however, wood mice abundance was positively influenced by the presence of arable land as an adjacent land use to motorways ($t=-2.787$, $p=0.005$) (Figure 3.3). When we excluded trap lines (n=5) adjacent to arable fields from the analysis, generally small mammal abundance between motorways and hedgerows was comparable ($F=0.03$, $p=0.864$). Overall, the explanatory variables included in our model (glm) explained 16% of the variation observed in small mammal abundance.

Small mammal biomass per trap night was comparable between motorway (6.20g) and non-motorway (6.1g) sites. The mean trap line biomass was higher, but not significantly, on motorways ($x=406.24$g) compared to hedgerows ($x=394.82$g). Small mammal species richness was higher on motorways ($W=432$, $p<0.001$) whilst species evenness ($W=267$, $p=0.510$) and diversity ($W=406.5$, $p=0.033$) was comparable between treatments.

A higher proportion of juvenile wood mice were present in hedgerows (42%) compared to motorways (24.1%). The opposite was true for Bank Voles with 19.6% and 13.7% of all captures comprising juveniles on motorways and hedgerows respectively. The proportion of female Bank Voles was higher on motorways with 1.34 females to every male compared to 1.12 in hedgerows. The inverse was true for wood mice with a greater proportion of females on hedgerows (1.05 females to every male) than on motorways (0.6 females to every male).

Table 3.1 Comparison of small mammal communities in motorway verges and hedgerow habitats.

	Motorway	Hedgerow	Significance
Small mammal species (individual)			
Wood Mouse	163	86	T=-2.787, p=0.005
House Mouse	25	26	-
Bank Vole	284	326	-
Greater White-toothed Shrew	270	226	-
Total individuals caught	727	663	-

	Motorway	Hedgerow	Significance
Small mammal captures/trap night	0.488	0.438	F=0.021, p=0.884
Small mammal biomass (g)	6.20	6.1	-
Mean trap line biomass (g)	399.57	380.81	F=0.318, p=0.575
Species richness (mean) (S)	3.44	3.0	W=432, p<0.001
Species diversity (mean) - Shannon Weaver (H)	1.00	0.92	W=406.5, p=0.033
Equitability - evenness (mean) (E_H)	0.82	0.84	W=267, p=0.510

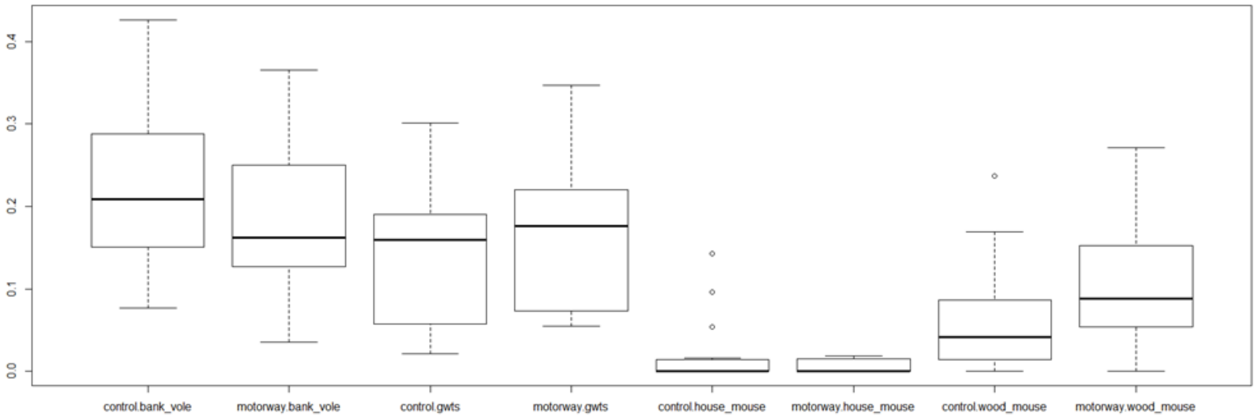


Figure 3.2 Comparison of the individual small mammal species abundance in motorway verges and hedgerows.

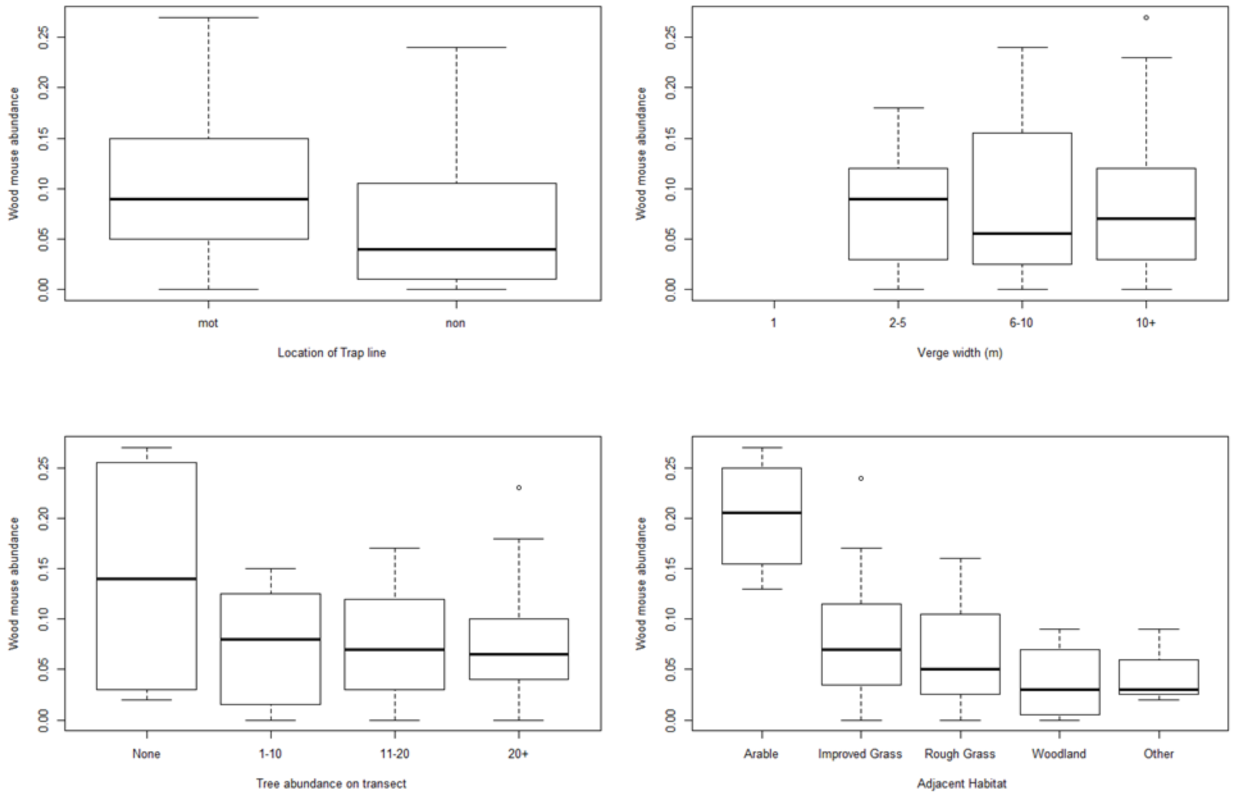


Figure 3.3 Comparison of Wood Mouse abundance in motorway verges and hedgerows in relation to the location of trap line, verge width, tree abundance and adjacent habitat type.

3.4 Discussion

This study confirms that motorway verge habitats provide an important refuge for small mammal populations in intensive agricultural landscapes in Ireland. Motorway verges support a similar abundance and greater diversity of small mammal species than hedgerow networks in pastoral farmland in Ireland. Our findings provide evidence of the behavioural response of small mammal populations to motorway verges in grassland-dominated landscapes and demonstrate the potential for road infrastructures to contribute to maintaining and enhancing biodiversity in heavily-modified landscapes.

Our findings broadly correspond with evidence on the importance of verge habitats of major roads for small mammals in Great Britain. Bellamy *et al.* (2000) showed that small mammal densities in the verges of major roads were similar to those in hedgerows in arable land. Similarly, small mammal abundance in national and municipal roadsides in Portugal were comparable to nearby riparian habitats (Sabino-Marques and Mira 2011). Few studies in Europe however have investigated small mammal communities in motorway verges, which differ in habitat structure, composition and management to the verges of other road types. In the Netherlands, the observed overall abundance of small mammals in motorway verges was found to be lower than in the surrounding countryside, which was attributed to intensive management of the verges (Reest 1992). Motorway verges in Ireland are not subject to regular or intensive management, which is likely to be a factor in their enhanced suitability for small mammals compared to motorways assessed in the Netherlands. In France and Spain, a greater abundance of small mammals was recorded in motorway verges in comparison to adjacent habitats (Meunier et al. 1999, Ruiz-Capillas *et al.* 2013). There are several potential factors to explain the greater relative importance of roadside verges in western Continental Europe compared to our study.

Firstly, Ireland has a unique small mammal fauna, which lacks grassland specialists. Grassland specialists generally prefer road verges to adjacent landscapes (Adams and Geis 1983) and are often one of the most common (Meunier *et al.* 1999), or the most common species in open grassland habitats (Reest 1992, Bellamy *et al.* 2000) which is typical of motorway verges. Furthermore, the importance of motorway verges for small mammal communities is relative to the availability and suitability of habitats in the wider landscape, which varies significantly on a local or regional basis. In Ireland, hedgerows are one of the most widespread semi-natural habitats, which cover 1.5% of the land area (Smal 1995). These linear networks, due to their extent, connectivity and structure provide a suitable refuge for small mammals, which may influence the relative importance of motorway verges for these species compared to different landscapes.

As the behavioural response of small mammals to roadside verges is influenced by a range of biotic and abiotic factors (Peter *et al.* 2013), assessing small mammal communities, in the context of the local environment, facilitates a more comprehensive appreciation of the value of roadsides for these species. It is clear that motorway verges provide suitable and additional habitat opportunities for small mammals in the Irish landscape. Roadside verges were found in this study to be of equal or greater value as a habitat for small mammals as hedgerows. Previous studies have shown that the abundance of small mammals in verge habitats in the Irish landscape is positively influenced by the density and diversity of trees (Montgomery and Dowie 1993, Ó hUallacháin and Madden 2011). In contrast, small mammal abundance was similar in the open, grassland-dominated motorway verges to hedgerows, which have greater tree cover and tree species diversity. There have been recent and dramatic changes to small mammal fauna in Ireland however (Classens and O'Gorman 1965, Tosh et al. 2008), which makes comparisons between studies difficult. For example, the two most abundant species in our study were not recorded in previous investigations of small mammal habitat preferences in Ireland (Montgomery and Dowie 1993, Ó hUallacháin and Madden 2011). Until recently, the Wood Mouse was the most dominant species in field boundaries throughout Ireland (Montgomery and Dowie 1993, Ó hUallacháin and Madden 2011), and remains as such across the majority of the country. However, this is no longer the case in our study area, as the Bank Vole and Greater White-toothed Shrew occurred in greater numbers in both motorways and hedgerow habitats. The arrival of both invasive species over the past century (Classens and O'Gorman 1965, Tosh *et al*. 2008) has profoundly affected long-established small mammal communities (Montgomery *et al.* 2012), with implications for shifting habitat associations. Our data also provides further evidence of the local extirpation of the Pygmy Shrew from parts of the south of Ireland (Tosh *et al.* 2008, McDevitt *et al.* 2013). This species was not recorded in this study, despite trapping in suitable habitat within its former traditional range. With the continued expansion of invasive small mammals, and associated changes in population dynamics, our findings on the use and importance of motorway verges for small mammals can be considered representative of the national situation in the future.

The Bank Vole, which has an expanding range currently covering one third of the island of Ireland (White *et al.* 2012), was the most common species recorded and occurred in similar numbers in both motorway verges and hedgerows. Bank Voles are a habitat specialist, typically associated with tree cover (Alibhai and Gipps 1985). It is somewhat surprising therefore that Bank Voles are seemingly able to exploit motorway verges to the same extent as hedgerows in the Irish countryside. Geeling *et al.* 2007 showed that small mammal species increase in relative abundance with width of the edge habitat. Motorway verges were wider than hedgerows in our study area, which may influence their suitability for small mammals relative to other linear habitats with more abundant tree cover. Habitat connectivity is also a positive indicator of small mammal abundance, which may explain the importance of motorway verges, which are continuous over an extensive area. Motorway verges also represent a stable environment which is not prone to regular human disturbance or alteration in the same way as other habitats in agricultural systems. Small mammals can therefore occupy roadside verges throughout the year and utilise the continuous cover to exploit seasonally available food sources in adjacent habitats. This was apparent with the Wood Mouse, which was the only species that showed a preference for one treatment over the other, being nearly twice as abundant in motorway verges than in hedgerows. Wood Mice occupy a variety of habitats and exploit a wide range of food sources, depending on season and availability (Montgomery 1978, Flowerdew 1993).

Numerous studies have shown that Wood Mice inhabit arable fields for much of the year but take refuge in edge habitats after the crop is harvested (Tew *et al.* 1994, 2000, Todd *et al.* 2000, Tattersall *et al.* 2001). This study shows that the higher abundance of Wood Mice observed on roadsides was influenced by proximity to arable fields, indicating that this species utilises the continuous cover in motorway verges when resources in nearby arable land are unavailable. Greater White-toothed Shrews are well adapted to heterogeneous habitats (Genoud 1985) and can occupy open habitats (Genoud and Hutterer 1990); therefore, it is unsurprising that numbers were higher in motorway verges than in hedgerows, albeit not significantly. The use of motorway verges by Greater White-toothed Shrews may be influenced by the suitable conditions for invertebrates, created by the grass-dominated verges (Ó hUallacháin and Madden 2011).

Although the abundance of small mammals was similar between motorway verges and hedgerows, species diversity was higher on motorways. This finding is in line with Geier and Best (1980) who recorded more diverse small mammal communities in grass-dominated habitats along streams which experienced minimal disturbance from grazing, cutting and herbicides. Similarly, Butet *et al.* (2006) showed that grass-dominated habitats at field boundaries supported a more balanced diversity of the community.

Our data indicates that motorway verges support a similar abundance and greater diversity of small mammal species as hedgerows, and therefore represent a potentially important foraging resource for Barn Owls in the Irish landscape. The habitat composition of motorway verges may also be important to consider when assessing their value as a foraging resource for Barn Owls and other avian predators. Motorway verges are typically open grassland, compared to hedgerow networks which typically comprise more dense vegetation including trees and shrub cover. Therefore, despite supporting similar abundances of small mammals, there may be differences in the visibility and accessibility of small mammals for Barn Owls, based on the habitat composition. For example, several studies recommend planting dense scrub or other cover on motorway verges to make them less attractive to Barn Owls (Ramsden 2003, Gomes *et al.* 2008). The fact that motorway verges are long, linear strips of habitat may also make them more enticing for avian predators as they are a less energy-demanding habitat to hunt. Perches in the form of road signs and fence posts along motorway verges may also attract Barn Owls as these can be used as observation posts from which to hunt (Nero and Copland 1981, Borquin 1983).

4. Barn Owl Distribution in Relation to Road Networks

4.1 Introduction

Roads are among the most widespread forms of modification of the natural landscape during the past century which have altered ecosystems and can directly and indirectly affect animal populations. Barn Owls are affected by major roads through direct collision with vehicles, which represents a major cause of mortality and has been implicated as a contributing factor in the decline of their populations. In addition to direct mortality, the development of road networks can also affect the quality and quantity of available habitat for Barn Owls (Glista *et al.* 2009) and may cause local displacement of birds through loss of nest sites. These factors combined may cause the displacement of birds in areas in proximity to major roads and thus affect the distribution and limit the breeding range of Barn Owl populations.

Several studies to investigate the effects of major road infrastructures on Barn Owl distribution and abundance in Britain have reported negative impacts on Barn Owl populations. Shawyer (1987) indicated a significant disparity in the national distribution of Barn Owl breeding pairs in Britain in relation to major roads, indicating that only 20 pairs of an estimated 5,000 Barn Owl nesting sites recorded in the 1980s were situated within 1km of a major road and fewer than 100 pairs were within 3km of major roads. Shawyer and Dixon (1999) reported similar effects of roads on Barn Owl nesting distribution. Of almost 3,000 reported Barn Owl nest sites across England and Wales, less than 1% of sites were within 1km of a trunk road, this proportion being approximately five times lower than would be predicted by chance. Ramsden (2003) also investigated the impact of major roads on Barn Owl distribution in the south of England by comparing the density of occupied Barn Owl sites in three selected survey areas of similar size; one survey area along a stretch of motorway and two control areas which did not contain major roads. Only two sites in the motorway area contained evidence of Barn Owl occupation, whereas the control areas contained an average of 5.5 occupied sites, which led Ramsden (2003) to conclude that the presence of the motorway had a negative effect on Barn Owl occupancy.

The development of new major road schemes has also been reported to negatively affect Barn Owl distribution and abundance. Prior to the construction of a 22km section of dual carriageway in the south of England, Ramsden (2003) conducted an intensive survey which recorded two Barn Owl roosting sites, situated 150m and 300m from the planned route, and two additional roosting sites at distances of 1km and 1.3km. After the road was opened, the survey was repeated and the four roosting sites were found to be no longer occupied, leading to the conclusion that the road was the likely cause of this apparent local decline (Ramsden 2003). It should be noted however that the sample size of sites for these surveys was limited, and in addition the majority of the sites located seemed to be used only for roosting or their breeding status was undetermined. Roost sites may be used sporadically or for short periods of time, for example by juveniles during dispersal; therefore, the presence and occupation of nesting pairs provides a more reliable indication of Barn Owl distribution and status. Based on these findings, Ramsden (2003) suggested that risk of mortality to Barn Owls from motorways increases dramatically with proximity to roost and nest sites and indicated that new major road developments caused the loss of all Barn Owls within 0.5km, and severe depletion of populations within 0.5–2.5km of the route. Ramsden (2003) also estimated that major roads in rural England have caused the removal of Barn Owls from an area of between 8,100km^2 and 16,200km^2, and depleted the population over an area of roughly 48,600km^2 which corresponds to 40% of the total area of rural England. Shawyer (1998) ascertained that new major road schemes caused the local displacement of Barn Owls, predicting the rapid depletion of all Barn Owl sites within 2km of new major road developments. A study conducted by the Highways Agency in Britain supported these findings and concluded that although prime feeding and nesting habitats are readily available to Barn Owls within 1.0–1.5km of major roads, breeding populations are rapidly depleted and eventually lost within these 3km wide corridors following road construction or improvement (Highways Agency 2013).

Negative effects of major road developments on Barn Owl status and distribution have also been recorded elsewhere in Europe. Grillo *et al.* (2012) proposed that highways may act as sinks for Barn Owl populations on a regional level in Portugal, suggesting that the actual density next to the road is probably much lower than it could be, given the habitat quality. Grillo *et al.* (2012) suggested that breeding performance may be affected by road density and that the high death toll imposed by highways may decrease over time, because there are not enough individuals available to occupy these areas. Sousa *et al.* (2010) showed that roads appear to cause an avoidance effect on the establishment of Barn Owl home ranges in Portugal, and that core areas of Barn Owl home ranges typically did not include highways. In Spain, the expansion of the road network and subsequent mortality on roads has been implicated as one of the main factors causing local Barn Owl population declines (Martínez and Zuberogoitia 2004).

Although most effects of major roads on Barn Owl distribution and abundance has been reported to be negative, there is the potential that roads may have some positive affects for Barn Owls, which should be considered. Roadside verges can provide an important habitat refuge and support a higher abundance of small mammal populations than surrounding habitats. There is evidence that Barn Owls utilise verges of major roads for foraging; however, the importance of these verge habitats for Barn Owls, and the effects on foraging selection, breeding success and the associated risk of collision for birds which exploit verge habitats for hunting is not well known. The majority of Barn Owls killed on major roads are juvenile birds, and therefore it is possible that this source of mortality may have less of an effect on breeding adults in the local area than the benefits of the provision of extensive foraging habitat in the form of roadside verges. There is a lack of information regarding the learning process of Barn Owls in relation to major roads, and whether risk of collision for individuals may be reduced over time as encounter rates with roads increase. Clearly, there is a requirement to reduce the negative impacts of major roads on Barn Owl populations, but essential to this is also maximising any potential benefits. The verges of major roads represent extensive linear habitat corridors which provide a suitable refuge for small mammal populations, and a potentially important foraging habitat for Barn Owls. This requires that the potential benefits of road networks for Barn Owls are investigated, to inform appropriate verge management to maintain or enhance the biodiversity value of verges should this be appropriate.

We investigated the potential effects of major road networks on Barn Owl distribution, abundance, occupancy rates and breeding parameters in Ireland. We conducted surveys and monitoring to collate data on Barn Owl nesting sites and breeding data and analysed this data with respect to spatial proximity to major roads to determine whether major road networks impact on the following:

i. Breeding densities and distribution of Barn Owls on a local level
ii. Barn Owl distribution on a national scale
iii. Occupancy rates of breeding sites over time, including the survival of individual breeding adults
iv. Breeding success and productivity of breeding pairs

4.2 Methods

4.2.1 Study Area

To investigate the potential effect of major roads on Barn Owl populations at a local scale, we selected two survey areas, encompassing major road networks, and assessed Barn Owl densities, distribution and breeding performance within. The M8 survey area included a 72.2km section of the M8 Motorway, predominantly in County Tipperary, extending into east Limerick and north Cork. The Tralee Bypass survey area in County Kerry incorporated the entire length of the bypass (13.5km). Each survey area included a buffer of 5km radius either side of the route. The size of the survey areas was informed by best evidence of Barn Owl home range size in Ireland to include all Barn Owl sites potentially affected by these routes.

The M8 survey area comprised an area of 758km^2 and the Tralee Bypass survey area comprised 200km^2. In addition, we selected a control survey area which was paired with the M8 survey area to facilitate comparisons of Barn Owl breeding parameters in an area potentially affected by a major road with an area considered unaffected by major roads. The M8 control survey area was selected 20km to the west of the M8 survey area and is of identical size (758km^2) and dimension. The distance between paired survey areas (20km) was selected to ensure they were independent of each other (i.e. adult Barn Owls were unlikely to travel between surveys areas), while maintaining similarity with other factors which may influence Barn Owl populations (e.g. landscape and habitat conditions, nest and prey availability, etc.). The rationale for selecting the control survey area to the west of the M8 survey area is based on the distribution of introduced small mammal species, specifically the Bank Vole and Greater White-toothed Shrew, to ensure that the prey species base would be similar in both survey areas (Lysaght and Marnell 2016).

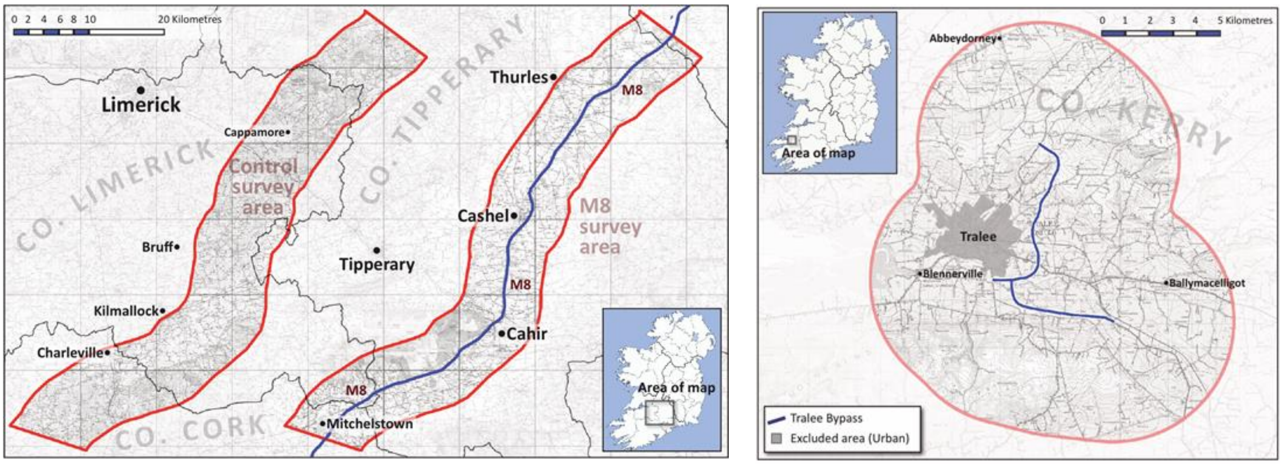


Figure 4.1 The M8 survey area and control area (left) and the Tralee Bypass survey area (right) which were selected to determine Barn Owl densities, distribution and occupancy in relation to major roads.

We also compared Barn Owl densities, distribution and breeding performance in the M8 and Tralee Bypass survey areas to breeding data on Barn Owl populations on a national scale which was collated between 2010 and 2017 using the same methods.

4.2.2 Barn Owl Breeding Densities

To determine Barn Owl densities and distribution in the selected survey areas (M8 survey area and control survey area, and Tralee Bypass survey area) we undertook intensive Barn Owl surveys to locate all Barn Owl active sites according to best practice methods defined by 'Barn Owl Surveying Standards for National Road Projects' (Transport Infrastructure Ireland 2017). Prior to initiating survey work, all relevant information on existing and previously active Barn Owl sites, sightings and mortality records in each survey area over the period of 2012–2017 were extracted from relevant databases (BWI Barn Owl databases and the *Bird Atlas 2007–2011 database*) to inform survey work.

Survey work was undertaken during the breeding season period (March to July) to facilitate determination of breeding status of occupied sites. The M8 survey and control areas were surveyed over two breeding seasons in 2016 and 2017. The Tralee Bypass survey area was surveyed over four breeding seasons between 2014 and 2017.

Field surveyors were equipped with official BWI identification, a copy of the BWI insurance policy, and appropriate Personal Protective Equipment including a torch, hard hat, boots, first-aid kit, whistle and mobile phone. Although attempts were made, it was not possible to gain access to all sites within survey areas to investigate the suitability and occupancy of Barn Owls due to safety reasons, or where permissions were not possible to obtain.

All buildings and quarries within the survey area were identified on Ordnance Survey and aerial maps prior to initiating survey work. All roads and tracks within the survey area were systematically travelled and the suitability of all buildings and quarries assessed. For each site, the following aspects were recorded:

- Date of survey visit
- Location details of the site (10 figure grid reference)
- Site type
- Site name (or townland name)
- Suitability of the site for Barn Owls based on a scale of 0–3
- Activity status of the site, based on signs or sightings indicating the presence of Barn Owls, and whether a nocturnal watch was required to confirm activity

Sites that were considered to be potentially suitable were comprehensively searched for signs indicating the presence of Barn Owls. These sites were categorised on a scale of 0–3, based on potential nesting and roosting opportunities for Barn Owls as follows:

- Category 0 sites were those which were not suitable for Barn Owls
- Category 1 sites represented potential for roosting but where there were no nesting opportunities
- Category 2 sites were considered suitable for roosting and where nesting was possible
- Category 3 represented sites considered to be very suitable for nesting

At each site, a thorough search was conducted inside and outside of the building or within quarries in order to locate signs indicating the presence of Barn Owls, particularly pellets, evidence of whitewash splashing’s and moulted feathers. Adjacent buildings and potential perches in the immediate vicinity of the site were assessed. At certain active Barn Owl sites, due to the concealed nature of nest and/or roost site (i.e., blocked chimneys, deep cavities, etc.), signs are not always obvious or accessible. Therefore, at sites where this was judged to be a possibility, it was recorded that a nocturnal watch was necessary to confirm activity. Roost watches were subsequently conducted at dusk on the same night or night thereafter. The site was watched from a suitable vantage point for up to two hours from 30 minutes before sun set to check for the presence of Barn Owls, either by actual sightings and/or audible vocalisations. Sites were recorded as active if Barn Owl activity was confirmed via evidence of fresh signs or confirmation of one or both adults via observation or vocalisation. These methods were designed to locate all Barn Owl sites in buildings and quarries within the study area.

It was not possible to survey all potential tree sites due to the time-consuming nature of the methods required and extent of the survey areas. Information on Barn Owl activity and sightings was sought from landowners when requesting permission to access lands and buildings. Interviews with landowners have been successfully used to assess Barn Owl occupation in Barn Owl surveys in the UK (Toms *et al.* 2001). This method was used to identify any areas of potential activity where trees might be used, and which would not be recorded through searches of buildings or quarries. Landowners were asked a series of standardised questions, shown images and played vocalisations of Barn Owls to determine whether they had encountered Barn Owl activity. An assessment was made as to the reliability of individual reports based on the account and the observer’s description. Reliable reports were divided into two categories based on the timing of the sighting as either within the ‘breeding season’, consisting of the period March to July, or the ‘non-breeding season’ which comprises the remainder of the year. This categorisation was used to differentiate between sightings that were likely to be resident breeding birds (breeding season sightings) or sightings which could be either a resident adult bird or a dispersing juvenile (non-breeding season). The location and behavior of the sighting was recorded where this information was available.

Additional survey effort including nocturnal watches were focused in areas with reliable evidence of Barn Owls during the breeding season and where activity in buildings or quarries was not recorded.

At all sites where Barn Owl activity was confirmed (either via presence of signs or via nocturnal watches), nocturnal visits were carried out to confirm activity and breeding status. Active sites were classed as a 'breeding site' where a pair was present during the breeding season, a 'potential breeding site' where breeding was suspected but not possible to prove, or a 'non-breeding site' where no breeding activity was recorded.

All active Barn Owl sites in each survey area were mapped using ArcGIS ArcMap 10.2 (ESRI Inc., Redlands, CA). The density of recorded breeding sites (both confirmed breeding sites and potential breeding sites) was expressed as the number of sites per 100km^2 for all survey areas. The number of confirmed breeding sites and potential breeding sites were used to derive density estimates and for comparisons between survey areas. A breeding pair may use several roost sites or non-breeding sites in addition to the breeding site, and roost sites may also be used on a sporadic basis (Shawyer 1998). The density and occupancy of breeding sites therefore provides a more accurate indication of the status and trends of populations, and non-breeding sites were not used to derive density estimates for this reason.

