FACTORS INFLUENCING DIET, REPRODUCTIVE SUCCESS AND ROAD TRAFFIC MORTALITY IN THE BARN OWL (*TYTO ALBA*)

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Submitted for the degree of Master of Science

September 2018

Declaration

I declare that the work in this thesis is my own work, except where acknowledged, and has not been submitted elsewhere for the award of degree of Master of Science by Research.

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September 2018

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Abstract

In the UK, a decline in the Barn Owl population has been attributed to increased agricultural intensity and urbanization. Shifts in farming practices have resulted in a reduction of habitat diversity and homogenization of the UK's landscape, causing a reduction in the number and diversity of prey animals for predatory species. One species that has been affected by these ecological shifts is the Barn Owl. The expansion of road networks, to accommodate more vehicles on the road, has led to habitat fragmentation and ecological traps. The Barn Owl has shifted its feeding patterns due to the pressure of ecological traps caused by the expansion of road networks to accommodate more vehicles and are now the most frequent bird species encountered on road casualty surveys, with over half of known Barn Owl deaths being a result of wildlife-vehicle collisions. The objectives of this study were to investigate factors affecting diet and reproductive success in the Barn Owl, as well as to identify characteristics of Barn Owl road casualty hotspots.

The study was conducted in Anglesey, north Wales. Diet was investigated through the morphological analysis of owl pellets; 377 pellets were collected from 26 nest/roost box locations during the Barn Owl breeding season and winter roosting season. Reproductive success was analyzed using data provided by the British Trust for Ornithology (BTO), and nest/roost box locations allowed habitat analysis to be performed using Arcmap GIS. Barn Owl road mortality hotspots were investigated using data provided from the North and Mid Trunk Road Agency in correspondence to Arcmap GIS and Google Earth, which allowed for habitat analysis. The date that the road mortality was reported to the North

and Mid Trunk Road Agency was used for the seasonal analysis. Data provided by the BTO allowed the effects of population in relation to road casualties to be studied, using reproductive success as a proxy for population success.

The results of the study found, 12 species of vertebrates form regurgitated Barn Owl pellets, with the three most abundant being the Field Vole (60.52%), Common Shrew (16.31%) and Wood Mouse (8.65%). The results of the study found that the mean field vole weight per pellet was higher outside the Barn Owl breeding season (64.65g) than during it (53.53g). The mean Wood Mouse weight per pellet was lower outside the breeding season (4.06g) when compared to inside (7.16g). The home range of the Barn Owl is typically within the 1km-4km radius around the nest site, which is compromised of a variety of habitats depending on location. The Barn Owl home range habitat composition on Anglesey varied from 14-99% agriculturally improved grassland, 0-43% arable horticulture and 0-9% fen marsh swamp. These habitats were found to have a negative association with the number of successful fledglings per nest, which could reflect prey availability and abundance within these habitats, as an owl which can provide more food will be able to raise more young. However, small mammal trapping would be needed to confirm the abundance and availability of prey in these habitats. There were 117 Barn Owl road casualties on the A55 Anglesey recorded by the North Trunk Road Agent between 2001 and 2017, this equates to 0.196 Barn Owls/year/km. The month of April incurred the most deaths (18) and the least August, with only 1 death being reported. No relationship was identified between the time of year and the number of Barn

Owl road casualties. Additionally, no relationship was found between habitat and owl road mortalities. However, a relationship was found between the presence of grass slope verges at the side of the A55 and bi-monthly road mortality. For instance, the number of deaths of barn owls in areas with grass sloping verges were reported as 29 and those without grass slopes recorded as 87.

In conclusion, the results from this study highlights that in areas of intense agriculture, maintaining species rich diverse habitats is important for the success of Barn Owls. The results of this study suggest conservation efforts should be focused on the restoration of varied habitats in order to provide rich biodiversity through ecological management. The conservation management of habitats of different levels - which contain a wider variety of vegetation - should allow predatory birds, such as the barn owl, to exploit habitats at different times of the year depending on food abundance. Additionally, measures have been suggested t prevent the occurrence of wildlife-vehicle collisions such as low flight barriers which would target low flying animals such as the Barn Owl. Many studies have outlined the importance of grass verges as foraging grounds for Barn Owls, (Taylor, 1994 and Bolger *et al.,* 2001), which suggest instead of removing these key foraging grounds and introducing manmade structures, conservation efforts could focus on making these foraging grounds safer. For instance, the introduction of grass lope verges could be used as a wildlife-vehicle collision preventative measure in the future.