To investigate the potential influence of major road infrastructures on Barn Owl breeding densities, we compared the following:

i. Numbers of recorded Barn Owl breeding sites in the M8 survey area and the control survey area
ii. Barn Owl breeding densities recorded in the major road survey areas (M8 survey area and Tralee Bypass survey area) to data on Barn Owl densities (2010–2017) in areas greater than 5km from major roads to determine any variation in Barn Owl populations in areas in proximity to and areas unaffected by major roads

4.2.3 Barn Owl Distribution

To investigate Barn Owl distribution in relation to major road infrastructures, we calculated the distance (m) of confirmed breeding sites in the M8 and Tralee Bypass survey areas to the nearest major road using Arc GIS ArcMap 10.2 (ESRI Inc., Redlands, CA). Using the Random Point Generator in ArcMap, we generated random points in the M8 survey area (n=100) and the Tralee Bypass survey area (n=50) and calculated the distance from each point to the nearest major road. The distance of breeding sites and random points to the nearest major road were compared to determine whether nests were located at random with respect to major roads or were influenced by these routes.

To identify the potential effects of road infrastructures on Barn Owl breeding distribution at a national scale, we collated and mapped all confirmed Barn Owl breeding sites in the Republic of Ireland between 2006 and 2017 (n=259). We created a buffer of 20km around each breeding site and generated 1,000 random points within using the Random Point Generator in ArcMap. To determine whether the distribution of breeding sites was influenced by roads, we compared the distance (m) of Barn Owl breeding sites (n=259) and random points (n=1,000) to the nearest national road (all national roads, dual carriageways and motorways) and to the nearest motorway.

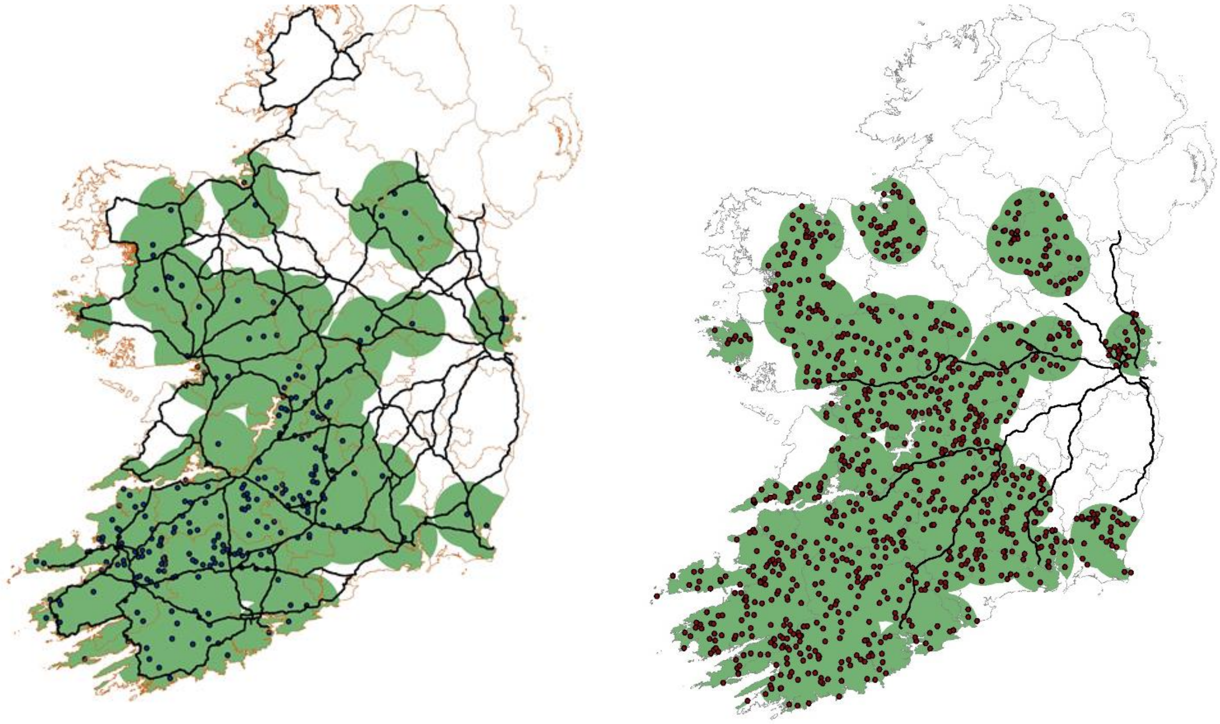


Figure 4.2 **Map of Ireland showing the distribution of all Barn Owl nest sites (n=259) in relation to the national road network (left) and all random points (n=1,000) in relation to the motorway network (right) used to assess spatial patterns of Barn Owl breeding distribution in relation to national roads.**

4.2.4 Barn Owl Breeding Performance

To determine Barn Owl breeding performance, nocturnal visits were carried out to record breeding success and performance of nesting pairs in selected survey areas and on a national scale between 2014 and 2017. At accessible breeding sites, nest visits were carried out under licence from the NPWS to determine the number of young (brood size) and to ring the owlets. A metal ring was fitted to each owlet under licence from the NPWS and the British Trust for Ornithology (BTO), and their sex, weight and age was recorded (Shawyer 1998).

The following measures were used to quantify the breeding performance of confirmed Barn Owl pairs:

i. Breeding success was defined as the success or failure of a breeding attempt to fledge one or more young in a single year
ii. Number of fledged young from successful nests described the number of young raised to, or close to, the stage of fledging for successful pairs
iii. Productivity described the number of fledged young for all breeding attempts for which the outcome was known (where a failed pair = 0 fledged young)

We compared the breeding performance of Barn Owl pairs in:

i. The M8 survey area and control area
ii. The major road survey areas (M8 survey area and Tralee Bypass survey area) with Barn Owl breeding data on a national scale (2014 and 2017)

4.2.5 Data Analysis

We performed a Two-sample T-test to investigate the influence of major roads on Barn Owl breeding distribution at a national scale by comparing the distance of breeding sites and random points to national and major road infrastructures.

4.3 Results

4.3.1 Barn Owl Breeding Densities

M8 Motorway

Nest Site Availability

A total of 407 sites were assessed for the suitability and occupancy of Barn Owls in the M8 survey area (758km^2) in 2016. Of these, 100 sites (24.5%) were considered to be unsuitable for Barn Owls (category 0), 215 sites (52.8%) were deemed to offer potential roosting opportunities but were unsuitable for nesting (category 1), 48 (11.8%) sites were considered to be suitable for roosting and potentially suitable for nesting (category 2), and 44 sites (10.8%) were suitable for nesting (category 3). Therefore, a total of 92 sites (category 2 and 3) were recorded which could be used by breeding Barn Owls, representing a density of 12.1 suitable sites per 100km^2 in the M8 survey area.

In the M8 control area, a total of 457 sites were assessed to determine suitability for and occupancy of Barn Owls. Of these, 113 sites (24.7%) were considered to be unsuitable for Barn Owls (category 0), 227 sites (49.6%) were deemed to offer potential roosting opportunities but were not suitable for nesting (category 1), and 66 (14.4%) sites were considered to be suitable for roosting and potentially suitable for nesting (category 2). The remaining 48 sites (10.5%) were assigned to category 3, considered to be suitable for nesting. Therefore, there were a total of 114 sites (category 2 and 3) in the 758km^2 study area that could be used by breeding Barn Owls, representing a density of 15 suitable sites per 100km^2.

Breeding Densities

In the M8 survey area, evidence of Barn Owl occupation was confirmed at 18 sites in 2016. Monitoring confirmed that six of these held breeding pairs. In addition, three possible breeding sites were identified where nesting was suspected, based on reports received and observations. Therefore, within the M8 survey area in 2016, there was a recorded breeding density of 0.8–1.2 pairs per 100km^2. In 2017, seven breeding pairs were confirmed in addition to two possible pairs, which equates to a breeding density of 0.9–1.2 pairs per 100km^2. In both years combined, there were eight breeding sites and two potential breeding sites recorded in the M8 survey area, representing a density of 1–1.3 pairs per 100km^2.

In the control area, evidence of Barn Owl occupation was confirmed in 19 sites in 2016. Monitoring confirmed that nine sites held breeding pairs. In addition, three possible breeding sites were identified where nesting was suspected but not possible to confirm. This represented a breeding density of 1.1–1.5 pairs per 100km^2 in the M8 control area in 2016. In 2017, there were seven confirmed breeding pairs and four possible pairs, which equates to a breeding density of 0.9–1.4 pairs per 100km^2. In both years combined, there were 10 breeding sites and three potential breeding sites, representing a density of 1.3–1.7 pairs per 100km^2. The number and distribution of breeding sites and potential breeding sites recorded in the M8 survey area and control area in both survey years combined (2016 and 2017) is illustrated in Figure 4.3, with details on breeding densities provided in Table 4.1.

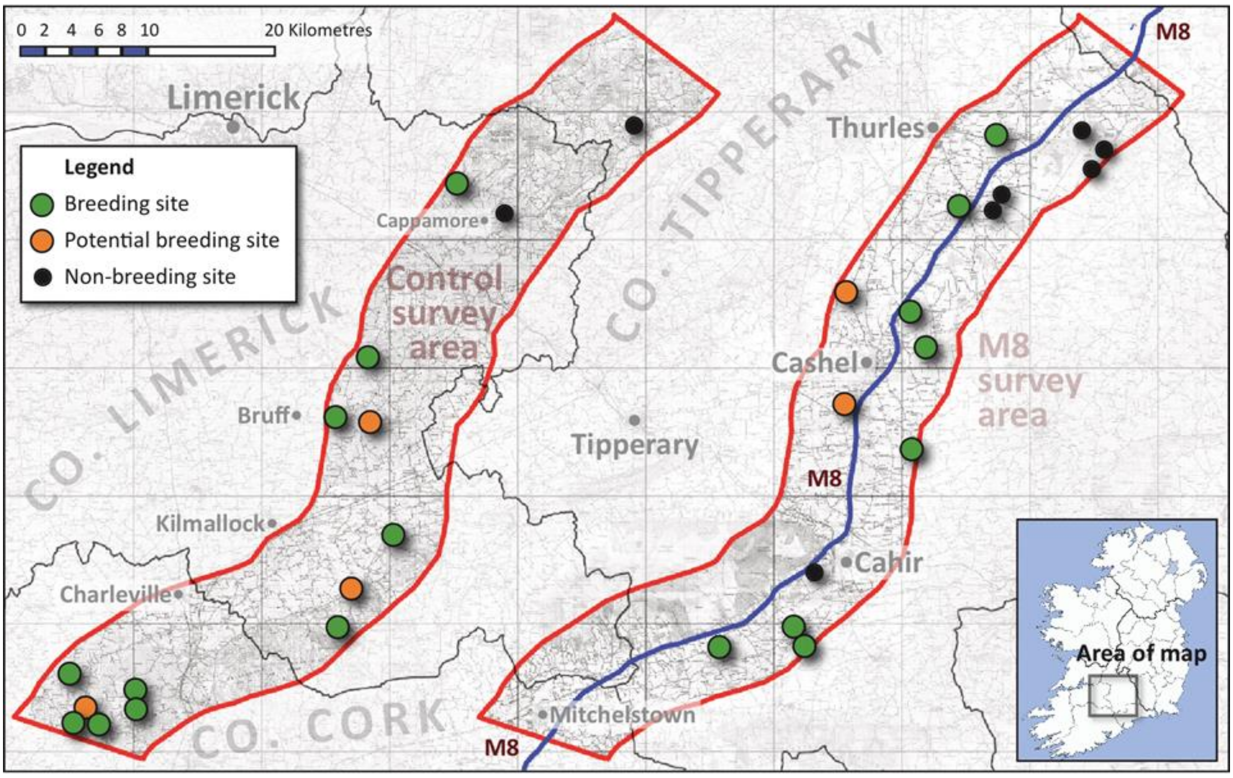


Figure 4.3 **The distribution of Barn Owl breeding sites, potential breeding sites and non-breeding sites recorded in the M8 survey area and control area in 2016 and 2017.**

Table 4.1 **Details of the M8 survey area and control area, and the nest site availability and Barn Owl breeding densities recorded within in 2016 and 2017.**

Survey area	Size (km^2)	Major road	Nest site availability (per $100km^2$)	Breeding density (per $100km^2$) 2016	Breeding density (per $100km^2$) 2017
M8 Survey Area	758	M8 Motorway	12.7	0.8–1.2	0.9–1.2
Control Area	758	-	15.7	1.1–1.5	0.9–1.4

Tralee Bypass

Nest Site Availability

In the Tralee Bypass survey area, a total of 147 sites were assessed in 2014 to determine suitability for and occupancy of Barn Owls. Of these, 50 sites (34%) were considered to be unsuitable for Barn Owls (category 0), 42 sites (28%) were deemed to offer potential roosting opportunities but were not suitable for nesting (category 1), 23 (16%) sites were considered to be suitable for roosting and potentially suitable for nesting (category 2), and 32 sites (22%) were assigned to category 3, considered to be suitable for nesting. Therefore, there were a total of 55 sites (category 2 and 3) in the $200km^2$ study area that could be used by breeding Barn Owls, representing a density of 27.5 suitable sites per $100km^2$. These 55 sites consisted of derelict cottages (n=28), two-story farmhouses (n=22), stone barns (n=3) and a single derelict mansion and derelict warehouse.

Barn Owl Densities

In 2014, evidence of Barn Owl occupation was confirmed in 10 sites in the Tralee Bypass survey area. Monitoring confirmed that two of these held breeding pairs and five were used for roosting. In addition, it was not possible to obtain permission to access one site, which was previously used for breeding up to 2012, and which remained suitable, with several sightings reported in the vicinity; therefore, this site was classed as a potential breeding site. All other sites (n=7) where signs of occupation were confirmed were deemed to be inactive in 2014. Therefore, in 2014 there was a recorded density of 1–1.5 breeding pairs per 100km^2 within the survey area. In 2015, there were four confirmed breeding pairs, and one potential pair which equates to a breeding density of 2–2.5 pairs per 100km^2. In both 2016 and 2017, there were three nest sites and two potential breeding pairs recorded which equates to 1.5–2.5 pairs per 100km^2. The number and distribution of breeding sites and potential breeding sites recorded in the Tralee Bypass survey area in all survey years combined (2014–2017) is illustrated in Figure 4.4.

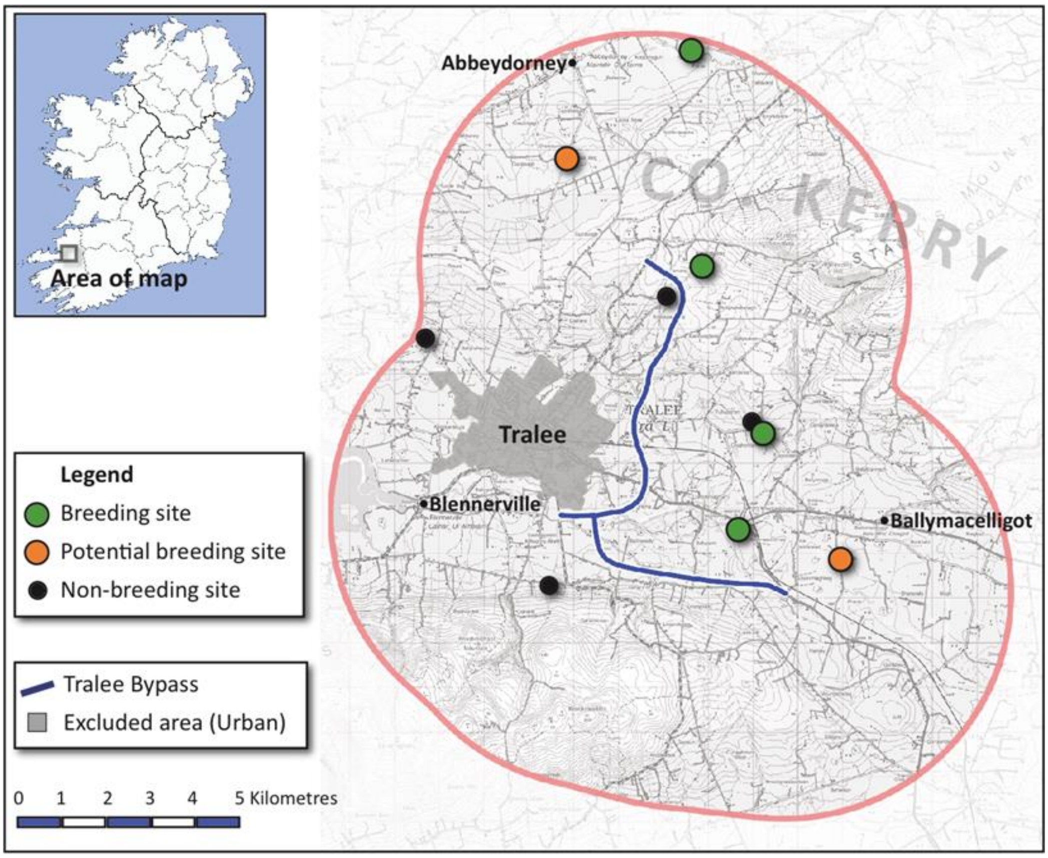


Figure 4.4 The distribution of Barn Owl breeding sites, potential breeding sites and non-breeding sites recorded in the Tralee Bypass survey area (2014–2017).

Barn Owl Breeding Densities in Areas Affected and Unaffected by Major Roads

Barn Owl breeding densities surrounding major roads were within the mid-range or higher-range of recorded densities in areas located away from major roads as shown in Table 4.2 and were above the average breeding density recorded nationally as illustrated in Figure 4.5.

Table 4.2. Barn Owl breeding densities in areas surrounding major roads (n=2) and areas located away from major roads (n=13) between 2010 and 2016, including details of the size, location, time period surveyed and recorded nest site availability in each survey area.

Survey area	Size (km^2)	County	Major road	Nest site availability (per $100km^2$)	Surveyed	Breeding density (per $100km^2$)
M8	758	Tipperary, Limerick & Cork	M8 Motorway	12.7	2016–2017	0.8–1.1*
Tralee Bypass	200	Kerry	Tralee Bypass	27.5	2014–2017	1.5–2.2*
M8 control area	758	Limerick & Cork	-	15.7	2016–2017	1–1.5*
North Cork	850	Limerick & Cork		10.8	2010	0.3
Limerick	163.5	Limerick		15.3	2010	0
Survey square - IR10	100	Cork & Kerry		10	2012	2
Survey square - IR30	100	Cork		14	2012	4
Survey square - IW19	100	Cork & Kerry		27	2012	1
Survey square - IN02	100	Offaly		13	2012	1
Survey square - IN12	100	Offaly		7	2012	0
Survey square - IN01	100	Offaly		16	2012	0
Survey square - IQ93	100	Kerry		11	2013	1
Survey square - IQ82	100	Kerry		24	2013	2
Survey square - IQ91	100	Kerry		17	2013	0
Galway	195	Galway		8.2	2014–2016	0.3
All areas	**3,824.5**			**13.9**	**-**	**0.8–1***

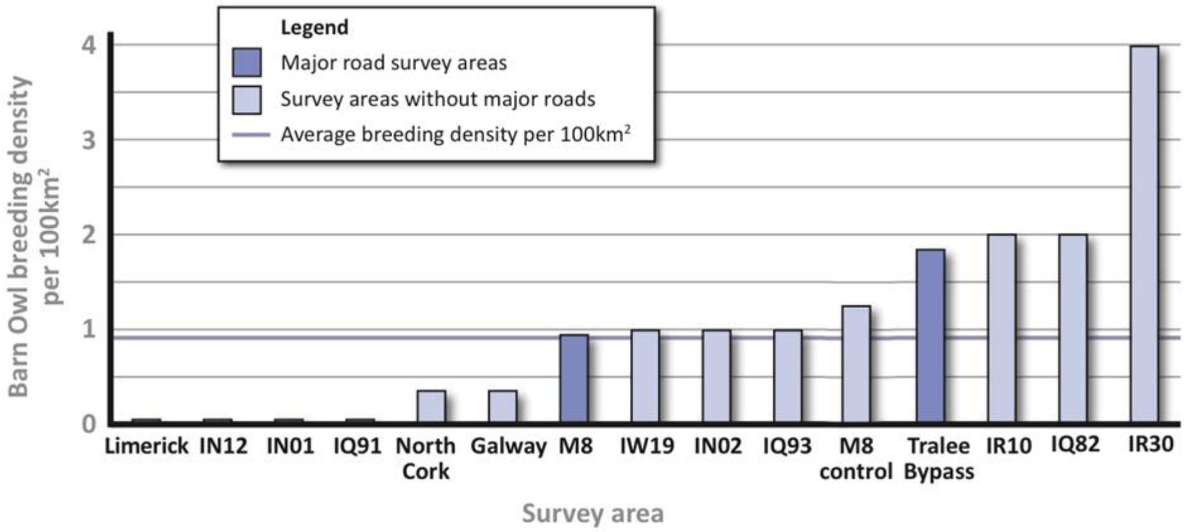


Figure 4.5 Recorded Barn Owl breeding densities in major road survey areas (dark blue) and other areas surveyed between 2010 and 2017 in the Republic of Ireland. The lowest breeding densities are shown on the left.

**For areas where a maximum and minimum number of pairs were recorded (confirmed breeding sites and potential breeding sites), we used the mid-range figures to express number of breeding pairs.*

4.3.2 Barn Owl Distribution

In the M8 survey area, the average distance of Barn Owl breeding sites to the M8 Motorway was 2.3km in 2016 (SE=0.5, n=6, range=580m–4.39km), and 2.2km in 2017 (SE=0.6, n=7, range=580m–4.39km).

In the Tralee Bypass survey area, the average distance of Barn Owl breeding sites to the bypass was 2.4km in 2014 (SE=0.1, n=2, range=2.2–2.6km), and 2.5km in 2015 (SE=0.9, n=4, range=0.4–4.8km). In 2016 and 2017, the average distance of breeding sites to the bypass was 3.2km (SE=0.7, n=3, range=2.2–4.8km). The distance of all confirmed breeding sites and their status on an annual basis over the period of monitoring in the M8 and Tralee Bypass survey areas are shown in Table 4.3.

Table 4.3 The distance of all confirmed breeding sites in the M8 (n=7) and Tralee Bypass survey areas (n=4) to the nearest major road, and the status of each site over the period of monitoring (2014–2017).

Survey area	Site	Distance to major road (km)	Status			
			2014	2015	2016	2017
M8	Ballydoyle	4.2	-	Nest	Potential nest	Nest
M8	Burges	4.3	-	-	Nest	Nest
M8	Burncourt	1.1	-	-	Nest	Nest
M8	Glasscoyne	0.6	-	-	Nest	Nest
M8	Knockannapisha	3.1	-	-	Nest	Not active
M8	Meldrum	1.8	-	Nest	Nest	Nest
M8	Moycarky	0.8	-	-	Not active	Nest
M8	Rathmanagh	2.5	-		Nest	Nest
Tralee	Ballycarty	2.2	Nest	Nest	Nest	Nest

Survey area	Site	Distance to major road (km)	Status			
			2014	2015	2016	2017
Tralee	Ballynahinch	2.6	Nest	Nest	Nest	Nest
Tralee	Ballyconnell	4.8	Non-breeding	Nest	Nest	Nest
Tralee	Ballintobeenig	0.4	Non-breeding	Nest	Not active	Not active

There was no significant difference in the location of Barn Owl breeding sites relative to the M8 (P=0.38) and the Tralee Bypass (P=0.49) compared to the expected distribution, based on the location random points in the M8 (n=100) and Tralee Bypass survey areas (n=50).

On a national scale, Barn Owl breeding sites (n=259) were located significantly closer to the national road network (mean distance to national road=4.4km, range, n=259) than would be expected if nests were located at random (mean distance to national road=5.0km) (df= 420.66, P=0.02). There was no significant difference in distance of Barn Owl breeding sites (n=259) and random points (n=1,000) to motorways (df=458.53, P=0.6).

4.3.3 Barn Owl Breeding Performance

In the M8 survey area in 2016, of six confirmed breeding sites, five (83%) were successful and one failed to breed. The number of fledged young per successful pair in the M8 survey area was 2.8 (se=0.3, n=5, range=2–4) and the productivity of pairs in the M8 survey area was 2.3 young per breeding attempt (se=0.5, n=6, range=0–4). In 2017, all six breeding sites accurately monitored were successful (100%), with a recorded productivity of 2.75 (se=0.6, n=4, range=1–4). In the control area in 2016, of eight confirmed breeding sites accurately monitored, all were successful (n=8, 100%). The number of fledged young per successful pair and productivity in the control area was 2.6 (se=0.4, n=6, range=1–4). In 2017, of five confirmed breeding sites accurately monitored, all were successful (n=5, 100%). Three pairs accurately monitored all fledged four young.

In the Tralee Bypass survey area in 2014, of two confirmed breeding sites, one (50%) was successful and the other failed. The single successful pair fledged two young and therefore there was an average productivity of one young per breeding attempt (se=1, n=2, range=0–2). In 2015, of four confirmed breeding sites, three (75%) were successful, with a fledging success of three young (se=0, n=3, range=3) and a productivity of 2.25 young per pair (se=0.7, n=4, range=0–3). In 2016, of three confirmed breeding sites, all were successful (100%); of two pairs for which it was possible to accurately monitor breeding, the number of fledged young and productivity was two young (se=1, n=2, range=1–3). In 2017, of three confirmed breeding sites, two were successful (66%), and there was a recorded productivity of 1.5 young per breeding attempt (se=1.5, n=2, range=0–3). The breeding success, fledging success and productivity of all recorded Barn Owl pairs in the major road survey areas and survey areas located >5km from major roads between 2014 and 2017 are illustrated in Figure 4.6.

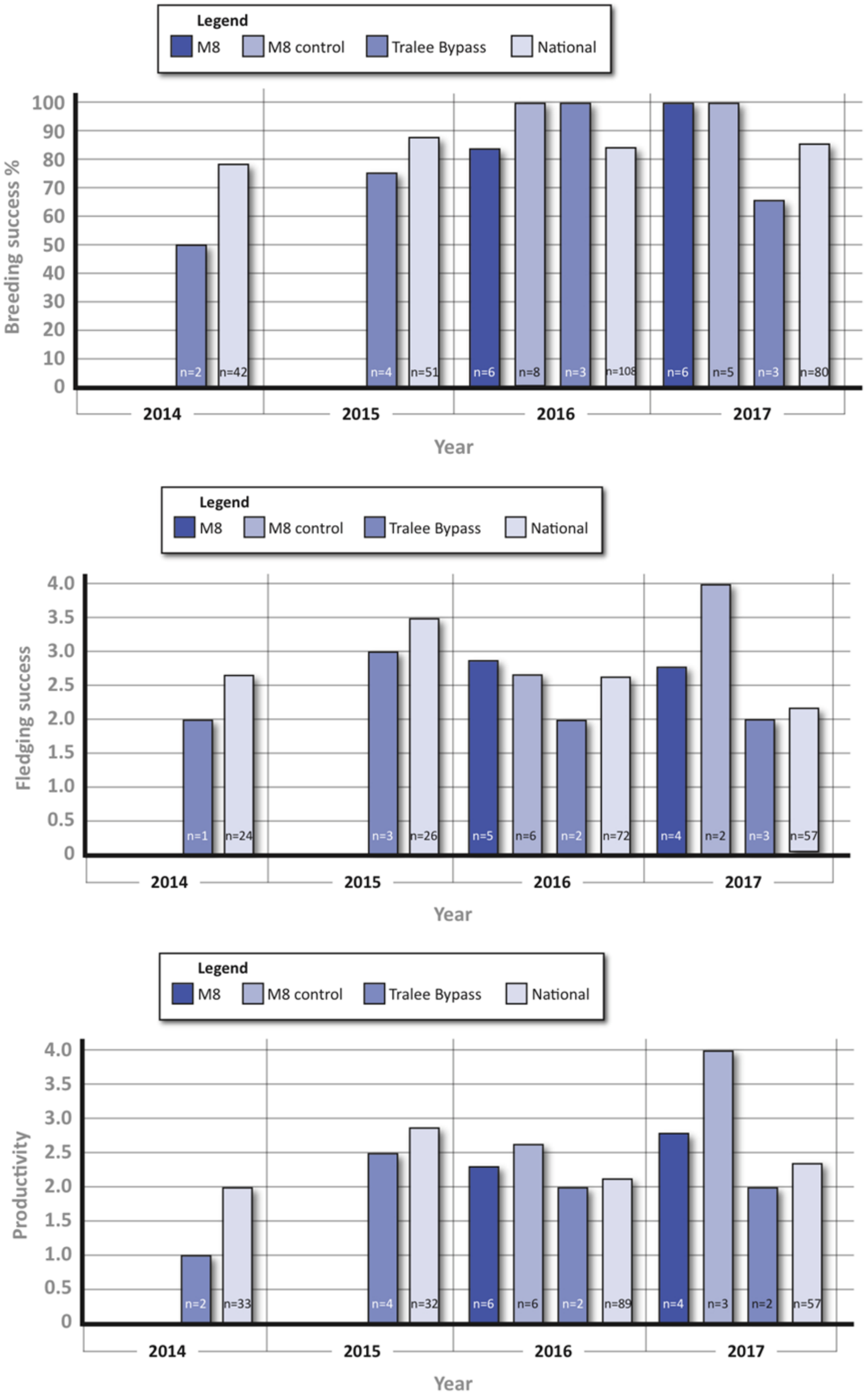


Figure 4.6 The breeding success (top), fledging success (middle) and productivity (bottom) of all recorded Barn Owl pairs in the major road survey areas (M8 survey area and Tralee Bypass survey area) and survey areas which are >5km from major roads (M8 control area and national) between 2014 and 2017.

4.4 Discussion

Barn Owl breeding densities were comparable in an area surrounding a motorway to an area of similar habitat and landscape conditions where there were no major roads. The breeding population size was marginally higher (based on mid-range estimates) in the control survey area, located away from major roads, compared with the survey area surrounding the M8 Motorway across two survey years. The availability of potential nesting sites was also similar in both survey areas, which validates the comparison of breeding densities. The availability of nesting sites was significantly higher than the number of nesting pairs recorded in these areas, which indicates that Barn Owls were not limited by the lack of nest sites, and that other factors influence Barn Owl population levels in these areas.