Chapter 1. General Introduction

Agricultural intensification

Changes in land use as a result of a growing human population have resulted in some of the major issues facing wildlife conservation. Among these, urbanization and agricultural intensification are probably the factors having the greatest impact across Europe (Firbank *et al*., 2008). An increasing human population also means a greater demand for food, which leads to an increase in agricultural intensification to meet the ever growing demand. Such escalating pressures of modern land use result in the continued loss of habitats and wildlife (Brumm, 2004; Fuller *et al*., 1995; Fahrig & Rytwinski, 2009; Ware *et al.*, 2015). In the late 1800s to early 1900s, the sudden rise in the human population led to an increase in the intensity of land management, which was then accelerated further during WWI and WWII (The Barn Owl Trust, 2018c). During this time government grants encouraged farmers to destroy wildlife rich fields and hedges with the aim of producing as much food as possible for as cheaply as possible, which continued up until the 1980s (The Barn Owl Trust, 2018c). The increased demand for food over the last 70 years has resulted in the move away from mixed farming practices and more towards agricultural intensification. As a result there has been homogenization of land-use within the landscapes and a subsequent reduction in species abundance and diversity (Love *et al*., 2000).

There is now a large body of evidence to suggest that changes in agricultural methods have driven the population reductions in European bird species that have occurred in recent decades (Newton, 2004; Vaisanen *et al*., 2007; Billeter *et al.,* 2008; Stoate *et al*., 2009). For example, since the mid-1970s the Skylark has declined by over 60% as a result of agricultural intensification (Siriwardena *et al*. 1998). Additionally, the decline of the Barn Owl has also been suggested to be largely related to land use change, thus causing habitat loss (Fajardo, 2001), as a result of farming intensification. The barn owl's earliest population numbers were estimated at 12,000 breeding pairs during 1932 in England and Wales, suggesting a substantial decline over the previous 30-40 years (Blaker, 1933), which continued through 1950s and 1960s (Prestt, 1965). The first reliable UK population estimate was 4,000 breeding pairs from a survey conducted between 1995 and 1997 (Toms *et al*., 2001). The British Trust for Ornithology (BTO) Breeding Bird Survey (BBS) (Figure 1.1), found a strong increase in population numbers since 1995 which peaked around 2009, likely a result of widespread nest box schemes. However, population numbers then began to decline again; the Barn Owl population experienced a difficult year in 2013 with an overall drop in nesting occupancy of 70% (BTO Bird Trends, 2018a).