Barn Owl breeding densities surrounding the M8 Motorway and the Tralee Bypass were above the average breeding density recorded in the Republic of Ireland. The area surrounding the Tralee Bypass held one of the highest breeding densities registered in the country. Our findings therefore provide evidence that Barn Owl breeding densities are not significantly negatively affected by major roads in the Republic of Ireland; at least to the same extent as has been reported for Barn Owl populations in the UK and parts of Europe. Ramsden (2003) recorded a lower density of occupied Barn Owl sites along a stretch of motorway compared to two control areas which did not contain major roads. There are several potential reasons to explain the variation in findings between studies despite the similar approach, with one difference being that Ramsden (2003) included all occupied sites in the comparison between motorway and non-motorway areas; whereas our study only assessed breeding sites, which provides a more accurate indication of the health of local populations and their viability over time. Ramsden (2003) recorded an average of 1.5 breeding sites in the control areas and no breeding sites in the motorway area. The low number of breeding sites recorded is likely influenced by the relatively small survey area (which was 35 times smaller than our study area) and based on this small sample of sites, Ramsden (2003), recommends caution in drawing conclusions from these survey findings. Ramsden (2003) inferred that reduced breeding densities in proximity to major roads has depleted Barn Owl populations over approximately 40% of the English countryside. Our findings do not support a similar conclusion for Barn Owl populations in Ireland. The roads selected in our study (M8 and Tralee Bypass) are considered representative of the major road network in Ireland, and high mortality rates of Barn Owls have been recorded on these routes. The fact that the areas surrounding both roads support Barn Owl populations which are similar or healthier than in other areas of the country unaffected by roads, indicates that major road infrastructures do not cause the significant reduction in Barn Owl populations over extensive areas.

The distribution of Barn Owl breeding pairs in relation to the M8 Motorway and Tralee Bypass provides further evidence that major roads do not influence Barn Owl breeding densities or nesting distribution at this scale. Barn Owl breeding sites were distributed as expected within 5km of the M8 Motorway and the Tralee Bypass, indicating that nest site selection and distribution is not influenced by the presence of these major roads. This was also the case on a national scale as we showed that the country-wide distribution of Barn Owl nesting sites is neither positively or negatively influenced by distribution of the motorway network. Breeding sites were located closer to national roads than expected within the Barn Owl breeding range; however, it is possible that this relationship may be influenced by the proximity of buildings to national roads, as opposed to an actual attraction to nesting close to the national road network. Regardless, our findings demonstrate that there is no obvious avoidance effect of motorways and national roads on nesting Barn Owls, and further, that road infrastructures do not appear to restrict the breeding range of Barn Owls in Ireland, at least based on the current extent of road infrastructures and the distribution of the Barn Owl population. Sousa et al. (2010) also reported Barn Owls nesting within 500m of a highway in Portugal, and these birds which were radio tracked included the highway with their home range, although not within their core areas. In general, our findings differ to available evidence of the impacts of major roads on Barn Owl distribution in Britain where a strong avoidance effect of Barn Owls nesting within 1km of major roads has been reported (Shawyer 1987, Shawyer and Dixon 1999).

Available evidence in Britain indicates that nesting Barn Owls are rapidly displaced by new major road schemes, with Shawyer (1998) reporting the loss of nesting pairs within 2km, and Ramsden (2003) indicating severe depletion of populations up to 2.5km from new major roads. The home range size of Barn Owls in Ireland (refer to Section 5) is substantially larger than in Britain (Askew 2007) and therefore it should be expected that any effects of major roads on Barn Owl distribution would be more noticeable over a wider area, however we show the opposite to be the case. Of eight breeding pairs confirmed within a 5km radius of the M8 Motorway, five were located less than 2.5km from the motorway, the closest of which was less than 600m from the road. Similarly, of four confirmed breeding pairs within 5km of the Tralee Bypass, two were situated within 2.5km of the bypass, with a third site located just beyond this range. The M8 Motorway and Tralee Bypass have been in operation since 2009 and 2013 respectively, and therefore any displacement effects on the local population should have been noticeable at the time of our study. Although we only have limited baseline data on nesting pairs in these areas prior to the development of the roads, the density estimates of breeding pairs in these areas, compared with the national average, indicates that there has not been a substantial decline in numbers. This assessment is further strengthened by the fact that the majority of breeding sites situated close to major roads remained occupied over the survey period.

Our findings confirm that Barn Owls can successfully nest in close proximity to major roads over a sustained period of time in the Republic of Ireland. We recorded an increase in the number of breeding sites surrounding the M8 Motorway and Tralee Bypass during the survey period. All four nest sites, located within 2.5km of the M8 Motorway, remained occupied by breeding pairs over both survey years, with an additional pair confirmed less than 1km from the motorway in the second year of the survey. In the Tralee Bypass survey area, two nest sites which were 2.2km and 2.6km from the bypass were used for breeding in each of the four survey years. One of these sites (2.6km from the bypass) is known to have supported a breeding pair since 2009 and has been active on a continuous basis before, during and after the construction and opening of the bypass. One nest site which was located just over 400m from the bypass was used for breeding in only one year, and was subsequently abandoned, the reason for which is unknown. This may indicate that where Barn Owls establish nest sites in close proximity to major roads (*c.* less than 500m), these nest sites may be less viable long-term; however, we did not detect such affects beyond this distance. There has been concern that major roads may create 'sink' areas for the population (Grillo *et al.* 2012), should birds be attracted to nest in close proximity to roads and subsequently suffer high mortality rates. While our data on the occupancy rates of breeding sites suggests that this is not the case in Ireland, it is also important to consider the individual survival and turnover rates at nest sites. The continued occupancy of breeding sites may provide a false indication of the health of the population, if the adults associated with these nests are frequently killed on roads and then replaced by other individuals. It was only possible to collect limited data on the survival of individual birds in our survey areas. We confirmed that one nest, located 1.8km from the M8 Motorway, was occupied by the same breeding adults over two survey seasons. At another traditional breeding site, located 2.6km from the Tralee Bypass, both adults were known to be in residence over three consecutive breeding seasons (2013–2015), at which time the male was killed on the bypass (early 2016) and replaced by another adult male, which bred successfully at this site for the subsequent two years of monitoring (2016 and 2017). However, in the absence of more detailed information on the survival of individuals at nests close to and at distance from major roads, it is not possible to speculate as to whether nests in proximity to major roads have an increased turnover of adults compared with nests in areas unaffected by major roads, and this is an aspect which warrants further attention. In general, however, our data shows that Barn Owl nests in close proximity to roads can remain viable and be used over consecutive years.

Although it is difficult to infer specific relationships on the effect or otherwise of roads on Barn Owl breeding performance, the trends observed do not indicate reduced breeding success in areas surrounding major road networks, as has been speculated by Grillo *et al.* (2012). The sample of breeding sites in the survey areas surrounding major roads were relatively small compared with the breeding data available for nest sites nationally, which is due to the extent of the survey areas surrounding major roads. Nonetheless, we observed that the breeding success of pairs within the M8 survey area was similar or higher to breeding success rates recorded for all pairs nationally over two survey years.

One of the causes of failed breeding attempts is mortality of adults during the critical breeding period, and based on our data, this did not affect birds in proximity to major roads more than pairs elsewhere in the country. For all breeding attempts, which are known to have failed in the areas surrounding major roads during the survey period, we confirmed that adult mortality was not the cause. The fledging success and productivity of pairs close to the M8 Motorway were higher than the national averages for the same years; however, the sample size of sites in the M8 survey area was low and not possible to test statistically. Nonetheless, based on our data it would seem that pairs located close to major roads did not experience reduced breeding performance compared to pairs elsewhere.

5. Individual Behaviour and Response of Barn Owls to Roads

5.1 Introduction

Although negative impacts of roads on wildlife are routinely reported, the specific mechanisms by which species are affected are often complicated and unknown. One of the most obvious effects of roads on wildlife is mortality caused by vehicle collisions (Malo *et al.* 2004). Other direct effects on wildlife include the loss and fragmentation of habitat (Laurance *et al.* 2009), and the restriction of animal movements and range (Riley *et al.* 2006, Holderegger and Di Giulio 2010). Many wildlife species which are vulnerable to the effects of roads are endangered or elusive, and it is often difficult to gather information on their behavioural response and the specific nature of impacts of roads on individuals or populations. A limited understanding of the response of wildlife species to roads can compromise the ability to develop effective evidence-based solutions to mitigate the potential negative impacts of roads. This is the case with the Barn Owl, which is particularly susceptible to vehicle collisions (Illner 1992, De Bruin 1994, Massemin and Zorn 1998, Ramsden 2003, Boves and Belthoff 2012). The extent of mortality on roads and the wider effects of roads on the distribution and range of Barn Owl populations have been reported for several populations; however, there is limited or conflicting evidence of the interactions and the behavioural response of Barn Owls to roads. For example, several studies have reported an avoidance effect of roads (Sousa *et al.* 2010, Grillo et al. 2012), whereas it has also been suggested that birds are actively attracted to hunt along the verges of major roads in other parts of their range (Ramsden 2003). Despite knowledge on the extent of road mortality, identification of mortality hotspots and the route and landscape characteristics which influence collision on specific road systems, the implementation of effective and evaluated mitigation solutions to minimise negative effects of roads on Barn Owl populations remains a significant challenge. One of the main knowledge gaps is understanding Barn Owl behaviour and response to roads in different situations and how this is related to risk of collision. A greater understanding of Barn Owl behaviour in relation to roads is also required to inform the potential benefits of road infrastructures for Barn Owls, which is essential in road management and the development of mitigation to maintain or deliver conservation benefits.

The recent advancement and application of tracking technologies has facilitated an increased understanding of the movement and behaviour of wildlife species. Several studies have employed very high frequency (VHF) radio transmitters to assess the foraging ecology of Barn Owls (Askew 2006), and in some cases, this has provided information on the response of individuals to roads (Sousa *et al.* 2010, Grillo *et al.* 2012). Sousa *et al.* (2010) used radio tracking to investigate the space-use patterns and movements of adult Barn Owls in relation to a highway in Portugal. The movements of seven Barn Owls which nested within 5km of a highway, revealed a general avoidance of the road. The home ranges of the birds generally extended in the opposite direction to the highway and the core areas used did not include the road. Birds did cross the highway however (one crossing per 17.09 hours of tracking) which showed that this infrastructure was not a barrier to Barn Owl movements. This study concluded highway verges were not frequently used, and were deemed to be unattractive to owls, despite supporting higher small mammal density than the surrounding areas. Grillo et al. (2012) also investigated the response of individual Barn Owls in their spatial behaviour to a highway in Portugal and showed broadly similar findings to Sousa *et al.* (2010). Grillo *et al.* (2012) radio tracked 11 Barn Owls and showed that these individuals established their home ranges in the vicinity of the highway, including them within their home range but with a lower probability of use. Barn Owls crossed the highway at a rate of 0.30 times per day and with greater frequency at sections of the highway which were above grade, with wide verges and a higher proportion of herbaceous cover in the verge.

Although use of radio tracking techniques has added to our knowledge of Barn Owl movements and behaviour, there are several limitations with this method. Specifically, this technique is subject to a high degree of error with respect to generating precise locations of the animal's position.

With the use of GPS telemetry technology, it is now possible to monitor and map details of animal movements at a finer resolution. GPS technology has facilitated the collection of highly regular and precise fixes of location information, enabling not only the tracking of space use, but also, either directly or indirectly, an assessment of the behaviour of animals. For example, clusters of stationary points may indicate that an individual has stopped for some reason, which could be to rest and/or to feed. GPS technology enables the compilation of vast quantities of data on a variety of species, and for some, cryptic, species may be the only mechanism for accurately assessing movements. GPS dataloggers have recently been successfully employed to study the movements and behaviour of Barn Owls; however, to our knowledge our study is the first to specifically use GPS technology to monitor the movements of Barn Owls in relation to roads.

We employed GPS technology to assess the movements and behaviour of Barn Owls to understand their response to major roads in the Republic of Ireland for the first time. We fitted GPS dataloggers to adult breeding Barn Owls (under licence to the NPWS and the BTO) in the south of Ireland, and collected extensive data on the movement patterns of individuals to:

i. Determine the home range size and movements patterns of Barn Owls with respect to major roads
ii. Investigate whether there was an avoidance or attraction effect of roads on Barn Owl home range selection and individual movements
iii. Identify Barn Owl behaviour and individual response to major roads
iv. Assess crossing patterns and behaviour of major roads
v. Investigate the potential importance of major road verges as a foraging resource for Barn Owls to inform mitigation and management policy

5.2 Methods

5.2.1 Using GPS Technology to Assess Barn Owl Movements and Behaviour

Capture Methods

We identified Barn Owl breeding sites to fit GPS dataloggers to resident adult birds based on the physical characteristics of the site to ensure high success rates of capture and recapture and to reduce unnecessary risk of disturbance to the breeding pair. An important factor was also proximity to major roads, as the main objective was to assess movement and behaviour of individuals in relation to roads. We selected sites which were in close proximity (<5km) to major roads and sites which were located at distance from major roads. Sites were selected where the presence of young were confirmed and where it was possible to establish their approximate age (based on nest inspection or behaviour of adults). All activities related to capture and tagging Barn Owls were carried out under specific licence to the NPWS and the BTO. Capture attempts and deployment of GPS dataloggers were confined to the period post brooding and at least one week prior to fledging of the young. This timing period was to ensure that data collection was standardised for all birds tagged, to reduce potential disturbance effects (in the event there were any issues with the tagged bird, the other adult would also be provisioning the young), and to increase success rates of tag retrieval. Capture methods were specifically designed for each site and informed by the physical characteristics of the nest or associated roost site, and knowledge of regular flight paths used by resident birds. Capture attempts were only carried out in suitable weather conditions, and on a night/day following a night of suitable hunting conditions. If a capture attempt failed and this resulted in a disturbance event, then we did not attempt capture for a minimum of three nights thereafter at the same site. If three attempts were made to capture a bird which resulted in disturbance events, then we made no further attempts to capture at this site for the remainder of the season but continued to monitor the site to record any effects of capture attempts on behaviour or breeding success of the pair.

GPS Datalogger Specifications

We used GiPSy-5 data loggers provided by TechnoSmart (http://www.technosmart.eu/index.php). These were one of the smallest GPS units available at the time of this study, which facilitated collection of high-resolution data over a sufficient time period required to meet the objectives of our study. GiPSy-5 dataloggers are archival and thus it was necessary to retrieve the tag to download the data. The dataloggers are enabled with sophisticated programming capabilities which allow the activity schedule of the tag to be set (e.g. to turn on and off at specific times) and to record fixes at a specific interval rate, thus conserving battery power and ensuring data is collected at the desired period relating to the activity patterns of the birds. For each fix, the following data were recorded and stored on the data logger:

- Time stamp: date/month/year and hour/minute/second
- Latitude and longitude: in decimal degrees
- Altitude: the height above mean sea level (metres)
- Speed: ground speed (km/h) based on satellites
- Satellite count: the total number of satellites that contributed to the fix details
- DOP: dilution of precision which is used to specify the additional multiplicative effect of navigation satellite geometry on positional measurement precision (Langley 1999)

Preparation of GPS Data Loggers

To reduce impacts on tagged birds and according to licence conditions, it was necessary that the weight of the tag was ≤ 3% of the body weight of the bird. GPS data loggers were fitted with two different battery types, 300 and 200 Milliamp Hour (mAh), which varied in size and weight and were deployed according to the body weight of individual birds. GiPSy-5 GPS data loggers which were fitted with a 300mAh battery, weighed 8.1g prior to covering with a protective sheath of clear heat shrink tubing and GiPSy-5 GPS data loggers fitted with a 200mAh battery, weighed 5.2g prior to covering with a protective sheath. Each tag (fitted with 300mAh or 200mAh battery) was covered in a section of clear heat shrink tubing (approximately 20 x 53mm or 20 x 48mm as appropriate). Clear heat shrink was used to ensure that the activation light-emitting diodes (LEDs) on the tag could be viewed after the tag was covered in the protective sheath. A small hole was pierced through the heat shrink tubing, just above the base of the antennae, so that the antennae could be pushed through the protective sheath. A heat gun was used to shrink the tubing to cover and seal the tag. The ends were sealed and flattened using the large ringing pliers. Excess tubing at either end were cut so that both ends of protective sheath were approximately 8mm in length (total length of protective sheath with tag was 48mm in length for tags with 300 mAh or 41mm in length for tags with 200mAh battery). A thin layer of dense foam of approximately 16mm x 30mm x 1.5mm was attached to the base of the tag using super glue to act as a buffer to reduce abrasion on the birds back. The tag was switched on and off by passing a magnet over the activator switch on the tag to ensure that it was working effectively. The weight and dimension of data loggers with both battery types are detailed in Table 5.1.

Table 5.1. The weight, dimension and battery type of the GiPSy GPS data loggers fitted to Barn Owls to assess their movement patterns and behaviour.

	Tag weight (g)	Tag dimensions (mm)	Tag weight with protective sheath (g)	Tag dimensions with protective sheath (g)
GiPSy-5 data logger (300mAh)	8.1	19 x 32	10.1	20 x 48
GiPSy-5 data logger (200mAh)	5.2	19 x 25	6.9	20 x 41

Attachment Methods

Two methods of attachment were used to fit the GPS data loggers to Barn Owls, which were using glue-mounted methods and harness-mounted backpacks. In 2016, and the early season of 2017, glue-mounted methods were used as per the licence conditions (BTO and NPWS). This temporary attachment technique had some success; however, of 15 birds tagged, nine birds were able to shed the tags prior to recapture. An additional drawback with this method was that it was necessary to reduce the period of time over which the bird was fitted with the tag in order to increase the likelihood of retrieval, and as such the period of data collection was less than the battery life of the tag, thereby underutilising the capabilities of the data loggers. Based on the issues encountered with glue-mounted methods, we were granted a licence (BTO and NPWS) in June 2017 to deploy dataloggers to Barn Owls using a harness-mounted backpack. This method of attachment proved to be successful and more appropriate to the design of our study, with eight birds successfully tagged using this technique in 2017. This method also facilitated enhanced data collection, as the tags remained on the birds and collected data for the duration of the battery life of the tag or until the bird was captured and tag removed.

The following sections provide an overview of the attachment methods for both tag types. An essential component of fitting tags to birds using unconventional methods is assessing the potential impacts of tagging on birds to understand and identify any negative effects. We assessed the body condition, behavior and breeding performance of all individuals before and after tagging and recorded no discernible negative impacts.

Glue-Mounted Methods

The tag was positioned on the back of the bird, above the base of the tail on the lower back. The tag was positioned to ensure it was located at sufficient distance from the preen gland so that the tag including antennae did not come into contact with the preen gland or cause any restriction in access of the bird to the preen gland. We used a dummy tag (made of foam) of the same dimensions to select the best position on the lower back, relative to the surface of the synsacrum and the preen gland so that the tag was ≥10mm from the preen gland. The feathers where the tag was to be fitted above the base of the tail on the very lower back were trimmed to the base on the area equivalent to the size of the tag. A thin strip (19mm x 30mm x 1.5mm) of dense foam was used as the point of contact with the birds back to which the tag was adhered. The rationale was that the soft foam should not cause abrasion but was lightweight and provided a suitable surface area to which to adhere the tag. The thin strip of foam was glued to the back of the bird in the appropriate position and the tag was then glued to the foam. On recapture, the tag was removed by slicing through the foam using a scalpel.

Harness-Mounted Backpacks

The tag was placed on the appropriate position on the middle of the bird's back, with antennae pointing downwards. The Teflon strap which runs through the holes at the top section of the protective sheath, above the tag, were placed over the shoulders of the bird, ensuring that the straps were not twisted and did not restrict feathers or movement. The Teflon straps from the shoulder of the bird were crossed over the breast at the top of the sternum, and then placed under the wings, ensuring that they were not twisted and did not restrict the feathers. The Teflon straps were inserted into the corresponding holes in the bottom section of the protective sheath, below the tag. The straps were adjusted accordingly by tightening or releasing tightness where the straps emerged from the holes in the protective sheath until the harness was in the appropriate position and of desired fit. Checks were made to ensure that the tag was in the appropriate position on the back of the bird and was the correct fit (so that a finger could be easily placed underneath the tag between the base of the tag and the bird's back), that the position where the straps crossed over the breast were correct, and that the harness was the appropriate fit throughout, checking to ensure it was neither too tight or loose in any position, and that the straps were not twisted and did not restrict feathers or movement. When the fit was deemed to be correct and comfortable, both ends of the Teflon strap at the base of the tag (where they emerge from protective sheath) were clamped together using a scissors clamp to hold them in place.

The overall fit was once again inspected, and the bird was allowed to move its wings to ensure natural movement and that the harness was not restricting any feathers. When confident that the fit was good, a small crimp (nickel crimp 3.5mm in diameter and cut to size to 2mm in depth) was placed over the two Teflon straps (each strap pushed through the crimp individually using an inoculating needle) where they emerge at the base of the tag. The crimp was pushed down to the base of the tag and then closed tightly over the Teflon straps by applying pressure using the pliers, which secured both straps to each other at the appropriate point and ensured the harness remained in place at the desired fit. The two straps were then sewed together where they emerge from the crimp for a length of approximately 6mm. The excess lengths of the straps were cut. A small piece of card was placed under the tag (between the tag and the bird's back) and super glue was applied to the stitching. The length of strap emerging from the tag (approximately 6mm) was folded over the base of the tag so that it was flush and glued in position to the protective sheath. The point at which the straps cross over the breast were sewed together (optional) using a curved needle, with all knots facing outward (away from the body). A card was placed under the breast strap and a small amount of glue applied over the stitching. Glue was applied to the exit points where the Teflon strap emerges from the holes in the protective sheath. A glue-drying spray was then applied to all areas where glue was used and the bird was held in position until the glue was dry, ensuring that no feathers came into contact with the glue. One final check was made to ensure that the tag and harness were fitted appropriately, and the bird was allowed to move its wings to ensure natural movement. The bird was released, and the time of release recorded.

Details of Individuals Fitted with GPS Tags

GPS tags were successfully fitted to 11 adult breeding Barn Owls in 2016 and 2017, which included nine females and three males, of which two females were tracked in both years. In 2016, two adults from the same nest site in County Kerry were tracked simultaneously. Five birds were tracked in 2016 (between the 22nd of June to the 11th of August), and eight birds were tracked in 2017 (between the 24th of June and the 15th of July). The 11 individuals were from 10 nest sites in Counties Kerry (six nests), Cork (one nest) and Tipperary (three nests) (Figure 5.1). Full details of the nest locations are presented in Table 5.2.

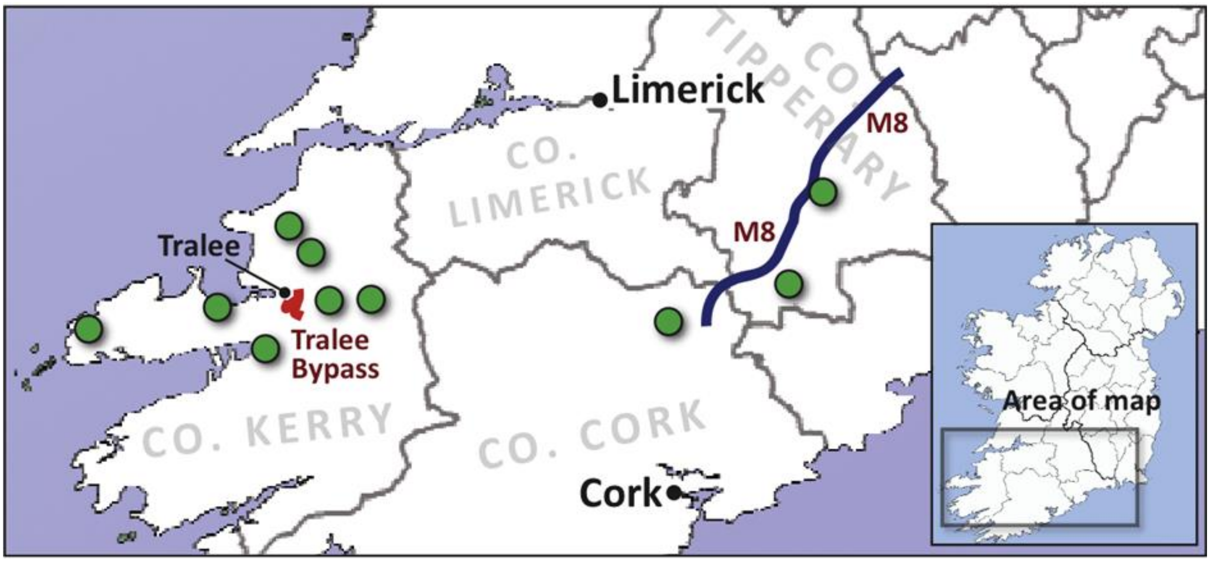


Figure 5.1 Locations of nests (green dots) at which individuals were captured and fitted with GPS tags in 2016 and 2017, also indicating the locations of nearest major roads of interest which are the M8 Motorway, the Tralee Bypass and the Castleisland Bypass.

Of the 10 breeding sites where Barn Owls were fitted with GPS data loggers, six were located within 5km of a major road (three <5km from the M8 Motorway, two <5km from the Tralee Bypass and one breeding site <5km from the Castleisland Bypass). The other four sites were located >5km from a major road.

Table 5.2 Locations of nests from which individual Barn Owls were captured and fitted with GPS tags, with details of the proximity of the nest to major and national roads.

Location	County	Major Road		National Primary	
		Dist.	Route	Dist.	Route
Meldrum	Tipperary	1.8	M8	3.1	N8
Ballyconnell	Kerry	4.8	N21	2.0	N69
Castleisland	Kerry	2.9	N21	3.2	N21
Aghamore	Kerry	-	-	9.0	N69
Killorglin	Kerry	-	-	2.0	N70
Burges	Tipperary	4.4	M8	4.7	N8
Ballynahinch	Kerry	2.6	N21	1.7	N21
Camp	Kerry	-	-	0.3	N86
Ballyferriter	Kerry	-	-	7.1	N86
Fermoy	Cork	4.7	M8	0.2	N72

For the first three birds tracked in 2016, tags were scheduled to record fixes at 1-second intervals, and to collate fixes between 22:00 and 07:00. These individuals were tracked for between one and three nights. We used this schedule (22:00–07:00) as it was known to extend beyond the main period of activity of Barn Owls both in the evening and the morning, in order to identify their main period of activity. This showed that the majority of activity occurred between 22:00 and 04:00, and hereafter, all individuals were tracked at 10-second intervals, and to collate fixes between 22:00 and 04:00. For the purpose of this study, we defined a 'night' as between 22:00 to 04:00 the following morning. As these tags were set to a shorter time period and greater interval rate between fixes, they remained active for longer, and these individuals were tracked for between seven and 13 days. The total number of fixes recorded by individual tags ranged from 9,728–135,404. Full details are presented in Table 5.3.

Table 5.3 Details of Barn Owls fitted with GPS data loggers and tracked in 2016 and 2017. The sex of each individual is specified with the appropriate letter (M/F) in the ID code. For individuals which were tracked in two years (2), the year of tracking is indicated in the individual code as either 6/7.

Individual	Ind ID	Sex	Year	Start date	End date	Number of days tracked	Total fixes	Fix interval (s)
MeldrumF	MEL6F	F	2016	22/06/2016	24/06/2016	2	19648	1
BallyconnellF	BCO6F	F	2016	11/07/2016	12/07/2016	1	13834	1
CastleislandF	CASTF	F	2016	14/07/2016	17/07/2016	3	135404	1
AghamoreF	AGHAF	F	2016	22/07/2016	29/07/2016	8	10282	10
KillorglinF	KILLF	F	2016	04/08/2016	14/08/2016	10	21673	10

Individual	Ind ID	Sex	Year	Start date	End date	Number of days tracked	Total fixes	Fix interval (s)
KillorglinM	KILLM	M	2016	04/08/2016	11/08/2016	7	12069	10
MeldrumF	MEL7F	F	2017	24/06/2017	03/07/2017	10	10288	10
BurgesF	BURGF	F	2017	25/06/2017	03/07/2017	8	9728	10
BallynahinchF	BHINF	F	2017	28/06/2017	09/07/2017	11	16541	10
CampM	CAMPM	M	2017	29/06/2017	10/07/2017	12	14716	10
BallyferriterF	BFERF	F	2017	01/07/2017	13/07/2017	13	20032	10
FermoyM	FERMM	M	2017	05/07/2017	14/07/2017	10	11415	10
BallyconnellF	BCO7F	F	2017	06/07/2017	15/07/2017	10	13878	10

Treatment of Data

Tagged birds were re-captured and the tags were removed. The data were downloaded using GiPSy-5 Utility Software. Data were collated in Microsoft Excel with a total of 315,757 fixes compiled. An initial visual inspection of the data highlighted 45 records for which the locations were not accurate, and which were subsequently removed. Further inspection of the dataset revealed additional records where the dates and/or times were incorrect. While their locations appeared to be correct (with respect to locations before and after), they were retained and flagged within the database as low-quality and were not used in further detailed analyses. The final dataset of 311,323 high-quality fixes were used in subsequent analyses. This dataset was imported to ArcMap (ArcView 10.5) and the fixes were converted to lines using the XY to Line facility.

Data Limitations

There were some limitations with the data which were important to assess and recognise. We had intended on using data on altitude which was assigned to each fix to determine the flight height of Barn Owls relative to the ground during different activities, and particularly when crossing or interacting with roads. We conducted trials to assess the accuracy of altitude recordings in different conditions (based on no. of Satellites, DOP, etc.), which revealed a high margin of error, and therefore it was not possible to assess Barn Owl flight height in relation to roads based on our data.

5.2.2 Home Range Estimation

The home range size for individual Barn Owls was defined using the Minimum Convex Polygon (MCP) (Burt 1943) to determine the largest area of movements for each bird, based on all fixes (White and Garrot 1990). The MCP was generated using *the Minimum Bounding Geometry* facility in ArcView. To calculate the intensity of usage of different areas within the MCP home range, we also used the kernel density estimation (KDE) technique (Worton 1989). The 50% and 95% KDEs were generated in QGIS Version 2.18LTR to provide a probabilistic measure of use intensity of the area used (Anderson 1982, White & Garrot 1990). Spatial autocorrelation was not relevant for these data as this study followed a sampling strategy that considered the circadian activity (Kernohan *et al.* 1998) and thus all animal movements were regularly recorded (Otis & White 1999).