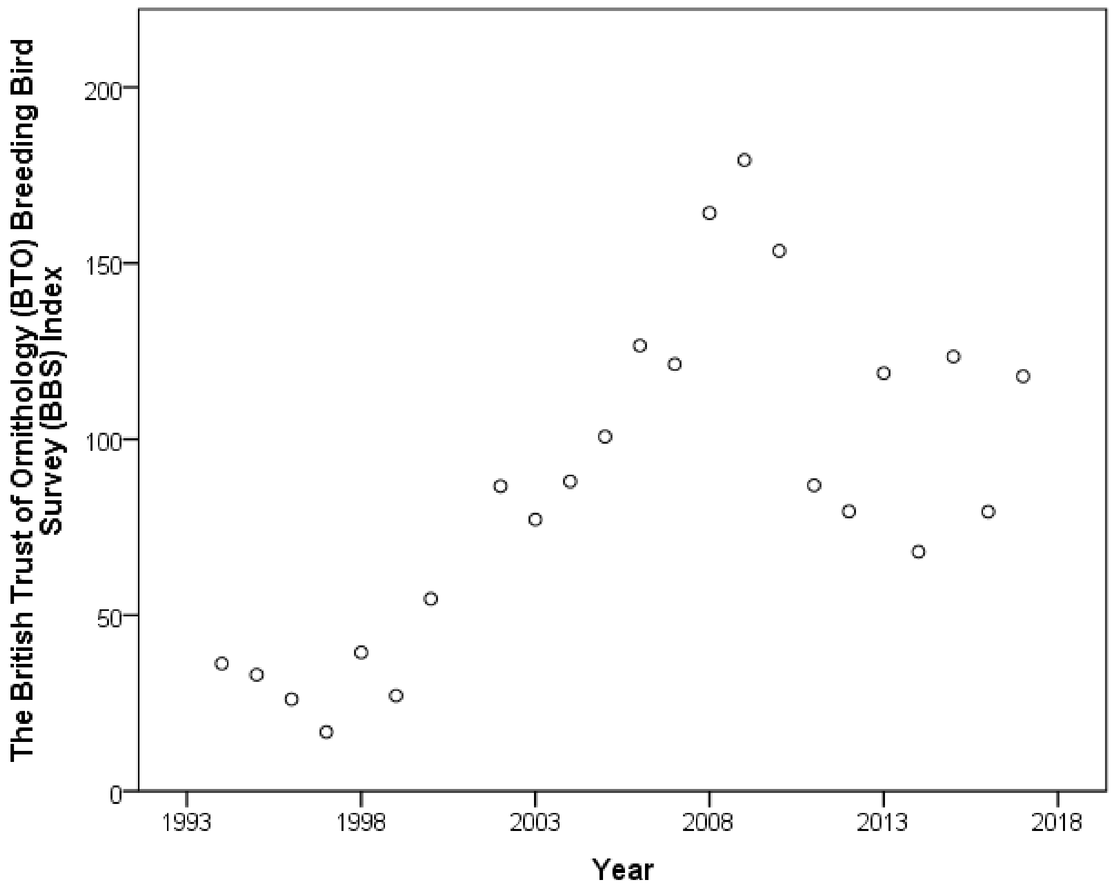


Figure 1.1 The results of the British Trust for Ornithology (BTO) Breeding Bird Survey (BBS) from 1994-2017. Data taken from the BTO Barn Owl bird trend webpage.

Barn Owl population change is known to be influenced by multiple factors including: weather (Altwegg *et al.*, 2003), fluctuations in food abundance (Taylor, 1994 and Klok & de Rood, 2007), habitat loss (Martinez & Zubergoitia, 2004) and human activity (De Bruijn, 1994 and Grilo *et al.*, 2012). Recent shifts in the ecology of predatory species, including the Barn Owl, are indicative of low rodent numbers, as a result of agricultural intensification (Hodora & Poggio, 2016). Despite being a synanthropic species, agricultural intensity and human activity have been found to negatively affect nestling fitness (Beziers *et al.*, 2015). Moreover, the decline of the Barn Owl has been suggested to be largely due to land use change, habitat loss (Fajardo, 2001) and pesticide use (Newton *et al.*, 1991), with road traffic casualties rising and becoming ever more relevant (Fajardo, 2001).

Wildlife road mortality

Urbanization results in a greater need for transport, with train lines and roads becoming ever more relevant in modern day society. This has become a major cause of native species extinction (Czech *et al*. 2000), with changes in habitat structure and the introduction of roads being the likely causes. Modern urban land use often gravitates toward the expansion of impervious surfaces and the structural simplification of vegetation, which fragments and reduces the habitats available for wildlife. The maintenance of vegetated areas typically involves scrub clearance and an increase in non-native plants and grasses (Marzluff and Ewing 2001), resulting in a decline in the diversity of invertebrates, birds and small mammals, which rely on vegetative complexity and plant species richness (Savard *et al*. 2000). Additionally, the expansion of transport networks that bring many social and economic benefits with urbanization can have detrimental effects on wildlife, through habitat reduction, fragmentation and disturbance (Brumm, 2004; Fuller *et al*., 1995; Fahrig & Rytwinski, 2009; Ware *et al.*, 2015). More directly, the increased traffic flow associated with urbanization can lead to significant animal mortality effects, such as an increased number of road kills. It is estimated that one million vertebrates are killed annually on roads in the USA (Slater, 1994). In the UK, 984 road-killed badgers were collected in Southern England during 1984 (Slater, 1994) and 37,000 White-tailed Deer are estimated to be killed annually on roads in Pennsylvania and Wisconsin (Slater, 1994). In the Netherlands, Jonkers & de Vries (1977) estimated 653,000 birds and 159,000 mammals are killed each year in wildlife-vehicle collisions. Understanding the impact that road kills have on wildlife ecology, allows for preventative conservation measures to be created to reduce overall negative impacts (Sadleir & Linklater, 2016).

Although agricultural intensification has been implicated as a major factor impacting negatively on Barn Owl populations, declines have also been linked to the expansion of road networks needed to accommodate traffic growth (Bard-de-Aqua *et al.*, 2012). Expansion of road networks, as a byproduct of urbanization, has led to habitat fragmentation, noise pollution, light pollution and direct mortality due to collisions with vehicles. The Barn Owl, is the most frequent bird species encountered on road casualty surveys in France (Massemin & Zorn, 1998 and Baudvin, 2004), the Meditarranean

(Gomes *et al*., 2009) and the USA (Boves & Belthoff, 2012), the majority of which are juvenile (Grilo *et al.*, 2014), likely having a negative impact on population growth. Over half of known Barn Owl deaths can be attributed to collisions with vehicles in the UK (Taylor, 1994), with numbers having increased from previous years (Glue, 1971 and Newton *et al.*, 1991). Wildlife-vehicle collision preventative measures typically focus on ungulates, meaning birds are often overlooked (Kociolek *et al.*, 2015). However, the low gliding flight of hunting Barn Owls makes them very susceptible to wildlife-vehicle collisions.