As there was variation between individuals in the number of tracking nights for each individual, it was necessary to determine the number of tracking nights required to generate an accurate estimate of their home range size (i.e. which provides a reasonable estimation of the area used). For the purpose of this assessment, MCP was used. For the 10 individuals which were tracked for more than three nights, we calculated separate MCPs for nights 1, 1 and 2 combined, 1, 2 and 3 combined, etc. through to the final night of tracking.

The MCP area was calculated (ha) for each permutation and compared to provide an assessment of the change (increase in area) per day and the robustness of the home range estimate.

Within each MCP home range, we defined the broad-scale land uses using CORINE (Co-ORdinated INformation on the Environment) 2012 Landcover dataset. An additional buffer of 500m was applied to the MCP generated for each individual for which an accurate MCP home range was generated. A larger buffer of 1,000m was assigned to the MCP of the individuals (3) which were tracked for fewer days, on the basis that the MCP for these individuals was known to be underestimated. The CORINE 2012 Landcover dataset was then clipped by each buffered MCP and the proportion and area (ha) of each of eight land use types were calculated within each MCP.

5.2.3 Barn Owl Behaviour and Movements

The information generated for each fix of the bird's position was interrogated to characterise the nature of movement and behaviour of each individual at that point. Using data on ground speed (km/h), we generated segments between sequential fixes within specific speed bands (<= 3.7km/hr, 7.4–18.5km/hr, >18.5km/hr). The first fix in each segment was used to define the speed for the segment, and a new segment was initiated when the speed changed to a new speed band.

For segments related to flight (7.4–18.5km/hr, >18.5/hr), we further defined these segments as 'straight' or 'meandering', based on the variation in bearing between segments. We plotted the speed of flight versus trajectory of flight to visually identify the pattern between flight speed and trajectory, as illustrated in Figure 5.2. Bearings in excess of 50 degrees were identified as meandering, which are indicative of hunting flight. However, Barn Owls can also hunt in 'straight' flight, for example along linear features. Hunting flight is typically characterised by lower speed compared to non-hunting flight when the bird is in transit (Taylor 1994). Bearing differences less than 50 degrees indicated straight flights, which were typically associated with higher speeds, reflecting birds in transit moving between areas, for example returning to or departing from the nest site.

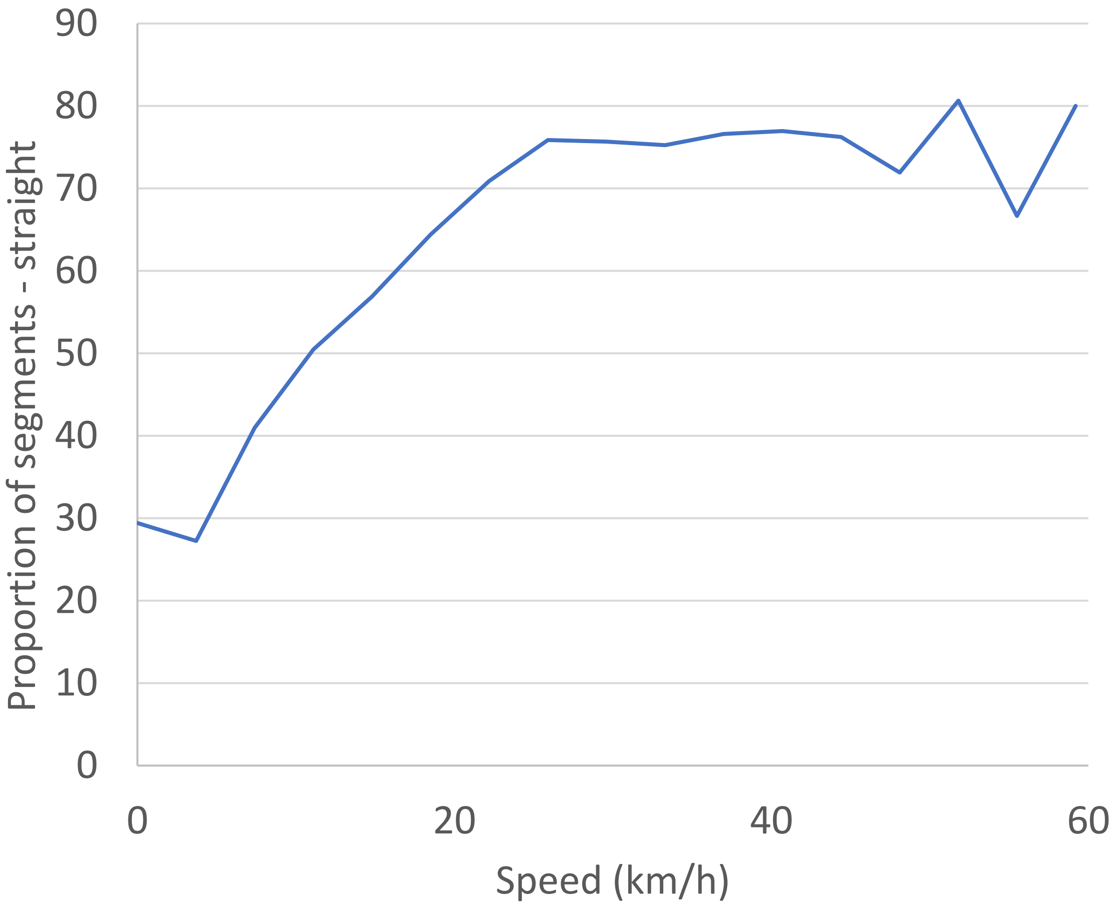


Figure 5.2 The flight speed (km/h) of Barn Owls in relation to trajectory of flight.

The information on the trajectory of each segment in combination with the speed of movement was used to define the behaviour in one of the following categories:

- Stationary: <= 3.7km/hour
- Hunting flight: 7.4–18.5km/hour
- Transit (fast) flight: >18.5/hour

When the bird was recorded as ‘stationary’, it was not possible to determine whether the bird was actively hunting or resting. An example of the movements of a Barn Owl (FERMM) close to the nest site, which are defined based on the behaviour criteria and colour coded accordingly, is illustrated in Figure 5.3.

Figure 5.3 The movements of a Barn Owl (FERMM) close to its nest (top right corner), showing each segment defined in one of three behaviour categories – red = stationary, orange = hunting flight and yellow = fast flight.

To characterise behaviour patterns of each bird, we calculated the proportion of time and the proportion of fixes within each of the three behaviour categories for each individual per tracking night (22:00–04:00), and for all nights combined. In all cases, the data from the first and/or last nights were removed from analyses where the duration of tracking was less than 80% of the normal active period of the tag (22:00–04:00). The activities of individuals during the first and last nights of deployment were in several cases limited due to the timing of capture and deployment or removal of the tags. Activity budgets were calculated based on the number of hours in each of the three behaviour categories for each individual in each tracking night. The time spent in each behaviour category was calculated by multiplying the proportions generated above by the period of activity of each tag (22:00–04:00). For each individual, the mean time (hours) within each flight category across the entire period that the individual was tracked was then calculated, along with standard deviations.

5.2.4 Barn Owl Movements in Relation to Roads

We performed a visual assessment of the MCP home range of each individual to determine whether their movements overlapped with major (motorway or dual carriageway) or national roads, and repeated this process using the 50% and 95% KDEs. We also categorised the fixes for each individual into distance bands (0–20, 20–50, 50–100, 100–500m) from major roads and national primary roads, to determine the proportion of time birds spent at different distances from roads.

To determine whether there was greater use or avoidance of major roads by Barn Owls than expected, we assessed the movements of birds relative to major roads within their home ranges (MCP). For this purpose, we only included the five birds which had a major road (motorway or dual carriageway) within their MCP home range in the analyses. We generated 30 random points along the centre point of each major road within the home range of each bird (n=5), and 30 random points distributed throughout the home range. Buffers of 100m were created around both sets of points. Within each buffered area, the total and mean number of fixes was calculated.

We compared the number of fixes in each buffered area to examine whether or not there were differences between those buffered points on the road compared with elsewhere in the home range to enable an assessment of whether birds actively avoided or were attracted to the road. An example of the buffered points randomly distributed on the road and throughout the home range is illustrated in Figure 5.4.

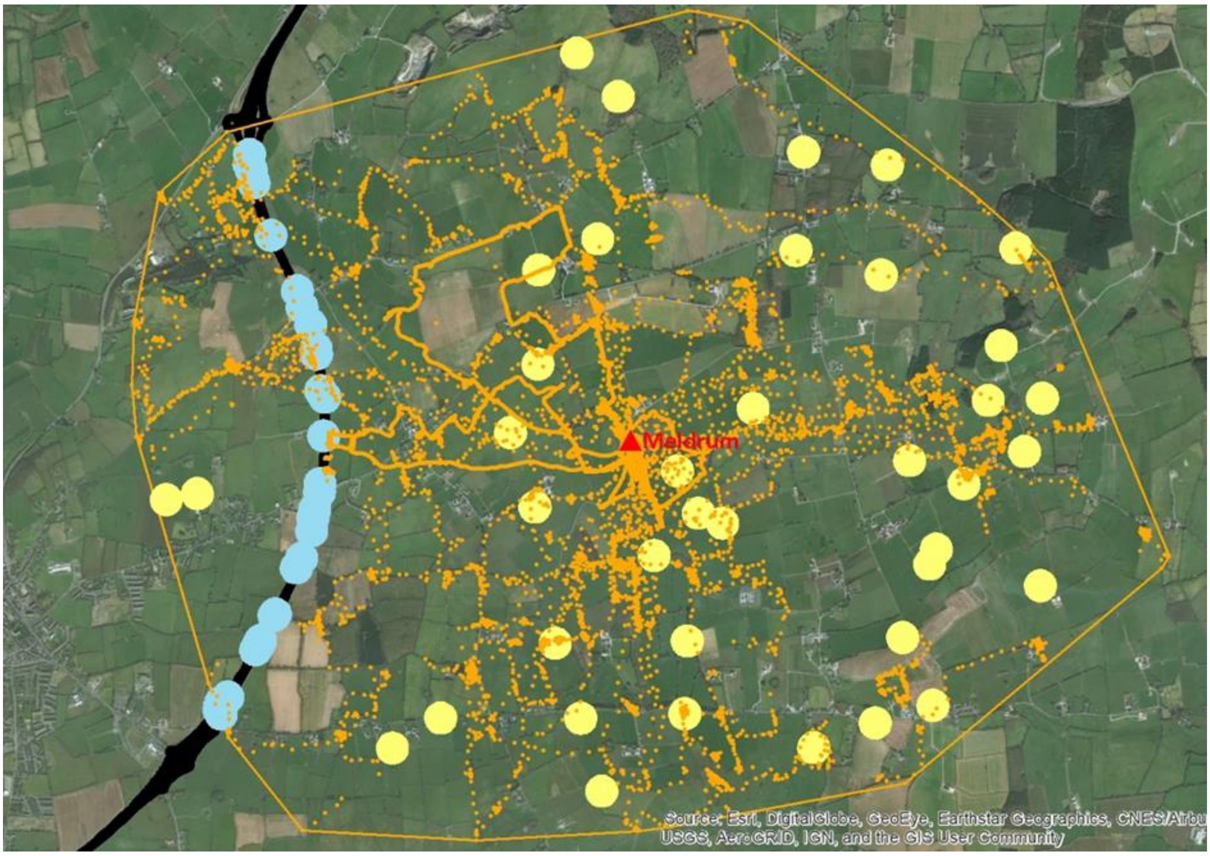


Figure 5.4 An example of a home range of BHINF, close to the Tralee Bypass in County Kerry, illustrating the buffered points selected at random along the bypass and throughout the home range.

5.2.5 Barn Owl Behaviour in Relation to Roads

To determine the behaviour of Barn Owls in relation to roads, we identified all segments for each individual which were within 20m of each of three different road types (major, national and secondary roads). The behaviour (stationary, hunting flight or fast flight) as defined for each segment was used to describe Barn Owl activity in close proximity to roads. We then generated a random sample of 1% of all fixes which were greater than 20m from the three road types for each individual. The behaviour of birds within 20m of roads was then compared with the behaviour of birds away from the roads (the random sample of fixes) to identify whether Barn Owl behaviour close to roads differed from their general behaviour elsewhere in their home range.

5.2.6 Crossing Behaviour

We identified the frequency with which birds crossed major and national roads on a nightly basis and overall. Crossing points were identified as segments (sequential fixes joined) which intersected a road. The total number of crossing points and the mean number of crossings per night were calculated for each individual and road type per night and for the entire tracking period.

5.2.7 Data Analysis

All data analyses were carried out using R 3.1.2 (R Development Core Team 2015). To determine whether Barn Owls were attracted to or avoided major roads, we compared the number of fixes within randomly selected buffered points on major roads to those randomly distributed within the home range (MCP) using the Wilcoxon test. The Mann-Whitney U test was used to determine the influence of roads on Barn Owl behaviour by comparing the proportion of segments of a defined behaviour within 20m of roads to elsewhere within the home range of individual birds.

5.3 Results

5.3.1 Home Range Size

Assessment of the number of tracking nights as a proportion of the MCP home range revealed that 10 birds had reached >95% the maximum MCP home range after 10 tracking nights. These results are illustrated in Figure 5.5 which show that after two tracking nights, four of 10 individuals had reached 90% the maximum MCP generated for the entire period tracked. After four nights, eight individuals had reached 85% the maximum MCP. After six nights, nine individuals had reached 85% the maximum MCP. After 10 nights, all 10 individuals had reached 97% the maximum MCP (one female reached 97% the maximum MCP on night 10 and was tracked for 11 nights and therefore the home range generated over 11 nights is likely to be an accurate representation of the home range). The results showed that it was not possible to generate a meaningful home range estimate for birds which were tracked for less than four days, which included three individuals (MEL6F, BCO6F and CASTF). Therefore, we were able to generate accurate home range estimates for 10 of 13 birds tracked in 2016 and 2017.

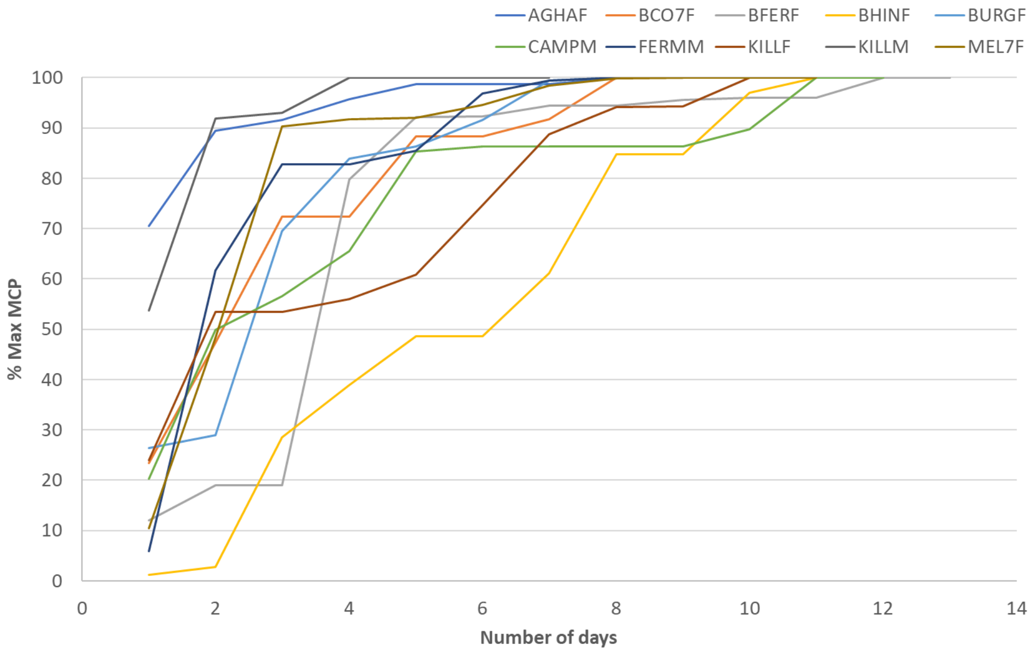


Figure 5.5 Home range size (MCP) based on fixes over time. For each individual, the MCP based on 1, 2, 3 days, etc. is expressed as a proportion of the maximum MCP, based on all available data.

The MCP home range size for Barn Owls was on average 3,059ha (n=10, range=991–9259ha). There was considerable variation in the home range size of individuals. The largest home range was occupied by BFERF (9,260ha) and the next largest by BHINF (5,263ha). All other individuals (n=8) occupied home ranges less than 3,000ha in size. The two smallest home ranges were of two individuals of the same breeding pair from a nest site in County Kerry: KILLM (1,265ha) and KILLF (991ha) respectively.

Two individuals which nested close to the County Kerry coastline (CAMPM and BFERF) had MCP home ranges which included substantial areas of open water. Following a review of movements, where it was shown that birds did not typically fly over open water, these non-terrestrial areas were omitted from the MCPs.

Table 5.4 Details of the home range sizes (based on MCP and KDE) of 10 individuals, in hectares.

individual	MCP	50% kernel	95% kernel
AGHAF	1880.48	29.76	532.67
BCO7F	2366.14	84.99	686.07
BFERF	9259.59	265.30	2279.31
BHINF	5263.12	45.37	732.04
BURGF	2913.39	64.02	750.76
CAMPM	2544.45	102.06	775.8
FERMM	1780.24	77.69	694.91
KILLF	990.80	18.98	249.78
KILLM	1265.19	27.97	357.20
MEL7F	2328.50	52.84	770.67
Average	**3059.19**	**76.898**	**782.921**

Home range sizes based on MCP were shown to correlate with those generated from the KDEs, as illustrated in Figure 5.6. An example of a MCP home range, showing the 95% and 50% KDEs for one bird (BHINF) which nested close to the Tralee Bypass in County Kerry is illustrated in Figure 5.7.

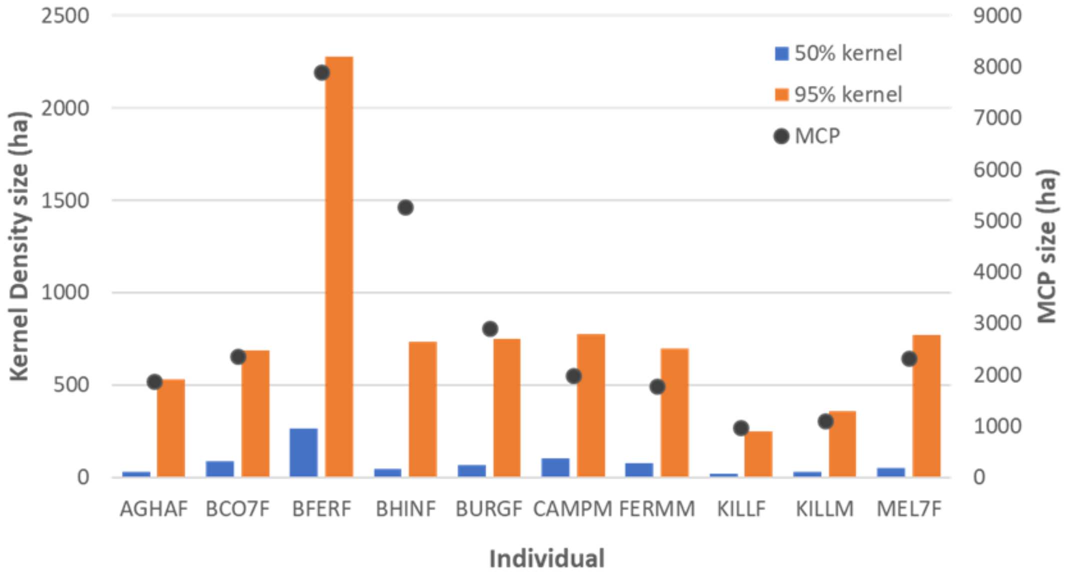


Figure 5.6 Home range size for individuals tracked on four or more days, illustrating MCP and the 50% and 95% KDEs. MCP is presented on a secondary axis because of the substantial difference in magnitude between the two measures of home range size.

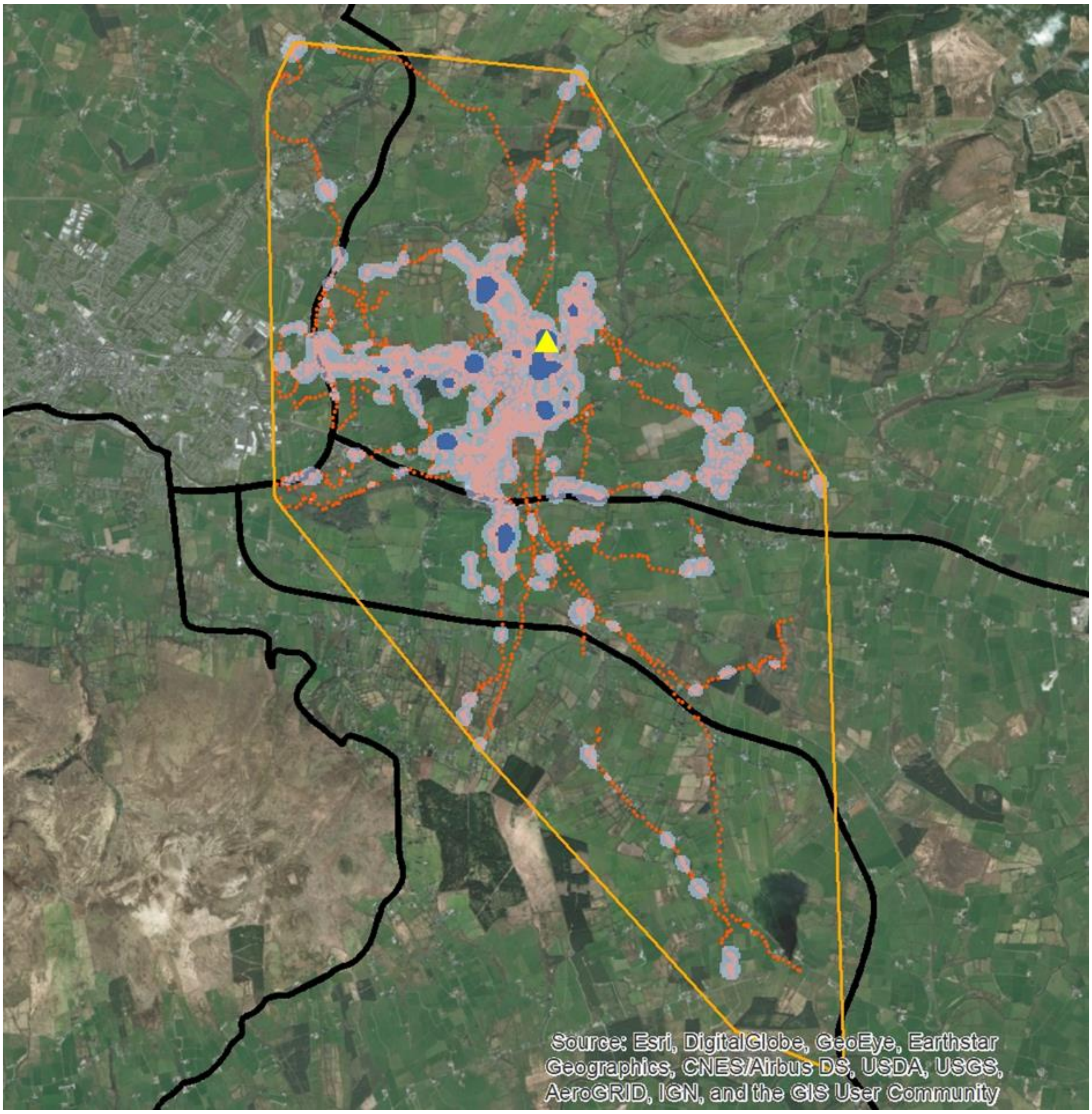


Figure 5.7 An example home range, showing the MCP (yellow boundary), the 95% (light blue) and 50% (dark blue) KDEs of BHINF in County Kerry. The fixes of the bird's position are shown as orange dots. The home range includes the Tralee Bypass which is shown in black.

The home range size of Barn Owls in Ireland was larger than recorded elsewhere in Europe. The MCP home range estimate is over 16 times higher and the 95% KDE is over five times larger than home range estimates in Britain. We have outlined available estimates for home range size in Table 5.5 according to MCP and KDEs (95% and 50%) for this study and to home range estimates for Barn Owls in other European countries, generated using either GPS or radio telemetry.

Table 5.5 Details of the home range sizes (based on MCP and KDEs) of Barn Owls in Ireland (this study) compared with Barn Owls elsewhere in Europe.

Country	MCP (ha)	95% KDE (ha)	50% KDE (ha)	N	Study
Ireland	3,059.20	782.9	76.8	10	This study
Portugal	763 ± 650	-	-	5	Grillo *et al.* (2012)

Country	MCP (ha)	95% KDE (ha)	50% KDE (ha)	N	Study
Portugal	-	578	80	4	Sousa *et al.* (2010)
Britain	190.6	152.6	-	11	Askew (2006)
Switzerland	-	497.9	-	36	Schalcher (2017)

Habitats Composition within Home Ranges

For all individuals, with the exception of CAMPM, pasture was the dominant habitat within each home range (Figure 5.8), occupying a significant proportion (>85%) of the home ranges of AGHAF, MEL6F and MEL7F. Arable land was present in the home ranges of four birds (BCO7F, BURGF, FERMM, and MEL6F/MEL7F) and was the second most important land use by surface area in the home ranges of three birds, which were all from the most easterly nest sites, in County Tipperary (BURGF and MEL6F/MEL7F) and County Cork (FERMM). Peat bogs were present in seven home ranges (CASTF, BCO6F, BCO7F, BFERF, BHINF, CAMPM and KILLF), all of which were from nests in County Kerry and were particularly notable (>15%) within the home ranges of BFERF and CAMPM. Intertidal flats and marine habitats were present and were the second most dominant land use (>15%) within the home range of four birds which occupied coastal home ranges in County Kerry (BFERF, CAMPM, KILLF and KILLM). Agriculture with semi-natural grassland was notable (>5%) within the home ranges of KILLF and KILLM, and also BHINF.

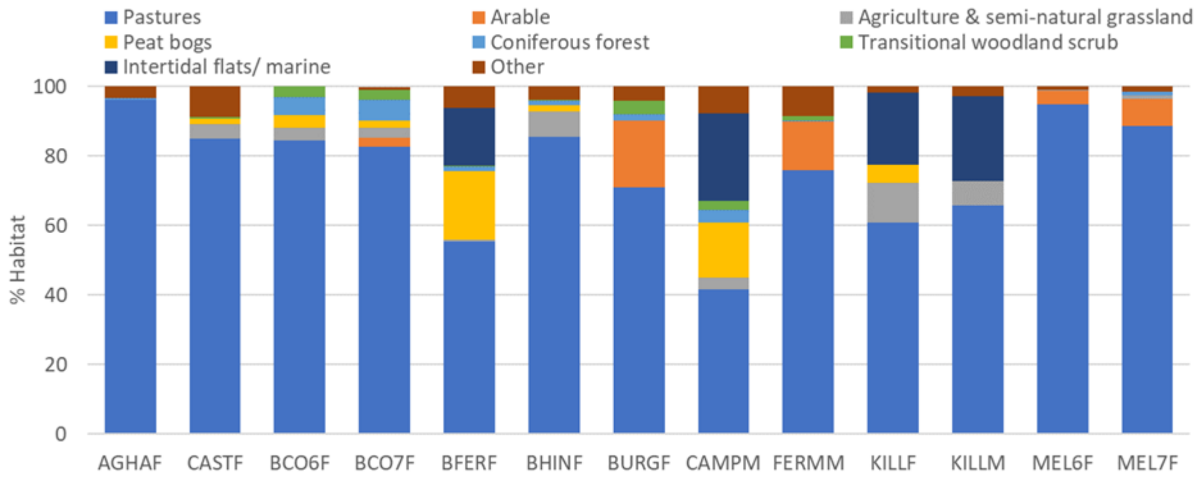


Figure 5.8 Broad-scale proportional habitat types present within the home ranges of the tracked individuals, based on CORINE 2012.

Visual assessment of the home range size, shape and movements of individual Barn Owls in relation to habitat features and altitude revealed a general avoidance of upland areas and higher altitudes in favour of low-lying areas, which is illustrated in Figures 5.9–5.11.

Figure 5.9 The movements (white fixes) of a Barn Owl (CAMPM) nesting 383m from a National Road (N86) in west Kerry. The distributions of fixes show this individual predominantly used the low-lying areas to the north of the road, with the exception of two valleys of low altitude to the south of the road which cut through more typical upland habitat which were avoided. This individual remained below 100m throughout most of its activities.

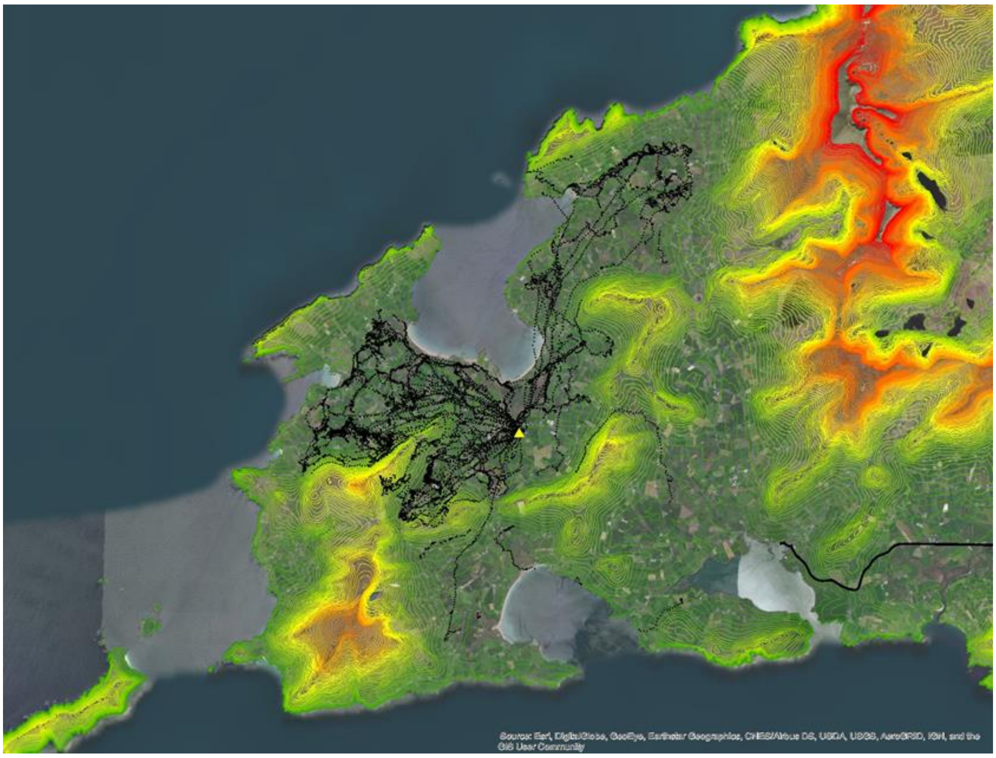


Figure 5.10 There were no main roads within the home range of BFERF in west Kerry, the movements of this individual was strongly influenced by altitude, clearly avoiding the elevated areas within its home range. This bird had the largest MCP home range (9,259ha), which was potentially influenced by the requirement to avoid the upland areas.

Figure 5.11 The movements of the two adults (KILLF and KILLM) from a nest site in west Kerry. The nest is located 2.4km from the National road (N70), which isn't encountered by either bird. The home ranges of both individuals were the smallest of all recorded, potentially indicating the suitability of habitats in the area and the fact that the entire home range was in an area of low elevation.

Barn Owl behaviour and movements

All individuals spent the majority of time and of each night (22:00–04:00) stationary. This was especially the case for KILLF (85% of time) and least for CAMPM (56% of time), with both individuals spending the least, and most time in hunting flight respectively (KILLF=7%, CAMPM=24%). BFERF spent most time (out of all individuals) in fast transit flight, which was not unexpected given this was the largest home range. Five birds spent more time in hunting flight than fast transit flight (AGHAF, CAMPM, FERMM, KILLM and MEL7F), which included each of the three males which were tracked. Three birds spent more time in fast transit flight (BFERF, BHINF and BURGF), which were also the birds with the largest home ranges, and two birds spent similar time in hunting flight and fast transit flight (BCO7F and KILLF).

Assessment of behaviour per hour shows that all birds spent more than three hours each night stationary, and seven birds spent greater than four hours stationary each night. Five birds spent more than one hour in hunting flight per night (BFERF, CAMPM, FERMM, KILLM and MELFF) which included all three males tracked. Four birds spent an hour or more in fast transit flight each night (BFERF, CAMPM, FERMM and MEL7F). Figure 5.12 illustrates the proportion of time and actual time that individuals spent stationary, in hunting flight and in fast flight, each night.

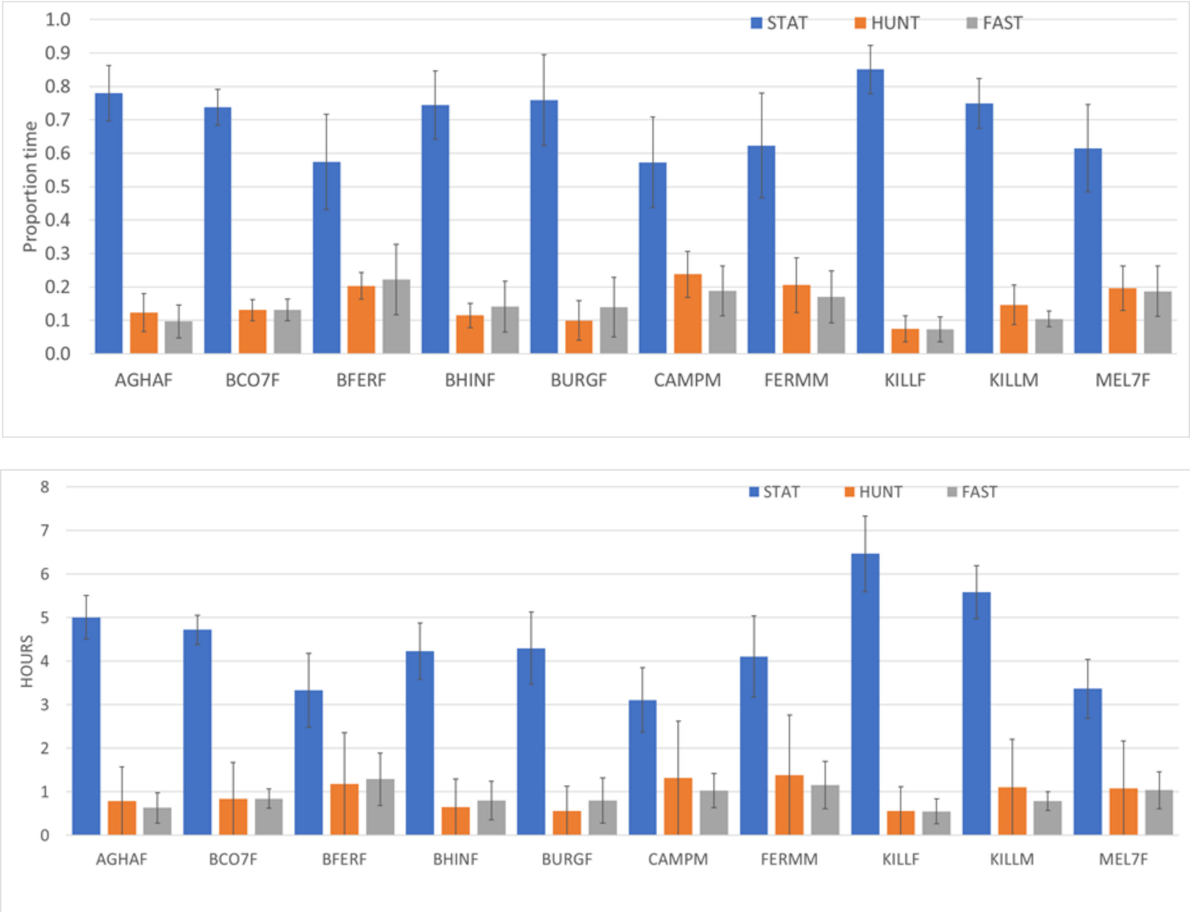


Figure 5.12 Activity budget of 10 Barn Owls fitted with GPS tags, illustrating the proportion of time (top) and actual time (bottom) each night that these individuals spent stationary (STAT), in hunting flight (HUNT) and in transit between areas (FAST). Means and standard deviations are illustrated.

5.3.2 Barn Owl Movements in Relation to Roads

Of six birds which had major roads (motorway or dual carriageway) within 5km of their nest site (BCO6F/BCO7F, BHINF, BURGF, CASTF, FERMM and MEL6F/MEL7F), four individuals encountered major roads, of which it was possible to generate home range size for three. The MCP home range, and the 95% KDE for these three birds (BHINF, BURGF and MEL6F/MEL7F) overlapped with major roads, and the 50% KDE for two birds (BURGF and MEL6F/MEL7F) overlapped with a major road. The two birds (BCO6F/BCO7F and FERMM) which home ranges did not overlap with major roads were located the furthest from these routes: 4.7km and 4.8km respectively. The MCP home range, 95% and 50% KDE of both birds overlapped with national roads, as was the case for CAMPM. The four remaining birds (AGHAF, BFERF, KILLF and KILLM) had home ranges which did not include national roads or major roads; two of these birds (AGHAF and BFERF) nested more than 5km from the nearest national or major road, and the other two birds (KILLF and KILLM) were from the same nest site located 2.1km from a national road. Figure 5.13 illustrates the MCP home range, 95% and 50% KDEs for all birds for which it was possible to generate accurate home ranges, in relation to major and national roads.

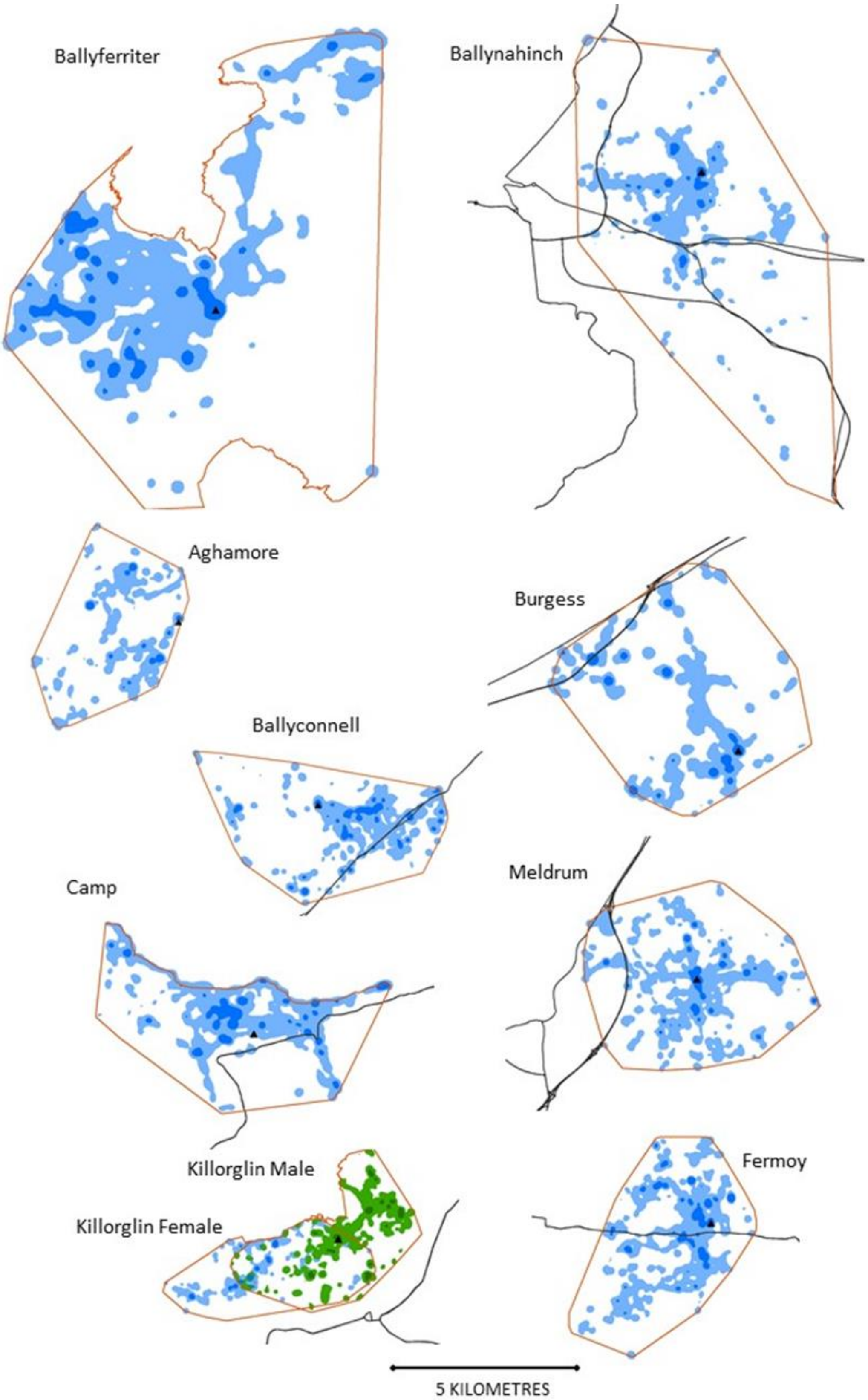


Figure 5.13 The home ranges of 10 Barn Owls shown as the MCP home range (outer yellow boundary), the 95% (light blue) and 50% (dark blue) KDEs, with the major roads (thick black) and national roads (thin black) which overlap with the home ranges displayed.

There was considerable variation between individuals in their interaction with roads as defined by the proportion of fixes within specific distance bands (0–20, 20–50, 50–100, 100–500m) from major roads and national primary roads, and the number of crossings, as illustrated in Figure 5.14.

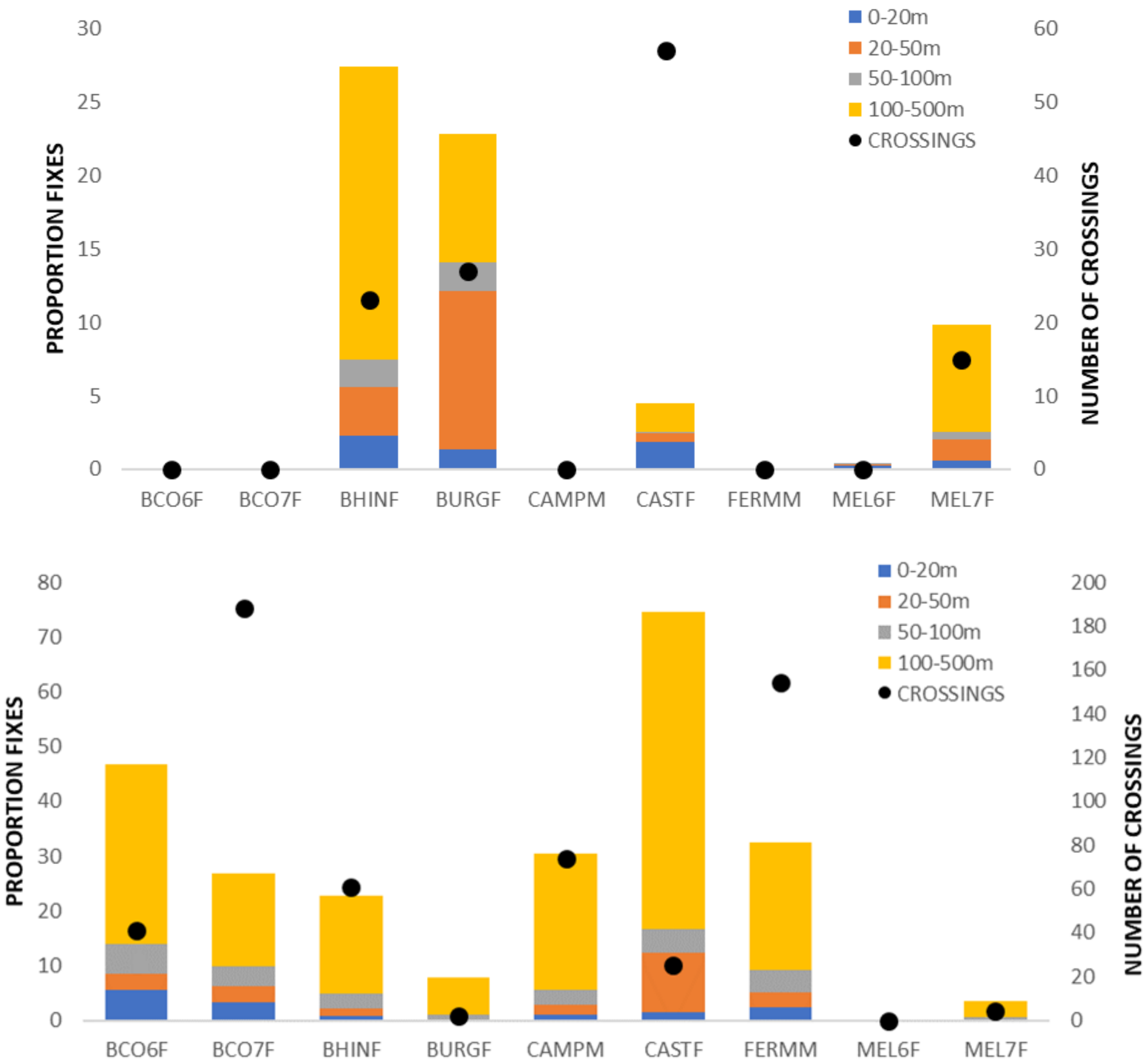


Figure 5.14 The proportion of fixes within varying distances (0-20, 20-50, 50-100, 100-500m) from major roads (top) and national roads (bottom), the number of crossings is shown as black dots on the secondary axis. Note that scales differ.

The Barn Owls which encountered major roads (n=4) spent proportionally more time close to these roads than expected (Wilcoxon signed-rank test, $P < 0.001$), which indicates positive selection of major roads. The mean number of fixes within the randomly selected buffered points on major roads (n=180) were 35.7 (SD=81.6, range = 0-789), compared with 16 fixes per buffered point (n=180) throughout the home range (SD=53, range=0-580).

5.3.3 Barn Owl Behaviour in Relation to Roads

The flight behaviour of Barn Owls (n=6) was significantly different in proximity (<20m) to major roads (Mann U Whitney test, $P < 0.001$) and national primary roads ((Mann U Whitney test, $P < 0.001$) when compared with a random sample of fixes (1%) for each individual. Barn Owls were more than twice as likely to hunt in flight along and in proximity to motorways compared to elsewhere in their home range and spent proportionally less time stationary or in fast transit flight. Barn Owls also spent proportionally more time in hunting flight along national primary roads than expected, although proportionally less time than on major roads.

Figure 5.15. shows the proportional difference in behaviour between individuals within 20m of major roads, national primary and national secondary roads, and Figure 5.16. shows the proportion of time in each behaviour category for each bird within 20m of each of the three road types.

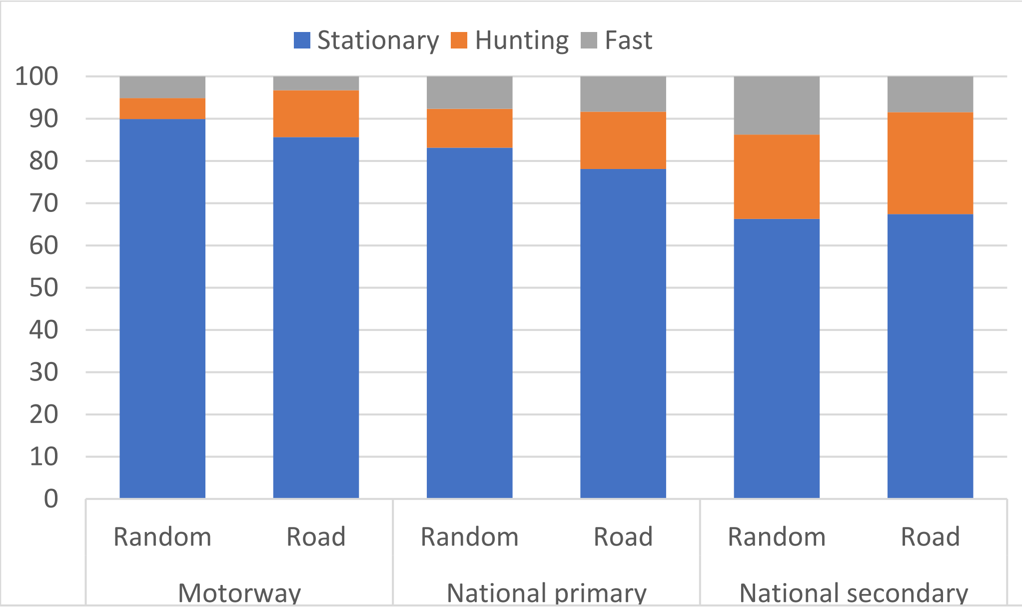


Figure 5.15 The proportion of time Barn Owls spent stationary, in hunting flight and fast transit flight within 20m of major roads, national primary roads and national secondary roads.

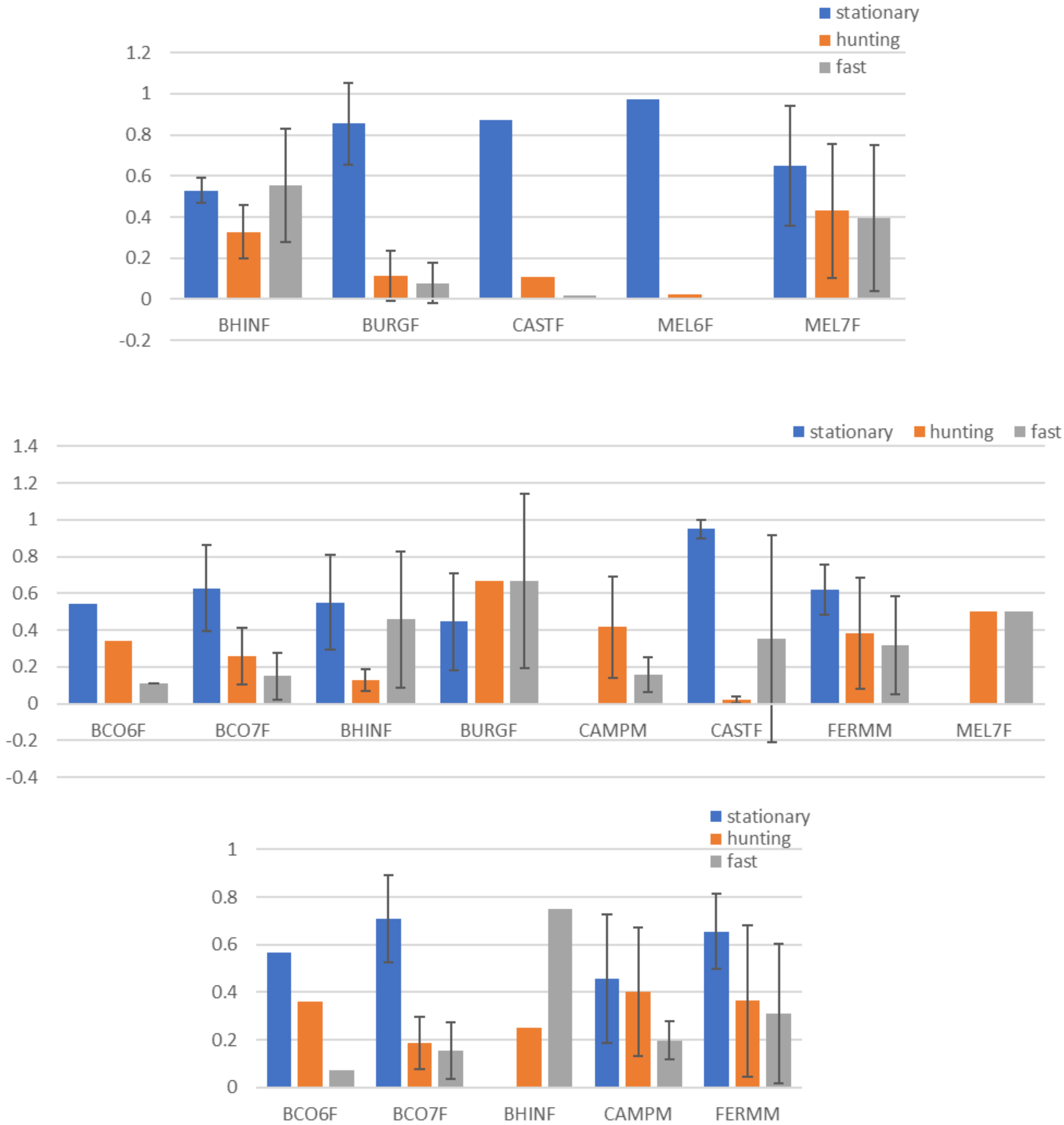


Figure 5.16 The proportion of time individual Barn Owls spent stationary, in hunting flight and fast transit flight within 20m of major roads (top), national primary roads (middle) and national secondary roads (bottom).

5.3.4 Crossing Behaviour

All birds which encountered a major road (n=4), crossed the road on a frequent basis. The mean number of crossings of a major road ranged from 1.4 to 19 times per night. The highest number of crossings recorded was for CASTF, in County Kerry, which was tracked for three nights and spent a large portion of time in close proximity to and frequently crossing the Castleisland Bypass. Birds which encountered national primary roads (n=7) all crossed these roads, and the number of crossings per night ranged between 0.2 and 15.3. The mean number of fixes within 20m of major roads and the mean number of crossings for each individual bird in relation to major roads and national roads are presented in Table 5.5.

Table 5.6 Mean number of intersects and fixes within 20m of major roads and national roads for each of nine tagged birds. Standard deviations are presented for individuals with samples of 2 or more days.

** Individuals with tags scheduled for a higher frequency of fixes (1 second) compared with others (10 seconds), hence the fixes were adjusted for comparability by dividing the total fixes by 10.*

	Day sample	Mean fixes (major roads)	Mean fixes (national roads)	Mean intersects (major roads)	Mean intersects (national roads)
BCO7F	9		51.6 ± 30.7		15.3 ± 7.9
BHINF	8	13.6 ± 21.5	16.9 ± 16.7	2.1 ± 2.8	4.5 ± 4.4
BURGF	6	22.7 ± 20.5	0.7 ± 1.2	2.8 ± 4.2	0.2 ± 0.4
CAMPM	7		23 ± 15.6		6.1 ± 5
FERMM	3		31.7 ± 44.6		9.8 ± 14.7
MEL7F	5	11.8 ± 13.3	0.4 ± 0.9	1.4 ± 0.5	0.2 ± 0.4
BCO6F*	1		76.3 ± 0		41 ± 0
CASTF*	3	83.1 ± 143.9	64.8 ± 55.4	19 ± 32.9	8.3 ± 8.1
MEL6F*	1	4 ± 0			

5.4 Discussion

This study shows that GPS technology can be successfully employed to collect extensive and high quality data on the movements and behaviour of Barn Owls without negative impacts to individual birds or their breeding performance. This is one of the first studies to use these methods with Barn Owls and the first to investigate Barn Owl behaviour in relation to road networks using GPS dataloggers. Our findings provide the most detailed information on Barn Owl foraging and home range in the Republic of Ireland which facilitates an increased understanding of the ecology of the species and provides the first data on the response and interactions of individual birds with major roads in this country.

Our estimates of Barn Owl home range were the first in the Republic of Ireland, which show that breeding Barn Owls move over extensive distances during the breeding season and have considerably larger home range sizes than elsewhere in Europe. The MCP home range of Irish Barn Owls was more than 16 times larger than the home range of Barn Owls described in Britain, and the 95% KDE home range for Irish birds was more than five times larger than in Britain (Askew *et al.* 2006). The area of movement of breeding birds in the Republic of Ireland was more similar to home range estimates for Barn Owls in Portugal and Switzerland. The MCP home range of Irish birds was four times larger than recorded in Portugal (Grillo *et al.* 2012); however, the estimated 95% KDE of Irish birds were only marginally larger than estimates for Portugal and Switzerland (Sousa *et al.* 2010, Schalcher 2017). Interestingly, the 50% KDE was marginally smaller in Ireland than recorded for Barn Owls in Portugal. This suggests that areas of suitable habitat for Barn Owl are more dispersed in the Irish landscape, which requires birds to travel longer distances to exploit these resources. In Britain, it has been shown that Barn Owl home range size is linked to breeding performance, with birds with smaller home ranges being more productive (Askew *et al.* 2006). The larger home range size of Irish Barn Owls compared to Barn Owl populations in other parts of their European range is indicative of poorer quality of habitat and/or more dispersed areas of suitable habitat. Barn Owls did not use all parts of their home range equally and clearly selected certain areas and avoided others, which was likely influenced by habitat conditions and suitability. The avoidance of elevated areas was also particularly noteable for individual birds.

For example, there were high elevation areas within the home range of both CAMPM and BFERF, which were completely avoided, and these birds showed a clear preference for the low-lying areas (mostly below 100m asl) within their range. This concurs with the known breeding distribution of Barn Owls in the Republic of Ireland, as the majority of nesting sites are below 150m asl with only a few outliers which are located just below 300m asl. In addition, differences in the prey species base and prey availability may require birds to hunt over more extensive areas to meet their prey requirements compared to elsewhere in Europe, which generally have more small mammal species available to Barn Owls.

We showed that there was no avoidance effect of roads in terms of the establishment of home ranges and general movements of Barn Owls within the landscape. Of six birds which nested within 5km of a major road, the home range of four included the major road. These four birds nested at distances of 1.8-4.4km from the road and analysis of their movements showed they frequently encountered the road, which overlapped with the 95% KDE for all of these birds. Of the two birds which did not encounter a major road, both were located furthest from this infrastructure (of the birds within 5km of major roads), at 4.7 and 4.8km respectively. Both birds had home ranges which did not extend as far as the road in any direction, which indicates that they were not actively avoiding the road, but rather the absence of the road in their home range was dictated by their home range size. This is further supported by the movement patterns of BURGF which nested 4.4km from the M8 Motorway and included this infrastructure within its MCP and 95% KDE home range. The home range of this bird extended in the direction of the motorway which was located at the furthest point from the nest, yet the motorway was frequently encountered and crossed. In Portugal, Barn Owls also included major roads in their home ranges, however in contrast to our study, birds showed an avoidance of these structures. Sousa *et al.* (2010) showed that individuals which nested 2km or more from the highway showed no interaction with the highway, while birds which nested within 2km of the highway, including two birds which nested within 500m, did cross the highway. These birds tended to avoid this infrastructure however, with home ranges extending in the opposite direction and core areas which do not include the highway. Grillo *et al.* (2012) also showed that Barn Owls established their home ranges mostly in the vicinity of the highway but included them in areas of their home ranges with a lower probability of use. Therefore, it seems like there was an attraction effect towards roads for Irish birds, versus an avoidance effect to roads for birds in Portugal. This variation clearly demonstrates that Barn Owls differ in their response to roads under different conditions. This variation may be influenced by habitat suitability in the landscape, for example, road verges may be more attractive to Barn Owls where the habitat suitability is poor in the surrounding landscape, and this is supported by the fact Irish Barn Owls required larger home ranges than elsewhere in their European range.

Our data shows that Barn Owls frequently crossed major roads within their home ranges, which were not barriers to movements. Interestingly, of the six birds which regularly encountered major roads, all survived and bred successfully in the same year they were tracked, whereas of 11 birds which were radio tracked in Portugal, four were killed on the road during the study period, despite significantly higher and crossing rates in Ireland (Grillo *et al.* 2012). This indicates that risk of collision is greater on the highway in Portugal than on the major roads which were included in our study. Based on ringing data, Ramsden (2003) estimated a very high probability of mortality when juvenile Barn Owls first encounter a major road. At least for adults in our study area, we showed that birds can frequently encounter major roads and survive. Although it was not possible to collect comprehensive data on the survival of individual birds, it is interesting that one adult which was tracked over two consecutive breeding seasons regularly encountered and crossed the M8 Motorway. This bird (MEL6F/MEL7F) crossed the M8 Motorway on average 1.4 times per night. In general the rate Irish birds crossed major roads was higher than recorded in Portugal, where Barn Owls were recorded crossing a highway on average one time per 17 hours of tracking (Sousa *et al.* 2010) and 0.3 times per day (Grillo *et al.* 2012). Grillo *et al.* (2012) also suggested that there was a greater likelihood of a Barn Owl crossing a highway at sections that were above grade, with wide verges and a higher proportion of herbaceous cover in the verge. We found that typically Barn Owls crossed the road at random when in transit flight, i.e., when birds were travelling in fast flight from one point to the next, they crossed the road where their flight path intersected with the route, as opposed to crossing at specific points with respect to the route characteristics.

Where birds crossed while hunting in close proximity to the road, there may have been features of the route or surrounding habitat which influenced the location of crossing, however we did not discern such patterns.

In addition to Barn Owls including major roads in their home range, we showed that birds were actively attracted to major roads and the areas in the immediate vicinity. Barn Owls spent significantly more time than expected in close proximity to major roads. The behaviour of individuals tracked indicates that they were attracted to these areas to forage, as they spent significantly more time in hunting flight than expected based on their behaviour elsewhere in their home range. In contrast, Sousa *et al.* (2010) found that Barn Owls did not frequently use highway verges in Portugal, despite the fact that these verges supported a higher abundance of small mammals. Our data supports the theory that the verge habitats of major roads in Ireland provide foraging opportunities for Barn Owls. This has been suggested previously based on the locations of Barn Owl road casualties; however, we provide detailed data showing that Barn Owls select major road verges and the areas in the immediate vicinity for foraging. Based on the distribution of the breeding population and the current extent of the major road network, approximately 12% of the national breeding population are within 4km and therefore have the potential to exploit foraging opportunities associated with major roads, however this proportion is likely to increase with current plans for expanding major road infrastructures in the Republic of Ireland. This has significant implications for management of roadside verges and the design and development of mitigation measures for Barn Owls, and highlights the importance of maintaining or enhancing the biodiversity value of verge habitats while reducing risk of collision.

6. Conclusions

This study reveals a range of behaviour responses of Barn Owls to roads which include negative, neutral and positive effects of road systems on Barn Owl populations. We showed that mortality on roads is a major cause of death for Barn Owls in Ireland, however their breeding distribution is unaffected by road networks, and Barn Owls exploit and can benefit from the grass verges associated with major roads, which represent an important foraging resource. The complexity of the interactions of Barn Owls with roads creates specific challenges for the development of mitigation, and we recommend measures which aim to reduce the risk of collision for Barn Owls on major roads without compromising the biodiversity value of roadside habitats.

Barn Owls were killed on Irish roads at a high frequency relative to their occurrence and compared to other wildlife species. They were the most susceptible bird to vehicle collisions based on number of road fatalities recorded and population densities per species. Although there is variation in survey methodologies between studies, our estimates of the rate of mortality of Barn Owls on major roads in Ireland were similar or higher to mortality rates on major roads elsewhere in Europe, where the figures were unadjusted for search and removal bias. This indicates that a higher proportion of Barn Owls are killed on major roads in Ireland compared to elsewhere in their European range where population densities are higher. A greater vulnerability to vehicle collision for Barn Owls on major roads in Ireland can be explained by several factors, firstly, Barn Owls are attracted to hunt along the verges of major roads, in addition to the expansive dispersal movements of juveniles and the extensive home ranges of adult Barn Owls, all of which can increase the likelihood of encountering major roads. We also demonstrated the value of incorporating search and removal bias to inform more accurate estimates of road mortality rates, and recommend that all future studies to assess wildlife road mortality take account of potential sources of bias in this way.

We confirmed that Barn Owl mortality on roads is widespread, occurs throughout the year and affects individuals of all age classes and condition, however we observed specific trends in spatial and temporal mortality patterns which allow us to understand the nature and causes of the problem. The majority of road fatalities are juveniles which are killed during the post-breeding dispersal phase in late autumn and winter. As juveniles can travel extensive distances, the young which disperse from breeding sites throughout the country can be affected by roads, regardless of proximity of nesting sites to roads. We showed that the majority of mortality incidents occur on major roads, which represent a small proportion of the national road network. The risk of collision for Barn Owls is significantly higher on major roads than on national roads and other road classes. We therefore recommend that mitigation is targeted towards major road networks for maximum benefit and we predict, that in the absence of an appropriate and effective mitigation response, Barn Owl road mortality levels will continue to increase alongside the planned expansion of the major road network.

We demonstrated that the factors which determine the occurrence of road fatalities operate at two scales - the road scale and the broad scale at the landscape level. At the road scale, we identified that the proportion of grass and herbaceous cover in roadside verges is the most important factor which influences the occurrence of Barn Owl mortality. This indicates that Barn Owls are attracted to hunt in roadside verges which subsequently increases their risk of mortality. This is supported by the fact that verge habitats provide an important refuge for small mammal populations and are actively selected for foraging by Barn Owls. We also infer that risk of collision is greater for birds when they are hunting in close proximity or alongside major roads as opposed to other behaviours, including fast non-hunting flight, and this has important implications for the development of mitigation solutions. At the landscape scale we showed that the distribution of elevated areas influence the movement and dispersal patterns of Barn Owls, which in turn can affect the locations that birds encounter roads and thus mortality spatial patterns. Both of these factors, at the road and landscape scale in combination, influence Barn Owl deaths on roads, and we showed that road mortality patterns, clustering and the presence of mortality hotspots vary between roads depending on these influences. Our data indicates that the landscape scale influences, specifically the location of a road with respect to areas of a high probability of use by Barn Owls have the greatest influence on mortality patterns.

This shows the importance of identification of potential mortality hotspots based on road conditions but also wider landscape influences. Our findings also indicate that a certain level of Barn Owl mortality should be expected but this should be minimised by the implementation of appropriate mitigation at the road level where problem areas are identified.

Despite the fact that mortality on roads is a major cause of death for Barn Owls in Ireland, their nesting distribution is not affected by road networks. We showed that breeding densities were similar or higher in areas surrounding major roads to areas unaffected by major road infrastructures. Major road developments do not necessarily cause the displacement of Barn Owl pairs in close proximity to the road, as has been reported in Great Britain. Therefore, appropriate mitigation through the provision of artificial nesting sites would help to ensure that pairs which are directly affected or disturbed by road developments are not displaced. The response of individual Barn Owls confirmed that major road infrastructures are not barriers to the movement of birds and that individuals can regularly encounter and cross major roads without negative effects. We recorded higher crossing rates of individual birds and reduced mortality per crossing event on major roads in Ireland compared to Portugal, which suggests more frequent overall crossing rates and interactions of Barn Owls with major roads in Ireland compared to elsewhere in Europe, based on similar or higher road mortality rates in Ireland. We observed an attraction effect to major roads, Barn Owls spent more time in proximity to major roads than expected and spent more time hunting along or in close proximity to major roads than elsewhere in their home range. This confirms that major roads can provide some benefits to Barn Owls in the form of the provision of suitable habitat. The fact that roadside verges are more important as a foraging habitat for Barn Owls in Ireland compared to other European countries is likely a reflection of the habitat conditions in the wider landscape, and the larger home range size of Irish birds further indicate poorer habitat quality. These findings indicate that the main negative effects of major roads on Barn Owl populations are from direct mortality through vehicle collisions and not by other means such as displacement, disturbance, or through a reduction of breeding range or suitable habitat. This reaffirms targeting the development and implementation of mitigation to reduce vehicle collisions and also highlights the existing and potential benefits of roadside verges for Barn Owls, which should be an essential consideration of mitigation measures.

Overall, our findings on Barn Owl mortality patterns and the behaviour response to major roads advances our understanding of the nature and factors which influence risk of collision and emphasises the challenges in developing conventional mitigation solutions. We showed the ability to identify mortality hotspots and the factors which influence risk of collision, which will help to inform and direct mitigation requirements. We also showed that mortality patterns and influencing factors can vary regionally and on individual roads, and given the complexity of the issues which dictate the occurrence of Barn Owl mortality on roads it may not always be possible to accurately identify the extent and specific locations of mortality on new roads, or on existing roads in the absence of mortality surveys. We recommend that mortality surveys to accurately detect high risk areas are conducted on new major roads during the early stages of operation, which would serve to determine the effectiveness of mitigation applied and refine the identification of predicted mortality patterns. Although it is necessary to implement most mitigation measures during road construction, we propose that retrospective fitting of mitigation during the operation phase, where this is limited to minor works, should be considered where this is deemed practical and beneficial based on the mortality survey. This approach would have several benefits, including allowing the accurate detection of high risk areas based on the confirmed locations of Barn Owl road fatalities, and would also facilitate assessment of the effectiveness of mitigation based on road casualty data before and after measures are applied. We propose a number of measures to enhance the value of habitats for Barn Owls away from major roads, in order to attract birds away from, and reduce encounter rates with major roads, while also providing conservation benefits to off-set mortality on roads. We designed specific mitigation recommendations for new and existing major roads which is targeted at deterring Barn Owls from flying or foraging in close proximity to the road through incorporating vegetation screening, which also serves to create a safe zone for birds to continue to exploit verge habitats. We have outlined the specific mitigation and research recommendations in the following relevant sections.

7. Mitigation Recommendations

We have outlined proposed mitigation strategies designed to minimise the negative effects of roads on Barn Owl populations in the Republic of Ireland. The proposed mitigation recommendations are based on an understanding of Barn Owl movements, behaviour and response to major roads, the factors which influence risk of collision and are also informed by current and proposed mitigation strategies for the species. The proposed mitigation recommendations are also informed by the outputs of a workshop with road planners, engineers and environmental researchers which assessed the practicalities and conservation benefits of mitigation strategies (informed by the research findings) while striving to achieve compatibility with road safety and engineering requirements. We acknowledge however that the proposed mitigation recommendations are primarily designed from an ecological perspective and that adjustments may be required to ensure compatibility with road user safety, road design, management and engineering priorities and are subject to these constraints.

The proposed mitigation strategies are each targeted to minimise the effects of major road networks on Barn Owl populations in one of three ways as outlined for each: 1) reduce direct effects, disturbance and displacement of breeding Barn Owls during the development of new road schemes (mitigation strategy 1), 2) reduce incidents of mortality of Barn Owls on major roads (mitigation strategies 2–5), and 3) deliver conservation benefits to Barn Owls to off-set mortality on major roads (mitigation strategies 5-6). We have specified whether the mitigation is a legal requirement to include in the development of roads or optional, and the relevant schemes or areas it should be targeted (e.g., new or existing roads). Due to the novel nature of the mitigation strategies proposed, and the fact that these measures have not been evaluated, we have outlined the likely effectiveness (high, medium, low) of each mitigation strategy in reducing negative impacts to Barn Owls, and the advantages and disadvantages associated with each. For these mitigation measures to be successfully implemented and evaluated, effective engagement with the range of stakeholders and specialists is essential and we have listed the relevant stakeholders required for effective implementation of each mitigation strategy. In addition, we have also prioritised each mitigation strategy (high, medium or low). The mitigation strategies can be implemented in combination (for example two or more mitigation strategies can be implemented in conjunction on the same road). The implementation of the mitigation measures outlined should be accompanied by appropriate monitoring to assess the effectiveness or otherwise of adopted measures to inform future best practice, and to detect any negative impacts on the target species or other wildlife should they occur. The specific monitoring requirements are detailed alongside each mitigation strategy.

It is clear that mitigation strategies to minimise impacts of major roads on Barn Owl populations require a novel approach given the complexity and range of confirmed and potential factors which influence risk of collision, the inherent difficulties in designing conventional mitigation measures for bird species, and the fact that effective mitigation solutions to reduce Barn Owl mortality on roads have yet to be achieved. In this context, we also recommend a review of the current policy and protocols for the design and implementation of wildlife mitigation measures on new road schemes. Current practice dictates that wildlife mitigation measures on new road schemes are devised and implemented during the road design and construction phase, however this has several limitations in terms of targeting mitigation solutions for Barn Owls. Our findings show that Barn Owl mortality rates and the factors which influence risk of collision can vary between roads and over a relatively short spatial range. Implementing effective mitigation measures to reduce Barn Owl mortality therefore requires the accurate prediction of all locations on a road prior to the operational phase. Our findings provide the methods and tools to identify high risk areas, however we acknowledge that this process may not accurately identify all problematic areas. We therefore recommend that there is flexibility to incorporate limited mitigation measures or improvements to existing measures during the operational phase of new road schemes where this is deemed appropriate (informed by data on the extent and spatial patterns of mortality as determined by road mortality surveys). We recognise that there are significant limitations on introducing new or extensive mitigation measures on roads during the operational phase of a road.

In practice it is likely that only mitigation works which do not require the road to be closed or which can be implemented alongside other necessary works on the road would be practical, however this would still represent a significant improvement on the current situation. This approach would have several advantages for devising and implementing mitigation solutions for Barn Owls. Firstly, it would allow the collection of data on Barn Owl mortality rates, the identification of mortality hotspots and the factors which influence vehicle collisions specific to the road system, which would facilitate a targeted approach to mitigation to maximise efforts to the areas which would be most beneficial in reducing road casualties. The ability to incorporate minor mitigation measures after the road has been in operation for a period of time, or amend existing mitigation, would also facilitate a more comprehensive evaluation of the effectiveness of applied mitigation (comparison of mortality rates and locations before and after mitigation is applied/amended) which is currently lacking.

In addition to the mitigation strategies outlined, it is important to highlight mitigation measures which have been previously proposed for Barn Owls and the rationale for excluding these, based on our findings. The primary mitigation measure proposed to reduce Barn Owl vehicle collision on major roads to date, is the use of artificial and/or natural screens, particularly on embanked sections of road. This mitigation is designed to deflect the flight path of birds which are crossing a major road above the height of vehicles. Our data indicates that the road height, and whether the road is embanked, level or excavated does not significantly determine Barn Owl mortality. We recommend therefore that in the absence of specific data to indicate that Barn Owls are at increased risk of mortality on embanked sections of a specific major road, that this measure is not implemented in its current form on Irish roads. The planting of dense vegetation or regular mowing of verges has also been proposed to reduce the suitability of these habitats for Barn Owls. Our data indicates that Barn Owls exploit verge habitats and that these represent an important foraging habitat and provide a refuge for small mammal populations. On this basis, we therefore do not recommend reducing the suitability of extensive areas of verge due to the potential negative biodiversity impacts of this measure. However, we have incorporated elements of this measure to the development of our mitigation strategies (refer to Mitigation Strategy 2).

<table>
<tr><td colspan="3">Mitigation Strategy 1:
Protection of established breeding sites and provision of alternative nesting sites</td></tr>
<tr><td colspan="3">Objective:
Ensure breeding Barn Owls and their nest sites are not directly affected, disturbed or displaced through the development of new road schemes.</td></tr>
<tr><td>Mitigation required: Yes</td><td>Likely effectiveness: High</td><td>Priority: High</td></tr>
<tr><td colspan="3">Implementation targeted to: New road schemes or road improvements (all road types)</td></tr>
<tr><td colspan="3">Stakeholders: Transport Infrastructure Ireland, Local Authority and National Parks and Wildlife Service</td></tr>
<tr><td colspan="3">Overview:
The legislative framework under the Wildlife (Amendment) Act, 2000 provides for the protection of all wild birds and their nests, eggs and young (www.npws.ie/legislation). Barn Owls are a Schedule II species under the Wildlife (Amendment) Act, 2000. It is an offence to intentionally cause disturbance at a nest site or to breeding Barn Owls.
The development of new road schemes can cause disturbance to or the displacement of Barn Owl breeding pairs. Identification and mitigation of the effects of new road developments on Barn Owl breeding sites is a requirement of the Environmental Impact Assessment (EIA) for proposed road schemes. Barn Owl Surveying Standards for National Road Projects were developed through this study to improve survey standards and provide detailed guidance on the requirements for the design and implementation of Barn Owl surveys to identify breeding sites within a 5km radius of proposed road schemes according to the specified methodology (http://www.tiipublications.ie/library/RE-ENV-07005-01.pdf). The distribution of Barn Owl breeding sites recorded by the survey should be interrogated to identify nest site/s which may be vulnerable or directly affected by a new road scheme, by disturbance or displacement during the construction or operation phase of the road.</td></tr>
</table>

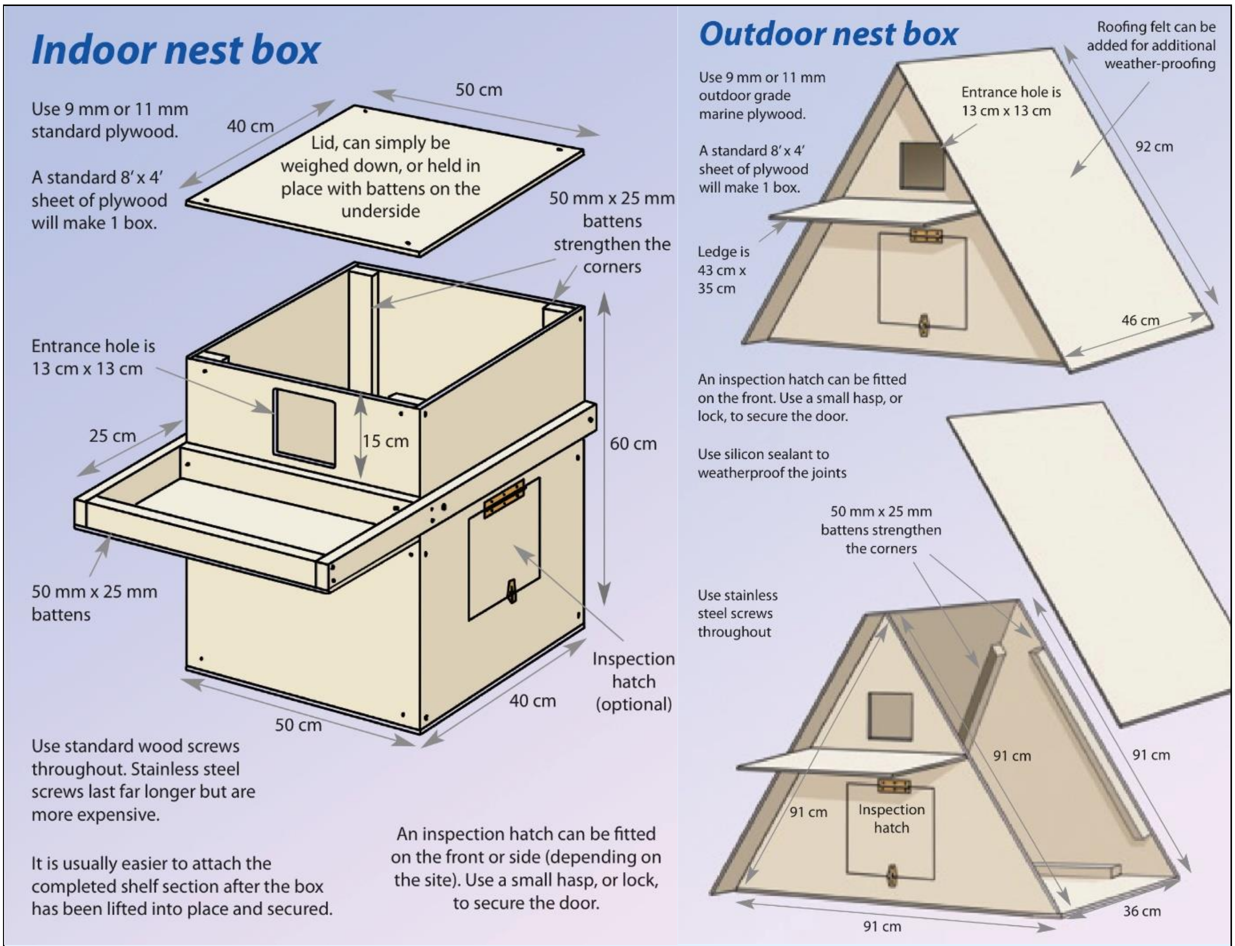
All works which have the potential to cause disturbance to Barn Owl breeding sites should be appropriately planned and undertaken outside of the breeding season as required under the Wildlife Act (1972 and 2012).

The timing of works which could affect individual breeding sites should be informed by monitoring to determine breeding status and stage of breeding on a site-specific basis, which would allow maximum time for works to be undertaken (typically a seven month period would be available for works to be undertaken which would avoid disturbance to Barn Owls during the breeding cycle), while minimising the potential for negative impacts to the breeding pair. The timing of works should be planned in consultation with the NPWS.

If the works are to render a breeding site unsuitable or potentially unsuitable (as assessed and determined by a competent ecologist and documented in the EIA) for Barn Owls (i.e. demolished, altered, prone to disturbance from construction works, situated in close proximity to the new road, etc.) then mitigation is required. A minimum of three alternative nesting sites (artificial nest boxes) should be provided in suitable locations at a distance of 500m-1km (which would ensure that nest boxes are at least 500m from the new road). This distance is selected to increase the likelihood of birds taking up the nest box (i.e. close to the original nest site to increase chances of birds encountering the nest box), while also attempting to relocate the breeding pair away from the major road. This distance selected is also informed by the typically high availability of buildings in the Irish landscape which can be used by Barn Owls (as recorded by this study), and therefore increasing the distance from the original nest site to artificial nest boxes would likely decrease the chances of uptake of the pair in favour of other closer alternatives. It is important to note that artificial nesting sites may not be taken up by Barn Owl, for several reasons, which may include the pair relocating to other available and suitable nesting sites in the area, or other species may occupy the nest box before Barn Owls have the opportunity to establish. In this context, this mitigation should not be deemed to have failed if the artificial nesting sites are not occupied by Barn Owl. The objective is that the pair, if displaced from the original nest site, relocates to another nest site and continues to breed, whether this is in an artificial nesting site provided or another site.

Potential and suitable locations for nest boxes should be recorded as part of the Barn Owl survey to inform the EIA. This will also negate the requirement to conduct a separate feasibility study to identify locations for artificial nesting sites. Nest boxes can be designed for installation in both indoor and outdoor situations. The selection of sites, placement and installation, and maintenance of nest boxes should consider the following:

- Select a suitable site based on Barn Owl nesting requirements, examples include buildings or mature and isolated trees
- Select a site which is likely to be investigated by Barn Owl (e.g. ruined building)
- Ensure the nest box is in view (e.g. not concealed by vegetation if on a tree etc.)
- Select a site where there is minimal human disturbance
- The position of the nest box depends on the site, typically nest boxes should be placed 3m or more from the ground
- Select a site or ensure access for potential predators (e.g. Cat, Pine Marten) is restricted
- If the nest box is not in use by Barn Owls, the nest box should be inspected and maintained each winter for a period of three years from its installation to ensure the nest box remains suitable for Barn Owls (e.g. remove nesting materials blocking the entrance, ensure the nest box is dry etc.)



Design plans and dimensions for Barn Owl indoor (left) and outdoor (right) nest boxes

Mitigation Measures (step by step approach):

- Conduct a survey for Barn Owls within a 5km radius of the proposed road scheme according to the required surveying standards (http://www.tiipublications.ie/library/RE-ENV-07005-01.pdf)
- Assess the distribution of Barn Owl breeding sites (based on survey findings) in relation to the proposed route and identify sites which may be directly affected (disturbed or displaced) by the route development or operation
- If a Barn Owl breeding site or sites are identified which may be directly affected by works associated with the new road scheme (i.e. disturbance or displacement) then mitigation is necessary
- All works which have the potential to cause disturbance or displacement to a breeding pair should be planned and confined to outside of the breeding period in accordance with the the Wildlife (Amendment) Act 2000
- The timing of works should be informed by monitoring of the breeding status and activity on a site-specific basis according to the methods defined in the surveying standards
- If the original nest site is deemed to or becomes no longer suitable for breeding Barn Owls due to construction works or proximity to the new road scheme, then the provision of alternative nesting sites (minimum of three) is required within 500m-1km from the original nest site
- Nest boxes should be designed and constructed to appropriate specification and materials and sited according to best practice standards
- Monitoring as outlined should be undertaken to confirm that Barn Owls no longer use the original site and to monitor uptake and management requirements of the artificial nest boxes

Additional resources:

Barn Owl Survey Standards for National Road Projects:

http://www.tiipublications.ie/library/RE-ENV-07005-01.pdf

Information on the design, siting and maintenance of Barn Owl nest boxes:

http://irishraptors.blogspot.com/2015/01/free-barn-owl-booklet-to-download.html

Advantages:

- Reduces the potential for direct negative effects to breeding Barn Owls from the development of new road schemes
- Straightforward and cost effective
- Low potential for negative impacts

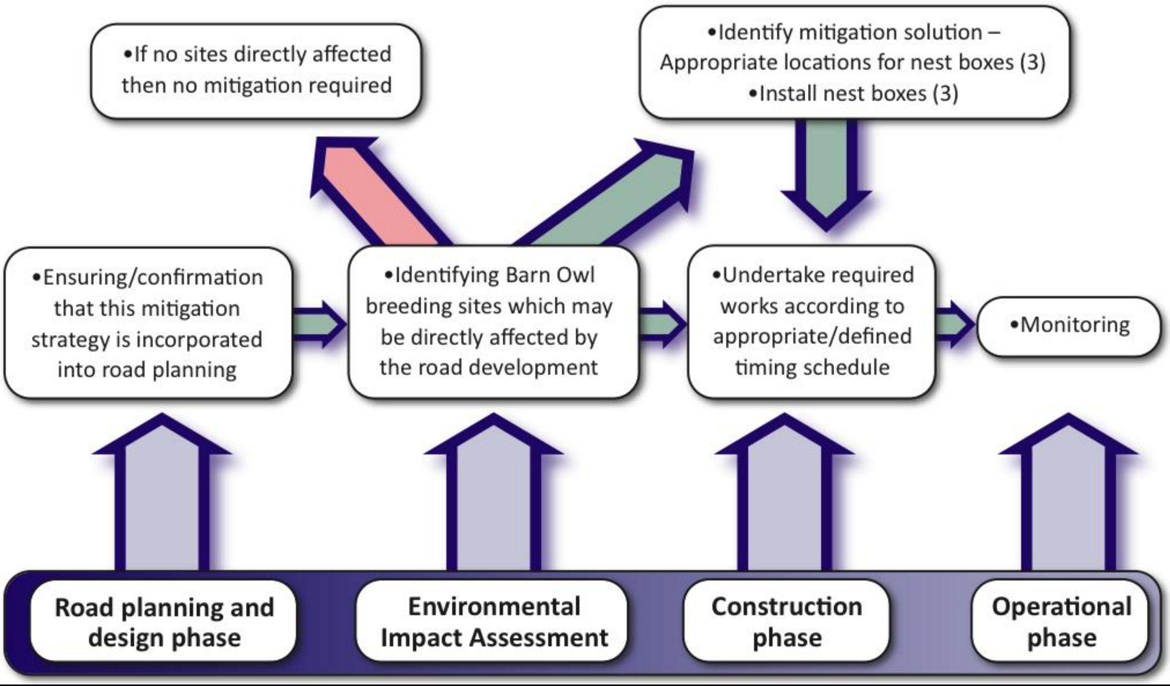
Disadvantages:

- May require a management agreement with relevant landowner/s to install, maintain and monitor nest box/es
- Could potentially encourage other Barn Owls to nest within 1km of a new road scheme
- Mitigation focused on reducing disturbance to breeding pairs and will not affect mortality rates on road

Monitoring requirements:

- Monitor occupancy (according to the methods specified in the Barn Owl Surveying Standards for National Road Projects) at the original breeding site for a period of three years (to include three breeding seasons) from the time of the initial potential disturbance activity (i.e. construction works, or opening of the road) to determine whether Barn Owls continue to use the site
- Monitor uptake of the artificial nesting sites for a period of three years to determine whether they are used by Barn Owls, and to maintain the nest boxes as required to ensure they remain suitable for Barn Owls

Schedule for implementation of mitigation:



Mitigation Strategy 2:

Reduce the habitat suitability of the verge in the immediate vicinity of the road

Objective:

Reduce Barn Owl mortality on major roads

Mitigation required: No - Optional	**Likely effectiveness:** Unknown	**Priority:** Medium

Implementation targeted to: New and existing major roads

Stakeholders: Transport Infrastructure Ireland

Overview:

Barn Owls in Ireland utilise the verges of major roads for foraging and mortality locations on roads have been linked to sections of road with suitable verge habitat conditions. The movements of individual birds fitted with GPS dataloggers show that roadside verges are an important foraging habitat for Barn Owls in the context of the wider landscape, and the suitability of verges should be maintained (and enhanced) where possible, while also reducing the risk of collision for birds which exploit verge habitats. In addition to Barn Owls being killed on roads through direct collision with vehicles, it is also suspected that birds in close proximity to the road may be killed due to the wake effect of Heavy Goods Vehicles (HGV's). On this basis, it is not only birds which cross the road which are at risk, but also when birds forage, fly or perch next to the road surface.

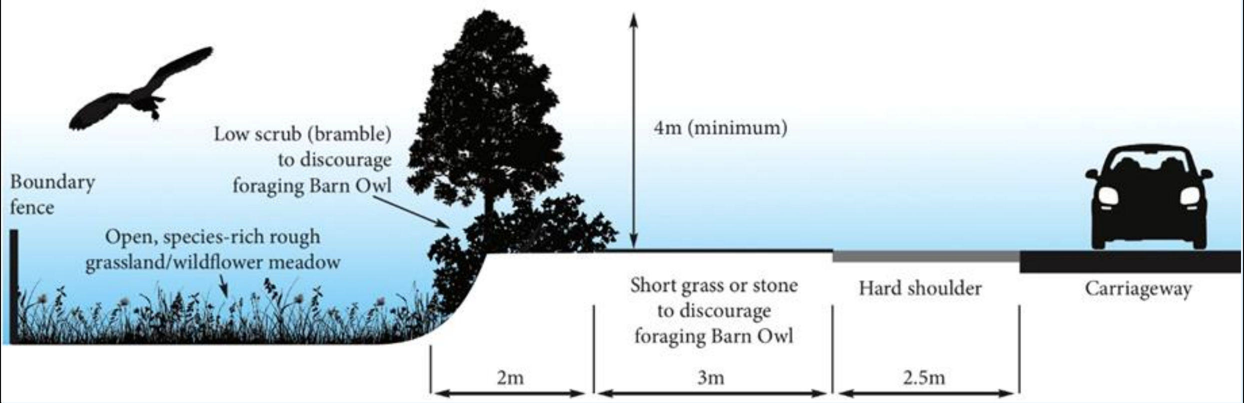
This measure is designed to discourage Barn Owls from flying and/or foraging in close proximity to major roads (within 7.5m), while maintaining the suitability and integrity of verge habitats. A buffer (3m) of unsuitable foraging conditions (short grass or stone) in the immediate vicinity to the road surface would discourage Barn Owls from hunting in this area and potentially reduce risk of direct vehicle collision and/or birds becoming caught in the wake of a HGV. A natural barrier of dense vegetation (bramble and tree line) would form an additional buffer which would serve to: (i) focus the foraging activities of birds further from the road, (ii) reduce the wake effect of HGVs, and (iii) deflect the flight path of Barn Owls which are crossing the road above the height of vehicles. The bramble would provide food and shelter for small mammals which would help to increase their numbers in the adjacent grassland. The verge behind the natural barrier (on the far side to the road) is considered relatively safe for Barn Owls and can be managed appropriately to encourage Barn Owls to exploit these areas.

On existing roads this measure should be targeted to mortality hotspots or sections of the road where Barn Owl mortality has been identified. On proposed roads, this measure should be targeted to: i) sections of road with wide verges (≥ 20m) of suitable open grass/herbaceous cover, ii) in proximity to junctions and road lighting, and (iii) sections of road which traverse areas of a high probability of use by Barn Owls (refer to Section 2).

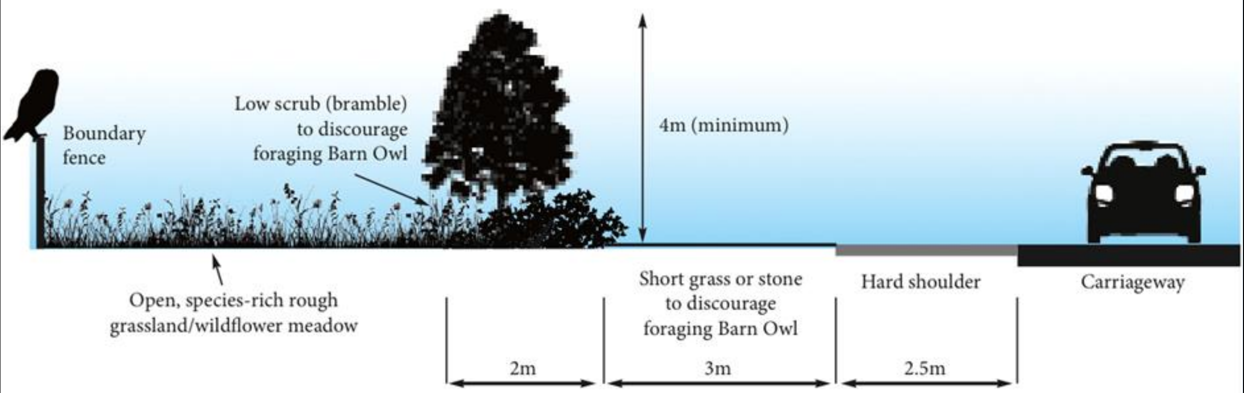
Mitigation Measures (step by step approach):

- A 3m strip of verge immediate to the hard shoulder should be maintained/managed as 'unsuitable' habitat for Barn Owls. This 3m strip could be grass which is maintained at a maximum sward height of 100mm through a regular mowing regime, or stone (the latter would require less management)
- A 2m strip of low and dense bramble (Rubus fruticosus agg. is preference) should be maintained along the verge, at a distance of 3m from the hard shoulder
- A tree line should be planted so that the base of the trees are in line with the edge of the bramble furthest from the road (i.e. 5m from the hard shoulder), or within the bramble. Trees should extend for a minimum of 4m above the height of the carriageway (which is informed by the height of HGVs and on the basis that Barn Owl flight lines may drop above the surface of the road, after flying over the tree line when crossing the road). Therefore, on embanked sections of road the trees will need to be sufficiently high to compensate for the fact that the base of the tree will be lower than the height of the carriageway, which may require increasing the distance of the tree from the road
- The tree line should be continuous, without breaks and be the desired length based on the verge features. The following native tree species can be used: Willow (Salix species), Birch, Alder, Hawthorn, Mountain Ash or Hazel
- It should be ensured that no areas of 'suitable' foraging habitat for Barn Owls exist between the natural barrier (bramble and tree line) and the road

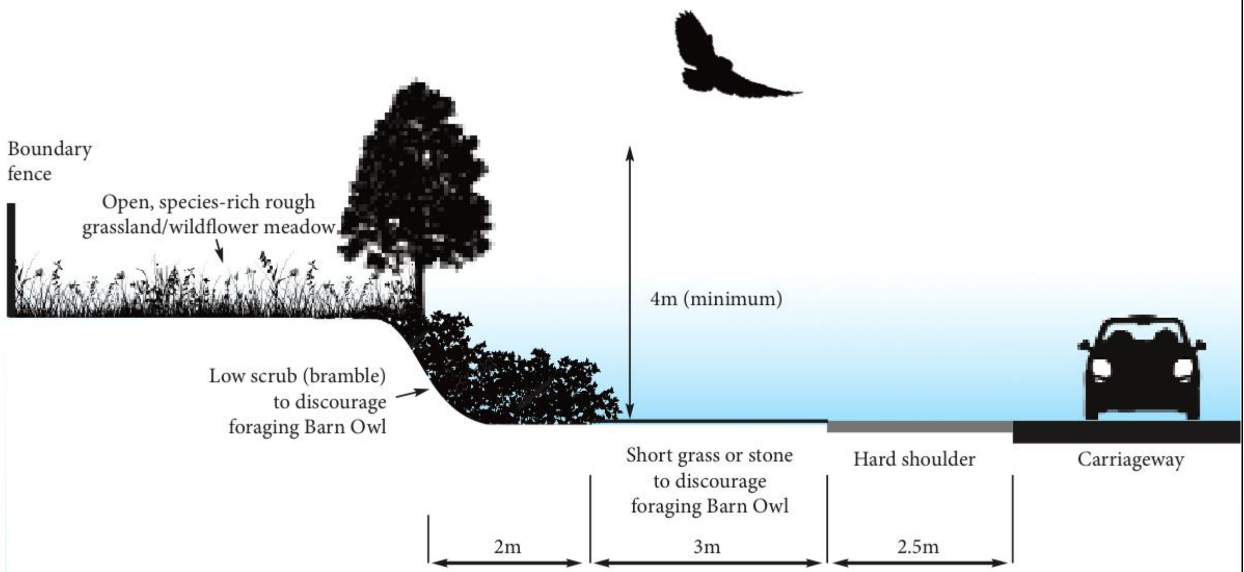
- The remainder of the verge (between the tree line and boundary fence line) should be maintained as open grassland and managed as suitable habitat for Barn Owl and in line with pollinator enrichment management (species rich meadow and wildflower areas). Artificial perches can also be installed in this area of verge



Proposed mitigation for sections of road which are embanked



Proposed mitigation for sections of road which are level



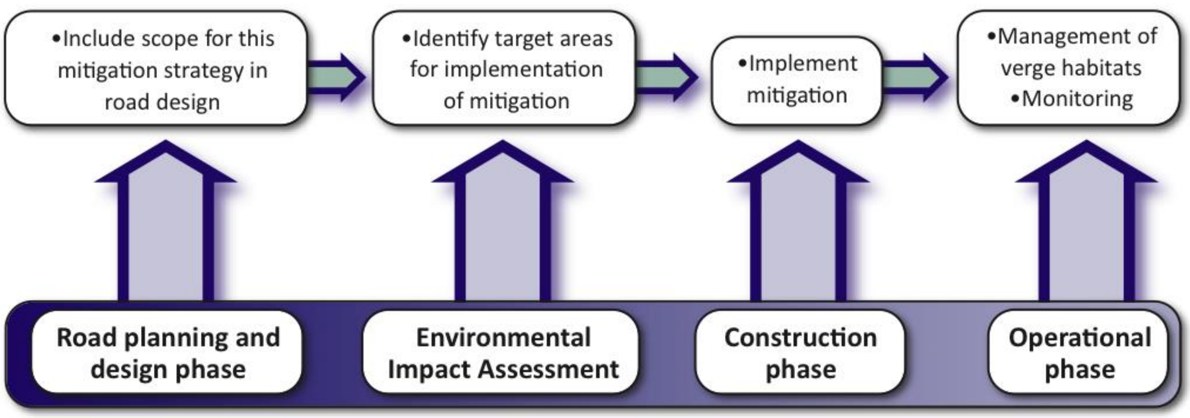
Proposed mitigation for sections of road which are embanked

Advantages	**Disadvantages**
• Provides 'safe' foraging areas for Barn Owls • Management (including use of bramble) should provide suitable conditions for small mammals in verge habitats • Mitigation is only targeted to areas most attractive to foraging Barn Owls	• Costly to implement and likely limited to small sections of road • Potential conflicts with road user and health and safety requirements • Is more appropriate to implement in post-construction phase and informed by data on mortality locations and hotspots • If implemented at construction phase this mitigation is difficult to evaluate • Effectiveness of this mitigation is untested and unknown

Monitoring requirements:

- Assess Barn Owl mortality rates and locations (via road casualty survey) in relation to mitigation measures. Road casualty survey to be carried out for a period of two years (from the opening of the road) according to the methods detailed in this report, which include a minimum of one survey visit per week to record the number and location of all Barn Owl road casualties.
- Assess the mortality rates and locations of other wildlife species (via road casualty survey) in relation to mitigation to determine any potential negative effects
- Determine the value of this mitigation (provision of bramble) for small mammal populations by comparing abundance in areas which are mitigated (minimum of two areas) to areas which are not mitigated (minimum of two areas)
- Monitor use of verge habitats behind the natural barrier via infra-red motion sensor cameras fixed on artificial perches and/or GPS tracking

Schedule for implementation of mitigation:



Mitigation Strategy 3: **Reducing artificial road lighting in areas with suitable foraging conditions**		
Objective: Reduce Barn Owl mortality on major roads		
Mitigation required: No – Optional	**Likely effectiveness:** Medium	**Priority:** Medium
Implementation targeted to: New and existing major roads		
Stakeholders: Transport Infrastructure Ireland		

Overview:

This measure is designed to reduce the attractiveness of roadside verge habitats for Barn Owl. We showed a positive relationship between the location of Barn Owl mortalities and the distance to road lighting, with a greater number of road fatalities recorded within 150m of road lighting than expected. Barn Owls may be attracted to sections of verge in proximity to road lighting which provide a visual aid for hunting, however further research is required to determine the relationship with road lighting and Barn Owl foraging behaviour. This measure would require altering the current road lighting systems by removing or turning off lights to make these areas less attractive for Barn Owls and to deter hunting activities in their proximity. This measure should be accompanied by monitoring to determine the response of Barn Owls and the benefits or otherwise.

Alternatively, this measure could be implemented alongside mitigation strategy 2 (outlined previously) to maintain road lighting in sections of road where safe foraging conditions are provided in the verge due to the implementation of a buffer zone and natural barrier close to the road.

Mitigation Measures (step by step approach):

- Identify sections of road where artificial road lighting and suitable verge habitats overlap
- Turn off lighting in these areas to reduce attractiveness to Barn Owls
  or
  Implement Mitigation Strategy 2 in these areas and maintain lighting at current levels

Advantages:	**Disadvantages:**
• Cost effective and easy to implement • May have immediate benefits • Low potential for negative effects	• Effectiveness remains to be proven, requires further research to determine Barn Owl use of areas of artificial lighting • May conflict with road user and health and safety requirements in certain areas of road

Monitoring requirements:

- Monitor Barn Owl mortality rates and locations via a road casualty survey (ideally before and after implementation of mitigation)
- Assess Barn Owl behaviour and response in relation to areas of artificial road lighting via GPS tracking (ideally before and after implementation of mitigation)

Mitigation Strategy 4:

Use of rollers on marker plates and other potential perches to deter Barn Owls

Objective:

Reduce Barn Owl mortality on major roads

Mitigation required: No – Optional	**Likely effectiveness:** Low (untested)	**Priority:** Low

Implementation targeted to: New and existing roads

Stakeholders: Transport Infrastructure Ireland

Overview:

This measure is designed to reduce the attractiveness of roadside verge habitats for Barn Owls by limiting the options for perching along the verge and close to the road. Although we found no significant relationship with Barn Owl mortality locations on major roads and the location of marker plates, birds are known to use these (based on a small number of visual observations) for perch hunting. A roller system fitted to the top of the marker plate, which would not allow the bird to balance or remain in position would deter birds from using these signs. Motion sensor cameras could be used to monitor the effectiveness of this measure and the rate that Barn Owls attempt to use these perches and visit these areas over time. This measure would be most successfully implemented during the operational phase of a road scheme where Barn Owl mortality locations and hotspots have been identified. This would therefore require that scope for this mitigation strategy is incorporated at the road design and planning phase.

Mitigation Measures (step by step approach):

- Include scope for specific mitigation to be implemented within a three-year period post construction
- Identify the requirement for mitigation based on a road casualty survey to determine the extent and location of Barn Owl road mortalities
- Should mitigation be required, identify mortality hotspots targeted for mitigation
- Fit roller systems to marker plates and other signs used as potential perches by Barn Owls close to the road surface

Advantages	**Disadvantages**
• Cost effective and easy to implement • Trials currently being conducted in the Netherlands which may help inform benefits or otherwise	• Effectiveness remains to be proven • Birds likely to continue to hunt in verges where perches unavailable by foraging flight • Perches along the boundary fence line will likely be used by Barn Owls

Monitoring requirements:

- Monitor attempted use and success of roller systems in deterring perching Barn Owls via infra-red motion sensor cameras
- Assess Barn Owl mortality rates and locations before and after fitting roller systems to marker plates (and other signage)

Mitigation Strategy 5:

Creating/enhancing alternative foraging opportunities to attract Barn Owls away from major roads

Objective:

Reduce Barn Owl mortality on major roads and deliver conservation benefits to off-set effects of road deaths

Mitigation required: No – Optional	**Likely effectiveness:** High	**Priority:** High

Implementation targeted to: New and existing roads

Stakeholders: Transport Infrastructure Ireland, Local Authority and National Parks and Wildlife Service

Overview:

The creation or enhancement of suitable foraging habitat for Barn Owls is designed to attract birds away from a major road, which would serve to reduce encounter rates with the road and associated risk of collision. This measure is primarily designed to reduce risk of collision for adult birds associated with breeding sites in the area surrounding a major road and is unlikely to affect the level of juvenile mortality on the road. However, provision of suitable foraging conditions would provide benefits to the local population and may increase the breeding output and population size of Barn Owls in the local area which would help to offset mortality of individuals (juveniles) on the road.

The home range of Barn Owls in the breeding season in Ireland is on average 3,000ha but varies in size between individuals, and does not extend equally in all directions from the nest site. The size of the home range and movement patterns of individuals is strongly influenced by the distribution and extent of suitable foraging habitat as well as other landscape features. Barn Owls do not spend their time equally throughout their range but focus their foraging efforts in a relatively small portion of their home range, as demonstrated by movements of individuals fitted with GPS dataloggers. On this basis, through the provision of appropriately sited suitable foraging habitat, the home range and movement patterns of individual adult birds could be manipulated to attract birds away from major roads and reduce encounter rates with the road and time spent foraging in roadside verge habitats. The potential success of this measure in attracting Barn Owls is also indicated by the fact that roadside verges were recorded to be a more important habitat for Barn Owls in Ireland compared with other studies on the species in Europe, and alongside larger home ranges of Irish birds, this indicates that the wider landscape is less suitable for Barn Owls than conditions elsewhere in Europe, which would suggest that birds would exploit areas suitable habitat where available.

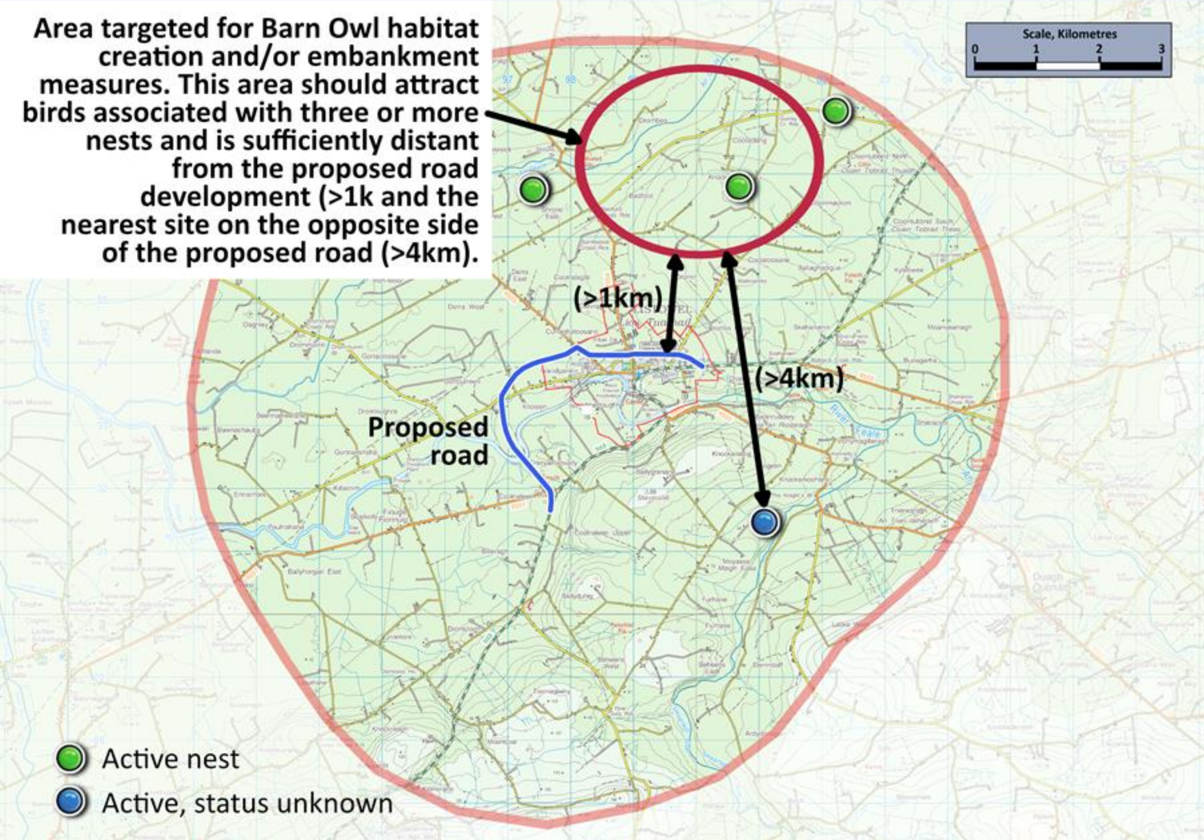
The areas targeted for habitat creation or enhancement should be informed by the distribution of breeding pairs in relation to the proposed or existing major road in order to maximise the number of birds/pairs that will exploit the foraging habitat provided. Given the resources required to implement, this measure should be targeted to attract and provide benefits for a minimum of three breeding pairs (target areas should be within 5km of a minimum of three breeding pairs). For this reason, this measure is likely to be most relevant to larger road schemes and areas with high Barn Owl densities. Target areas for habitat creation/enhancement should be located between 1-5km from the proposed road where this mitigation is designed to attract adults from nest sites on the same side of the road, but should be a minimum of 4km from confirmed nest sites on the opposite side of the road, to reduce the likelihood of birds regularly crossing the road to exploit the habitat associated with this measure.

Identification of suitable areas for habitat creation/enhancement should be conducted during the Barn Owl survey to inform the EIA and should be informed by the distribution of Barn Owl breeding pairs as confirmed via a comprehensive survey within a 5km radius of the proposed road according to best practice methods as defined by the Barn Owl Surveying Standards for National Road Projects (http://www.tiipublications.ie/library/RE-ENV-07005-01.pdf). The identification of target areas should also be informed by existing habitat features and focus on improvement and restoration of areas of suitable habitat where possible.

A Management Plan should be clearly set out which details the creation or enhancement of habitats and the long-term management requirements. Habitat management should aim to improve foraging conditions for Barn Owls in the selected area/s which could include the creation, extension or improvement of areas of Wild Bird Cover, Wild Flower areas and species-rich rough grassland, and can include enhancing/increasing margins of edge habitats (field margins, river corridors, woodland edge, etc.) on lands managed for agriculture. The use of artificial perches in areas of suitable foraging habitat and artificial nest boxes for Barn Owls should also be incorporated.

Mitigation Measures (step by step approach):

- Identify general area/s suitable for habitat creation and/or enhancement for Barn Owls as part of the EIA, relative to: (i) the proposed major road, (ii) the distribution of Barn Owl nest sites within a 5km radius of the proposed road, and (iii) available habitat and landscape features within a 5km radius of the proposed road
- Target areas should be located within 5km of three or more confirmed Barn Owl breeding pairs
- Target area/s should be located between 1 to 5km from the proposed road in relation to breeding pairs (≥3) on the same side of the road, and a minimum of 4km from the nearest pair on the opposite side of the proposed road
- The total area targeted for creation and/or improvement of habitat should be a minimum of 1.5ha
- A detailed Management Plan should set out the creation/improvement measures, on-going management requirements (in line with management of the road network) and roles and responsibilities to ensure effective and appropriate long-term management
- Habitat management measures should aim to improve foraging conditions for Barn Owls and can include the creation, extension or improvement of areas of Wild Bird cover, Wild Flower areas and species-rich rough grassland habitat, and enhancing/increasing margins of edge habitats (field margins, river corridors, etc.)
- Perches (minimum of five) should be established within areas of suitable foraging habitat and artificial nest boxes (2-4) should be installed in proximity



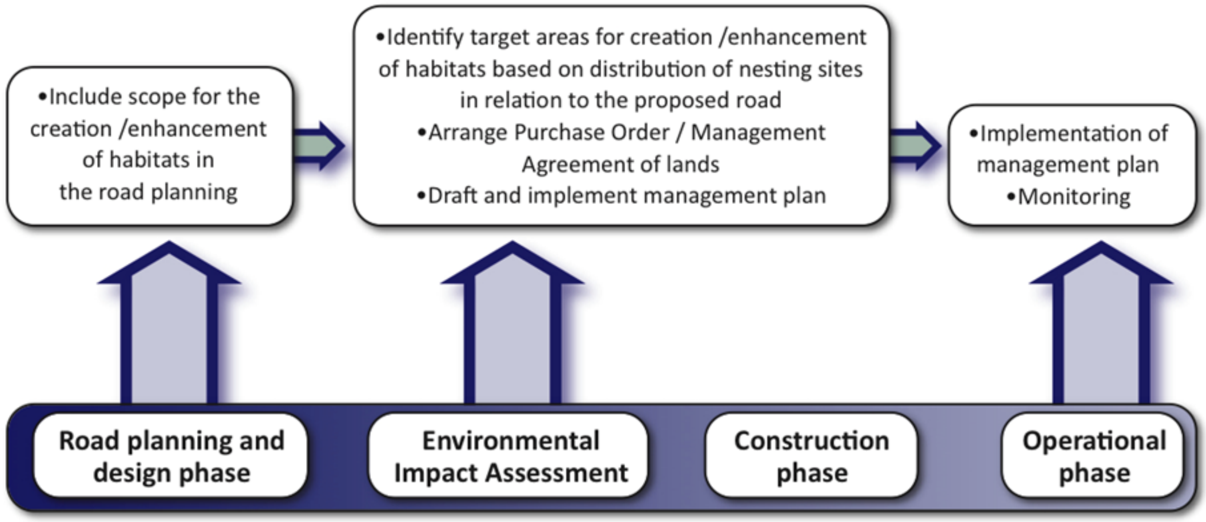
A map showing the potential target area for habitat creation/enhancement measures in relation to a proposed road and the distribution of Barn Owl breeding sites located on both sides of the proposed development.

Advantages:	Disadvantages:
• Delivers benefits to local Barn Owl population • Delivers wider biodiversity benefits • Low potential for negative impacts • Targets protection of the breeding adult population	• Difficult to implement • Requires long-term management plan • Unlikely to reduce numbers of juveniles killed on major roads

Monitoring requirements:

- Assess the use and importance of suitable foraging areas for adult Barn Owls including assessment of movement patterns and home range size in relation to these areas and the major road via GPS tracking (ideally before and after the habitat creation/management)
- Monitor the use of the suitable foraging areas and artificial perches via deployment of infra-red motion sensor cameras fixed on perches
- Assess the use and value of suitable foraging areas for small mammal populations (via small mammal survey)
- Determine Barn Owl road mortality patterns on the major road via a road casualty survey over a period of two years (from the opening of the road) to identify the age profile of individuals and whether the local adult population are affected (via ringing and nest site monitoring studies)
- Monitor the occupancy and breeding performance of the local population before and after the implementation of mitigation and the construction of the road to identify the benefits or otherwise of these measures

Schedule for implementation of mitigation:



Mitigation Strategy 6:

Delivering conservation benefits for Barn Owls to off-set the effects of mortality on roads

Objective:

Deliver conservation benefits for Barn Owl populations to off-set the negative effects of roads

Mitigation required: No – Optional	**Likely effectiveness:** High	**Priority:** High

Implementation targeted to: Areas away (>5km) from major roads

Stakeholders: Transport Infrastructure Ireland, Local Authority, National Parks and Wildlife Service and the Department of Agriculture, Food and the Marine

Overview:

Conservation measures in the form of improving habitat conditions for Barn Owl through habitat creation and enhancement can deliver significant benefits for Barn Owl populations, which can increase population size and breeding output. Such measures which increase the stability of the population could help to off-set the negative effects of the mortality of individuals on roads. These conservation measures could be implemented by: 1) targeting of specific sites to improve habitat conditions for Barn Owls (delivered by Transport Infrastructure Ireland) or, 2) delivering species-specific conservation measures on a wide scale via an agri-environment scheme (delivered by Department of Agriculture, Food and the Marine). The latter model has been successfully implemented and has provided benefits for Barn Owl populations in Great Britain and other European countries. Creating/improving habitat conditions for Barn Owls would also deliver wider biodiversity benefits. Habitat management should aim to improve foraging conditions for Barn Owls, which could include the creation, extension or improvement of areas of Wild Bird Cover, Wild Flower areas and species-rich rough grassland, and can include enhancing/increasing margins of edge habitats (field margins, river corridors, woodland edge, etc.) on lands managed for agriculture. Limiting the use of pesticides (and specifically rodenticides), and the use of artificial perches in areas of suitable foraging habitat and artificial nest boxes for Barn Owls should also be incorporated.

This measure could be implemented in areas away from major roads (>5km) on a national scale and targeted to areas/regions which would have the most benefit and where Barn Owl population densities are highest.

This mitigation strategy requires further development and detail as well as engagement with relevant stakeholders and we propose a review of existing conservation plans for Barn Owl and assessment of the most appropriate mechanisms through which effective conservation measures could be implemented, to include detail on the target areas, specific habitat management methods and conservation objectives.

Advantages:

- Delivers benefits to Barn Owl populations
- Potential to deliver benefits on a large scale
- Delivers wider biodiversity benefits
- Low potential for negative impacts

Disadvantages:

- Requires further work to detail conservation measures
- Will not reduce mortality on roads

8. Research Recommendations

This research provides new insight on Barn Owl ecology and behaviour in relation to major roads which facilitates an increased understanding of the direction and requirement for mitigation strategies to reduce negative impacts of major roads on Barn Owl populations in Ireland. The research findings also highlight existing gaps in our knowledge of the interactions and impacts of major roads on Barn Owls. We have identified the specific areas which require further attention to better understand the relationship between Barn Owls and major roads and the most effective mitigation and management solutions to deliver conservation benefits. We recommend building on this project through further research to address the following recommendations:

Research Recommendation 1:

Determine the landscape scale influences on the occurrence of Barn Owl mortality on major roads

Overview:

To assess landscape scale influences on the occurrence of Barn Owl mortality on the M8 Motorway and the Tralee Bypass, we collated data on Barn Owl movement patterns, space and landscape use in the regions surrounding both routes to identify areas of overlap between mortality locations on the roads and areas of high probability of use for Barn Owls. We reviewed fine scale resolution data on Barn Owl movements collated via GPS dataloggers fitted to 11 adult breeding Barn Owls within 70km of the M8 Motorway and the Tralee Bypass. The data illustrated that the movement of Barn Owls is strongly influenced by elevation. Using the programme Maxent (Phillips *et al.* 2019), we created a map of probability of use of Barn Owls for the regions surrounding the M8 Motorway and the Tralee Bypass. The Maxent software is based on the maximum-entropy approach for modelling species niches and distributions. It generates a probability of distribution or movements from a set of environmental (in this case Digital Elevation Model) and georeferenced occurrence (GPS fixes), and in this way allows the identification of areas or sections of road where Barn Owl encounter rates are likely to be highest. The development of probability maps is a valuable tool for identifying problematic or high-risk areas for vehicle collisions which can be used alongside finer scale information on the specific route and adjacent habitat features.

We primarily used elevation data to generate the probability maps and recognise that use of elevated areas for Barn Owls may vary on a geographic basis. A more detailed assessment of Barn Owl movements and space use over a wider geographic area would therefore inform the development of probability maps for Barn Owl which would be applicable on a national scale. In addition, inclusion of other potentially important variables which influence Barn Owl movements and distribution, to include habitat suitability criteria, data on juvenile dispersal patterns and the geographic distribution of nesting pairs would help to refine and increase the confidence in the probability maps. We also proposed testing the effectiveness of the probability maps under different scenarios to inform their suitability and future use.

Research objectives:

- Increase the sample and geographic spread of high resolution data on Barn Owl movements and space use via GPS tracking to inform the development of large scale probability of use maps for Barn Owls in the Republic of Ireland
- Refine the probability of use maps through incorporating habitat suitability criteria, data on juvenile dispersal and distribution of nesting pairs

Research Recommendation 2:

Determine Barn Owl mortality rates and the factors which influence risk of collision on major roads on a national scale

Overview:

Our study focused on identifying Barn Owl mortality patterns, rates and the factors which influence risk of collision on two selected major roads, the Tralee Bypass and the M8 Motorway.

Our findings demonstrate that Barn Owl mortality patterns vary between roads, even those in relatively close proximity, and we also showed that Barn Owls in Republic of Ireland respond differently to major roads as reported in other parts of their range. Our methods of data collection and analysis provides a template which can be applied to other road systems to assess the spatial patterns and rates of mortality and this would be beneficial in faciliting comparison to the current findings and to determine the nature and extent of vehicle collisions on other routes and nationally. This component would primarily rely on collation of existing data with additional road casualty survey work where required and where there are gaps in current data collection. We recommend that available data is collated, interrogated and analysed according to the methods defined in this study, to identify Barn Owl mortality patterns on other motorways in Ireland.

Research objectives:

- Collate and analyse data on Barn Owl mortality on motorways to identify mortality patterns, rates and the factors which influence collision on a national scale, and to allow comparison with the current findings for the M8 Motorway and Tralee Bypass

Research Recommendation 3:

Assess whether Barn Owls are attracted to artificial road lighting as a foraging aid

Overview:

We recorded significantly more Barn Owl road casualties within 150m of road lighting than expected on the M8 Motorway. Twelve Barn Owls (15%) were recovered within 150m of road lighting on the M8 Motorway, which was three times the number expected (5%) (the mean distance of random points to road lighting was over 8.7km). As road lighting on the M8 Motorway is largely restricted to junctions, it is possible there is a correlation between road lighting and junctions on the influence of Barn Owl mortality locations. There is limited literature available on Barn Owls use or avoidance of artificial lights for foraging; however, in the context of a major road where the noise levels from traffic can be high, the ability to visually detect prey at night may be beneficial and warrants further attention. It would be valuable to identify whether Barn Owls are attracted to artificial light sources on major roads. This would help inform mitigation to deter birds from these areas and reduce risk of collision would be relatively straightforward and cost and time effective.

Research objectives:

- Identify suitable Barn Owl nest sites in proximity to road lighting on major roads to assess use and movement patterns of adult breeding birds via GPS tracking

Research Recommendation 4:

Assess Barn Owl habitat selection in relation to roadside verges

Overview:

This study confirmed that Barn Owls were actively attracted to major roads and the areas in the immediate vicinity. Barn Owls spent significantly more time than expected in close proximity (within 20m) to major roads. The behaviour of birds indicates that they were attracted to these areas to forage, as they spent significantly more time in hunting flight than expected based on their behaviour elsewhere in their home range. This has significant implications for management of roadside verges and proposed mitigation for Barn Owls, and maintaining or enhancing the integrity of verge habitats while reducing risk of collision should be prioritised (as detailed in the mitigation strategies in Section 8). Based on the data generated through tracking the movements of individual birds, it was not possible to assess habitat selection of verges or the specific features of the verge which influenced Barn Owl foraging decisions and selection. This data would be beneficial to inform mitigation strategies and verge management to maximise conservation benefits. Increasing the sample size of data on the movement and foraging patterns of individual birds in proximity to major roads would facilitate an effective assessment of Barn Owl foraging selection in relation to verge habitats.

Research objectives:

- Assess the movements and foraging ecology of adult Barn Owls in proximity to major roads via GPS tracking to determine use and foraging selection of verge habitats

Research Recommendation 5:

Determine appropriate verge management and conditions to benefit small mammal populations

Overview:

This study confirms that motorway verge habitats provide an important refuge for small mammal populations in intensive agricultural landscapes in Ireland. Motorway verges were shown to support a similar abundance and greater diversity of small mammal species than hedgerow networks in surrounding pastoral farmland in the Republic of Ireland. These findings demonstrate the potential for road infrastructures to contribute to biodiversity in heavily modified landscapes. The small mammal fauna and species composition varies throughout the country however, and our findings and not applicable to large areas of the country with different small mammal species assemblages. A better understanding of importance of road side verges for small mammal populations in relation to areas where the two introduced species, the Greater White-toothed Shrew and Bank Vole, are not present would be beneficial. In addition an enhanced understanding of the conditions and verge management which benefit small mammal populations would help ensure these habitats are maintained or enhanced to improve small mammal abundance, which would have wider biodiversity benefits and help to maximise the biodiversity potential of roadside verges.

Research objectives:

- Determine the importance of roadside verges for small mammal populations within the different small mammal species distribution ranges in the Republic of Ireland
- Assess the habitat selection of small mammals in roadside verges to inform verge management

Research Recommendation 6:

Determine the population level effects of road mortality on Barn Owls in Ireland

Overview:

This study provides insight on the extent of Barn Owl mortality on major roads in Ireland for the first time, in addition to the age profile of individuals affected. In addition to data on Barn Owl population size, productivity and survival, this would facilitate the development of a model to determine the overall effect of different levels of mortality as informed by our estimates (and extrapolated to the major road network nationally) to assess the impacts of road mortality on Barn Owl population growth, and how this is likely to vary in relation to an increasing road network.

Research objectives:

- Develop a population model to assess the impact of road mortality on major roads (based on current estimates) on the Barn Owl population status and trajectory and how this will be affected by increases to the major road network

Research Recommendation 7:

Assess the potential to improve the value and foraging opportunities of the National Road Network for Barn Owls

Overview:

Our data shows that risk of collision for Barn Owls is significantly less on National Roads compared to major road networks (motorways and bypasses). The network of National Roads is substantially more extensive than major roads. The verges of National Roads can provide foraging opportunities for Barn Owls as shown by the hunting behaviour and selection of birds fitted with GPS dataloggers. If it was possible to improve verge habitats of National Roads for Barn Owls in selected areas (based on Barn Owl nesting distribution and existing conditions), this could provide benefits to local populations and help to off-set road mortality on major road systems.

Research objectives:

- Assess the feasability of improving the value of verge habitats of National Roads for Barn Owls to off-set the negative effects of mortality on major road systems

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Appendix A:

BARN OWL ECOLOGY AND SURVEY METHODS

Here we provide information on Barn Owl ecology and behaviour, which is necessary to inform the design, planning and implementation of surveys for the species as required to inform National Road Projects. This information is intended to supplement the survey requirements as detailed in the TII Standards 'Barn Owl Survey and Mitigation Standards for National Road Projects'. A video which demonstrates best practice survey methods for Barn Owls, is available here: https://www.youtube.com/watch?v=yYzEzW7PFdE&t=449s

Annual Cycle

Barn Owls have one of the longest breeding seasons of any terrestrial bird in Ireland. Courtship begins as early as January, when the male and female roost together at the chosen nest site. The male is typically vocal at this time of year, emitting loud drawn-out screeches after sunset. As the season progresses, the pair will regularly engage in courtship flights, soaring, or high-speed vocal pursuits around the nest site at dusk (Shawyer 1998).

In the days prior to egg-laying, the female will become less active and cease to hunt. She will remain in the nest for the next two months, leaving only for brief periods and the male will deliver prey to the nest throughout the night. Laying usually occurs in April or early May, but the timing can vary depending on several factors including weather conditions and local prey availability.

During the pre-laying and incubation phase the female will regularly 'snore' from the nest at night, which is a call similar to that made by the young later in the season. Only the female incubates the eggs, and once laying begins the male will typically leave the nest and roost elsewhere during the day. Usually four to six eggs are laid, two or three days apart. The eggs hatch after 30 to 31 days (Shawyer 1998) and the female will stay in the nest and brood the young until they are two to three weeks old.

At approximately three weeks old, once the young can maintain their own body temperature and swallow whole prey. The adults roost away from the nest during the day and return at night to feed the young, with up to 25 prey deliveries per night recorded in Barn Owl nests in Ireland. The owlets will 'snore' from the nest throughout the night. Once they reach between 55 and 60 days old, the feathers are nearly fully grown, and they will make their first flight.

In the late summer and autumn, the young start to disperse from the nesting area. Some birds may leave the nesting area soon after fledging, while others can remain into November or December. Average dispersal distance in Ireland is 32km, with some birds recorded as adults breeding as little as 11km from their natal site, while others disperse further, with a movement of 350km recorded (see Section 1.3.2). The young will establish in their own home range and can breed in the following nesting season, which is their second calendar year.

The adults may occupy the nest site throughout the winter or may use alternative roost sites within the home range, typically returning to the nest site early in the following year. Individual nest sites may be occupied over consecutive years by successive generations of Barn Owls, with records of traditional nest sites in Ireland remaining active on a regular basis over more than fifty years. However, pairs can use an alternative nest within the same site or relocate to another site within their home range, particularly, if the nest previously used becomes unsuitable.

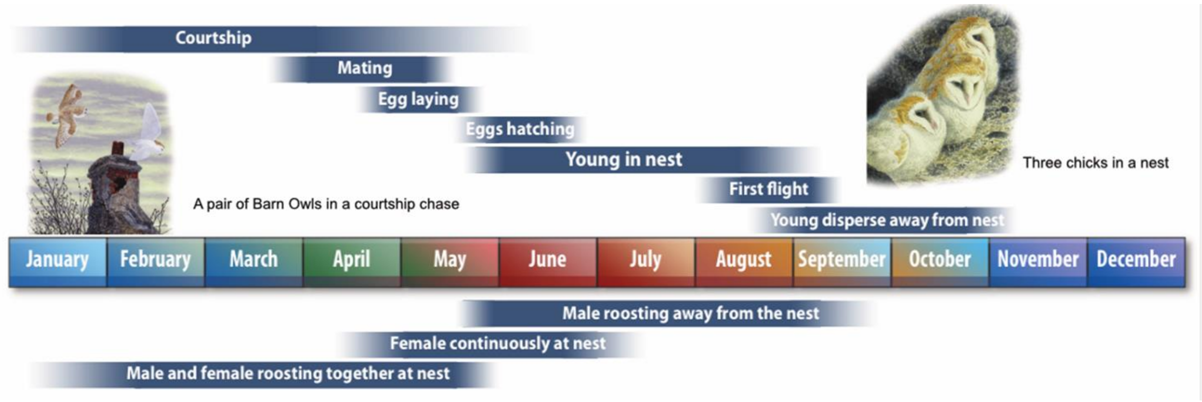

Figure A1 The Barn Owls annual cycle in Ireland

Habitat use and Home Range

Barn Owls are primarily associated with open countryside and occupy a range of landscapes provided there are suitable nesting sites and sufficient prey-rich, open foraging habitat. The majority of recorded breeding pairs in Ireland are located below 150m asl (above sea level), however, successful nesting has been confirmed above 300m asl, and areas of suitable habitat up to 350m asl should therefore be considered potentially suitable.

Optimal foraging habitat for Barn Owls includes rough, species rich and low-intensity or unmanaged grassland habitats suitable for small mammals, which include grass margins and edge habitats along field boundaries, hedgerows, ditches, road-side verges, and woodland edge, as well as open areas of rank vegetation, wetlands and arable areas (Figure A3). Barn Owls can occupy intensively managed landscapes provided there are suitable foraging habitats in the form of rough grassland and field margins. Although they do not typically breed within extensive built-up areas, Barn Owls can occur in urban and suburban areas provided their nesting and foraging requirements are met, breeding pairs have been confirmed in urban parks in towns and cities and in occupied dwellings and abandoned buildings in villages.

The home range size of breeding Barn Owls in Ireland varies according to habitat quality and prey availability and has been estimated to be on average 3,059 hectares, ranging from 991 to over 9,259 hectares, with the majority of foraging concentrated within 4 to 5km of the nest site (see Section 5.3.1). Birds can travel greater distances with movements up to 9km recorded during the nesting season (see Figure A2). They are not a strongly territorial species and only actively defend the immediate area of the nest site (Shawyer 1998), so home ranges can overlap, with nesting pairs recorded less than 200m apart in Ireland.

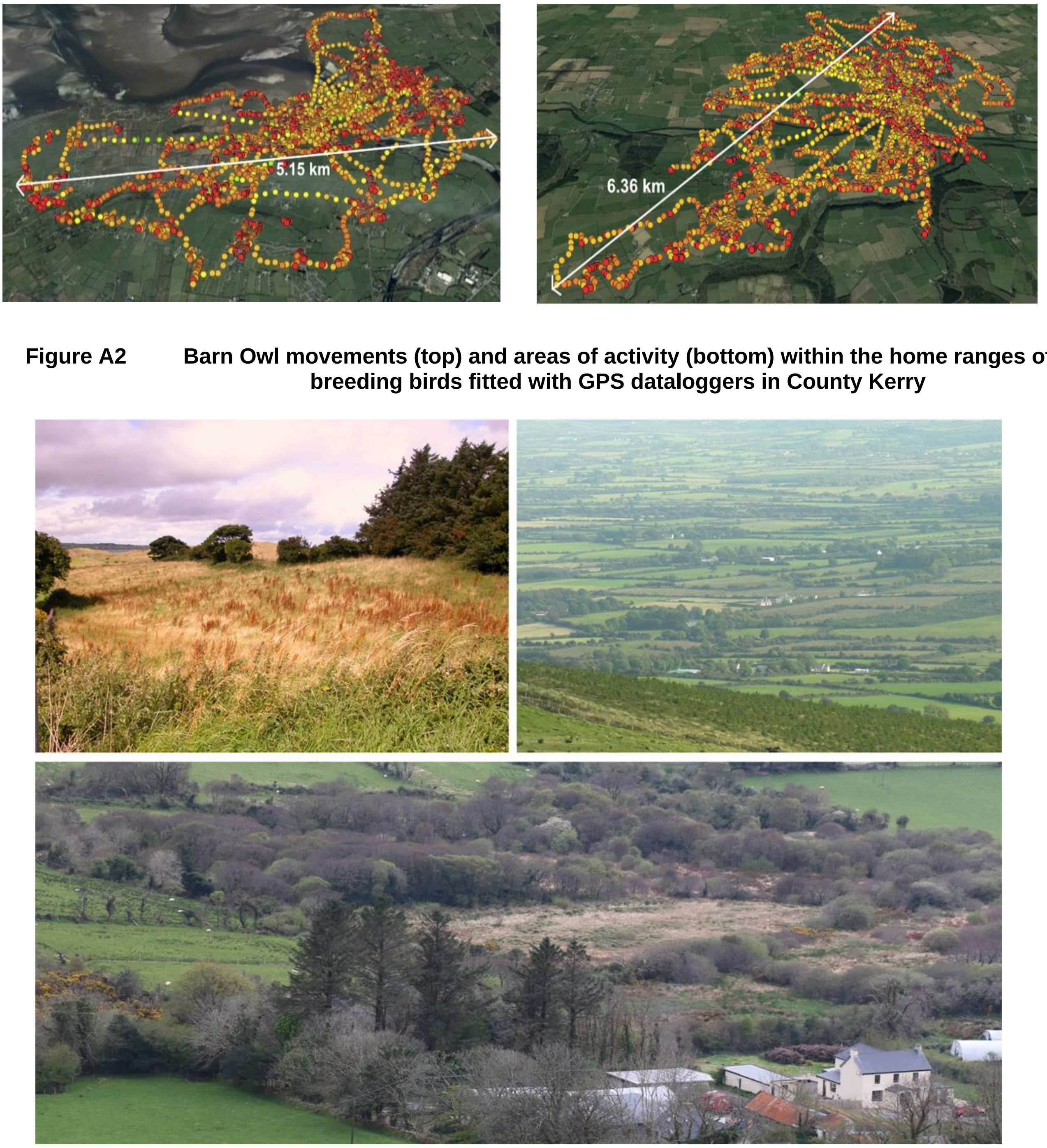

Figure A2 Barn Owl movements (top) and areas of activity (bottom) within the home ranges of breeding birds fitted with GPS dataloggers in County Kerry

Figure A3 Foraging habitats and typical landscapes used by Barn Owls in Ireland, including rough grassland (top left), field margins of cereal fields and hedgerows (bottom left), mixed lowland agricultural landscapes with hedgerows and young forest plantation (top right and centre) and farmed land with woodland, wetland margins and low intensity grassland (bottom right).

Nest Sites

Barn Owls are a cavity nesting species, and require a dry, dark and secluded space with a flat surface greater than 30cm x 30cm for nesting (Taylor 1994). They will use a range of sites which provide suitable cavities including buildings, trees, bale stacks, fissures in rocks and artificial nest boxes. The nest entrance or access to the nest site can vary in size from large openings to as small as approximately 7cm x 7cm in diameter (Barn Owl Trust, 2012). They do not construct a nest or bring in nesting material but will make a shallow scrape where the eggs are laid (Taylor 1994).

Of 338 Barn Owl sites assessed over a ten-year period between 2006 to 2016 (Figure A4), the majority were in man-made stone structures (n = 303), with trees (n = 32) and quarries (n = 3) also used by Barn Owls. The most common site types were farmhouses (n = 92), ruined mansions (n = 73) and castles (n = 69).

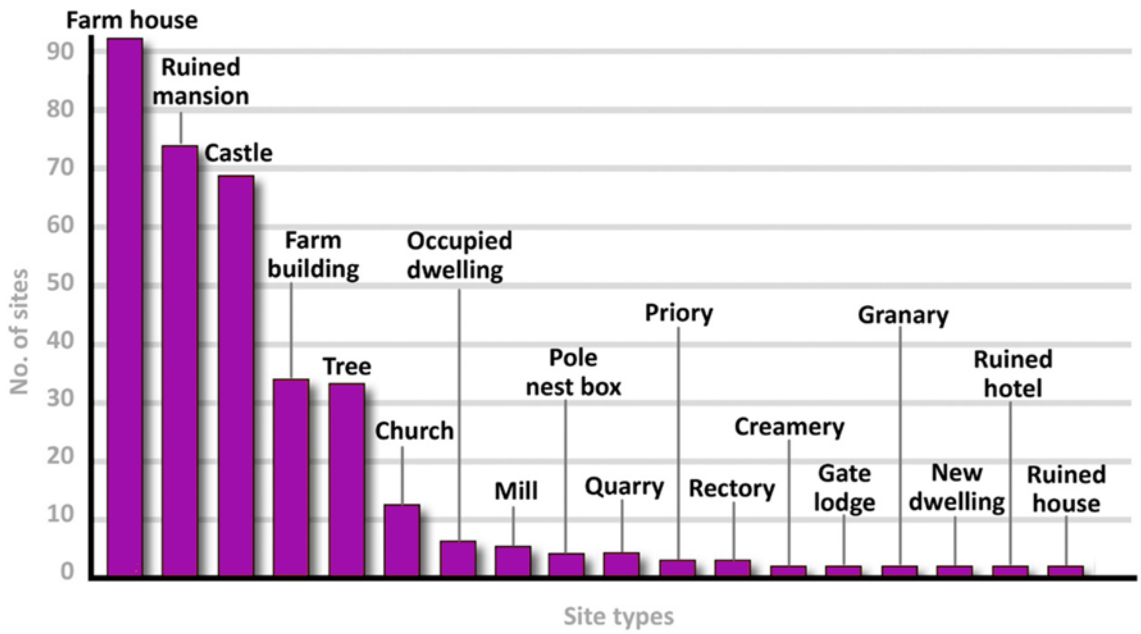

Figure A4 The variation in Barn Owl sites types recorded in Ireland between 2006 to 2016 (n = 338)

Buildings

Barn Owls use a range of building types for nesting (Figure A5). Within buildings nest sites are most frequently located within chimney structures, roof spaces, wall cavities and chutes. The gaps between stacked bales of hay or straw stored in farm buildings can also provide a suitable nesting site.

Although Barn Owls tend not to use buildings that are frequently used by people, provided the nest site is free from disturbance Barn Owls can tolerate human activity close to the nest. Nest sites have been recorded within the roof spaces and blocked chimneys of occupied dwellings, and houses which are being constructed. Breeding pairs have been recorded in active farmyards, nesting in between stacked bales or in nest boxes in modern farm buildings. Artificial nest boxes are now the most common recorded nesting site in Ireland and have been provided in a diverse range of built sites.

Several other species may occupy the same buildings as breeding Barn Owls. Jackdaws Corvus monedula nest within the majority of ruined buildings used by Barn Owls, and can nest in close proximity, with both species recorded nesting within the same chimney spaces and nest box. Over half of the known Barn Owl sites are also used by Kestrels Falco tinnunculus, for nesting or roosting, and breeding Peregrine Falcon Falco peregrinus, Raven Corvus corax, Chough Pyrrhocorax pyrrhocorax, Swift Apus apus and many other breeding birds have also been recorded within the same buildings used by Barn Owls, which are often used by bat species.

Figure A5 Buildings used by breeding Barn Owls in Ireland, including a nest within the roof space of an unfinished modern house (top left), a derelict two storey farmhouse (top centre), chimney system of a ruined mansion (top right), ruined mansion (centre left), ruined priory (centre), castle (centre right), barn in an active farmyard where the birds nested between bales (bottom left), and derelict cottage (bottom right).

Trees

Barn Owls select trees with a cavity of sufficient size for nesting, which are usually mature trees with a trunk diameter greater than 50cm (Figure A6). Barn Owl nesting sites have been confirmed in Beech Fagus sylvatica, Oak (Quercus species), Ash Fraxinus excelsior, Sycamore Acer pseudoplatanus, Horse Chestnut Aesculus hippocastanum, Lime Tilia cordata, and Monterey Pine Pinus radiata in Ireland. Typically, isolated trees or large trees within a tree line, hedgerow or at the edge of woodland facing out onto open habitat are selected, with trees in the interior of woodland generally avoided. Other species, particularly Jackdaw, may be found nesting within the same tree as Barn Owls.

Figure A6 **Trees used by breeding Barn Owls, including a Beech showing the nest entrance (top left), Ash with several nest entrances (top centre), Beech which was completely hollow after being struck by lightning (top right), Lime trees which were both used for nesting and roosting (bottom left) and a Monterey Pine at the edge of a forest track (bottom right).**

Quarries and rock faces

Quarries and rock faces with suitable cavities can be used by breeding Barn Owls (Figure A7). A range of other species including Peregrine, Kestrel, Raven and Jackdaw can also occupy quarries and rock faces which may be used by Barn Owl.

Figure A7 Barn Owl nests in quarries, showing entrances to nest cavities and white-wash (top and bottom left) and a nest entrance showing pellets and moulted feathers (bottom right).

Nest boxes

Artificial nest boxes designed specifically for Barn Owls have been installed in ruined buildings, farm buildings and fitted to occupied dwellings, on trees and also mounted on poles (Figure A8). In recent years nest boxes have become the most common nest site type used by Barn Owls with over 50 nesting pairs in nest boxes and likely to be more which are not recorded.

Figure A8 Barn Owl nest boxes, including an outdoor A-frame nest box on a tree (top left), nest box installed in the roof space of a ruined farmhouse (top centre), pole mounted nest box (top right), nest box situated on a chimney of a derelict cottage (bottom left) and nest box placed in the interior of a derelict two storey farmhouse (bottom right).

Survey Techniques

Sign Searching

Sign searching is an effective method for establishing presence of Barn Owls (Barn Owl Trust 2012). At many sites, the presence or absence of Barn Owls can be determined by a visual inspection during the day to search for signs of occupancy which include pellets, white-wash and moulted feathers. Confirmation of signs indicates that a site has been used by Barn Owls, however it is necessary to conduct a nocturnal watch to establish current occupancy and breeding status to inform road planning. Signs should be collected in a sealable bag and labelled with the site location and date, so that species identification can be validated if required, and this will also serve to ascertain recent activity at the site based on presence or absence of fresh signs on future visits. At certain sites, sign searching may not be an effective means of determining occupancy, as signs may not be obvious or accessible, for example sites which are inaccessible (a building which is unsafe or not possible to enter) or where the nest site is concealed (within a blocked chimney, roof space, or tree cavity which is not possible to access and where signs remain in the nest space).

At sites where sign searching is deemed to be ineffective in determining Barn Owl presence a nocturnal survey should be carried out to confirm occupancy.

Pellets

Barn Owls usually swallow their prey whole and regurgitate the undigested remains in the form of a pellet. Barn Owl pellets are large (approx. 4 cm x 2.5cm), dark in colour and contain large bones and skulls of small mammals and other prey items. Two pellets are generally cast over a 24-hour period (Shawyer 1998). At sites which have been in use for some time, large build-up of pellets may be obvious. However, depending on the characteristics of the site, pellets may not be evident, for example in active sites where pellets do not fall from the nest to the ground (e.g., if birds use a chimney which is blocked, a tree cavity or a roof space to which there is no access etc.).

Barn Owl pellets are similar to those of Long-eared Owl Asio otus. However, the two can generally be differentiated on the location where they are found. Long-eared Owls typically nest in old corvid nests in trees and rarely use buildings. Barn Owls typically only nest in trees which have hollow cavities of sufficient size and depth, and therefore close investigation of the tree itself will usually provide a reliable indication of the species present. Kestrels routinely use buildings for nesting and roosting, and it is common to find both Kestrel and Barn Owl pellets (Figure A9) in the same building.

Figure A9 Barn Owl pellets (left) and Kestrel pellets (right). With practice Kestrel pellets are easily distinguished from those of Barn Owl by their smaller size (2.5 x 1.5 cm), colouration and contents, as Kestrel pellets regularly contain invertebrate remains which are unusual in Barn Owl pellets.

White-wash

At most sites where Barn Owl are breeding, white-wash will be evident, either directly associated with the nest or roost site, or under regular perches within or close to the site. Barn Owls are habitual in their behaviour and regularly use the same perches, under which there is often a build-up of white-wash.

Barn Owl white-wash can be distinguished from most other species as it is large, often almost pure white and regularly occurs in long vertical streaks (similar to lines of “white paint”) (Figure A10). The white-wash of Kestrel, Peregrine and Raven which can frequently use the same sites, can be confused with Barn Owl, and further searching for additional signs (pellets or moulted feathers) and/or a nocturnal watch should be carried to confirm the species present as appropriate.

In situations where Barn Owls nest within chimneys, build-up of white-wash can often be observed in the fireplace or at the top of the chimney. Evidence of white-wash can be particularly useful at sites where pellets or moulted feathers are not obvious, such as derelict cottages where birds nest in the chimney but do not access the interior of the building. In such situations, birds will typically use perches close to the building, often inside adjacent open buildings. In these circumstances white-wash may be the only obvious signs to indicate Barn Owl occupancy.

Figure A10 Examples of Barn Owl 'whitewash' on a fireplace used to access a chimney nest (top left), on vegetation under a nest entrance (top centre), at the entrance to a cavity nest in a quarry (top right), and under regular perches in buildings (bottom).

Moulted feathers

Moulted feathers can provide a reliable indication of Barn Owl presence (Figure A11). White 'fluffy down' can gather around the nest entrance, and the presence of flies around the nest entrance may also provide a useful indications of nest location, as can prey remains or dropped prey items.

Figure A11 Barn Owl moulted feathers, including flight feathers (top left and bottom right), and a body feather (bottom left) which are distinctive, and fluffy down at the entrance to a chimney nest (top right), also the remains of a prey item dropped directly beneath the nest within a building (bottom centre).

Nocturnal Surveys

Nocturnal surveys involve observing a potentially suitable or active Barn Owl site from a selected vantage point during the period when the birds are active in order to establish occupancy and breeding status based on observations, vocalisations and/or behaviour of birds associated with the site. Nocturnal surveys should be conducted during the breeding period April to mid-July and should be carried out from a discrete vantage point to avoid disturbance to breeding birds. The position of the vantage point should be informed by the specific characteristics of the site to ensure a good view of the site, and/or area of suspected activity, including flight paths to and from the site, and preferably so that the site/area of interest is against a light background or clear sky to aid observations. Typically, 20 – 50m from the site is an appropriate distance to conduct a nocturnal survey, however, this may vary depending on site specific conditions including the scale of the site and access, (see Figure A12). If the nest site location is known or suspected based on existing evidence (presence of signs, information from previous nocturnal surveys etc.), the watch may focus specifically on this area. It may be necessary to conduct the watch from inside buildings in certain situations. Regardless of the position, the surveyor should remain discrete at all times, including when accessing and departing the vantage point, and position themselves against a dark background or cover where possible, wearing dark or camouflage clothing. If one or both adults alarm call due to the presence of a surveyor then they should finish the watch and make an obvious departure from the site, as alarm calling can be taken as evidence of breeding. For large sites or those with many potential nesting areas, two or more surveyors or repeated visits may be required to effectively establish occupancy and breeding status.

Nocturnal surveys should be conducted in calm and dry conditions for a minimum of two hours, commencing 30 minutes prior to sunset. In good conditions, where visibility is adequate to detect Barn Owls entering or exiting a site it is possible to conduct watches throughout the night, until sunrise.

When conducting a nocturnal survey, it is important to listen for and note all vocalisations which often can be the best means of establishing occupancy and information on breeding status. If it is not possible to hear vocalisations from the vantage point, then the site should be quietly approached on completion of the nocturnal watch to listen for calls which may indicate occupancy and breeding. The surveyor should remain stationary for a minimum of 15 minutes or until calls are confirmed.

Surveys should be undertaken until the status of the specific site is effectively determined. Multiple watches may be necessary to effectively establish occupancy and breeding status. The vantage point position may be adjusted on subsequent watches based on information gathered and areas of activity identified for the site. If evidence of breeding is confirmed, the site should be recorded as a ‘breeding site’ and there is no requirement for further visits unless necessary to obtain information on breeding success. If nocturnal watches during the breeding season produce no evidence of Barn Owls then the site can be considered as ‘unoccupied’.

Figure A12 Images of sites which are the focus of nocturnal watches taken from the vantage point, for the stone shed (left) the watch is focusing on birds approaching and entering or exiting via the roof space. In the case of the derelict farmhouse (right) the watch is focusing on the chimney. The vantage points are positioned to afford good views of the potential area of activity, against a clear sky and at sufficient distance to not cause disturbance.

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