Study species

The Barn Owl is a nocturnal bird found on all continents except Antarctica. They are a monogamous species (Taylor, 1994), that lay between 2 and 11 eggs per clutch (Lenton, 1984). Most Barn Owls begin breeding at one year of age and can produce up to two broods per year (Marti, 1994). The breeding season of the Barn Owl is typically influenced by rain, temperature and food abundance (Weatherhead, 2005 and Carey, 2009), with the majority of UK Barn Owls reproducing from early March to late August.

The home range of Barn Owls, although not typically circular, extends 1-2.5km in radius around the nest site during summer (Taylor, 1994), and up to 4-5km radius around the nest site during winter (Taylor, 1994). Roads, rivers and tree lines have been found to be used as home range boundaries (Grilo *et al.*, 2012), with overlapping home ranges, close nesting and the sharing of hunting habitats being common in this species (Smith *et al*., 1972; Colvin, 1985; Meek *et al*., 2003).

The diet of the Barn Owl varies with location, season and weather; factors which influence prey abundance and profitability (Love *et al.*, 2000; Taylor, 1994; Tores *et al.*, 2005; Durant *et al*., 2013), this is due to them being opportunistic hunters, which allows them to occupy a variety of different habitats (Bond *et al*., 2005; Leech *et al*., 2009; Meek *et al.*, 2009; Kitowski, 2013; Salek *et al*., 2016). The diet of the Barn Owl in the UK consists of small mammals, with birds, anurans and invertebrates making up a very small percentage (Glue 1974; Brown, 1981; Love et al., 2000). The most important prey in the diet is the Field Vole (Glue, 1974; Love *et al*., 2000; Hindmarch & Elliot, 2015; Hindmarch *et al.*, 2017), with reproductive success being positively related to the proportion of voles consumed (Klok and de Roos, 2007), in the UK (Taylor, 1994) and in Israel (Charter *et al*., 2015b). Important secondary prey items include the Wood Mouse, Common Shrew and Brown Rat (Glue, 1974).

Changes observed in the diet of the Barn Owl in the UK have been suggested to be due to habitat changes brought about by the intensification of agriculture, which has resulted in the loss of many habitats suitable for small mammal and other potential prey species (Love *et al*., 2000). Variation within the diet of the Barn Owl between studies is likely to be due to the seasonal fluctuations in small mammal populations. Oscillations in the abundance of small mammal species can be erratic, periodic or annual (Tait & Krebs, 1985 and Krebs & Myers, 1974). Habitat, season and year are all factors that influence the population dynamics of mice, voles and shrews (Janova & Heroldova, 2016), with changes in the length and severity of winter influencing the cyclic population fluctuations seen in small mammals such as voles (Stenseth et al., 2003).

The primary prey of Barn Owls, the Field Vole, has been found to have a strong relationship with areas of non-intensively used grassland (Aschwanden et al., 2007), as well as road side grass verges (Grilo et al., 2012). Road side grass verges have been found to have an increased availability and abundance of voles (Grilo et al., 2012), making grass verges increasingly important yet a potential risky foraging habitat for Barn Owls (Hindmarch et al., 2012). The densities of voles have been found to be much lower in habitats used to graze farm animals such as sheep and cows (Wheeler, 2008). The habitat requirements of voles' contrast with those of other important arable wildlife; ground nesting and game birds require open, frequently disturbed habitat which voles do not (Tattersall et al., 2000).

A secondary prey species of the Barn Owl, the Wood Mouse is a generalist with the ability to adapt to the changing countryside better than other species (Love *et al*., 2000), which may be why Wood Mice are found to be abundant in farmland habitats (Rodriguez & Peris, 2007). The use of habitat edges allows for a simultaneous access to different resources and thus positively affects the more opportunistic species such as the Wood Mouse (Hansson, 1994).

The Common Shrew was found to have no habitat preference based on land use (Rodriguez and Peris, 2007), likely due to it being an insectivore, allowing the species to occupy a variety of habitats such as grasslands, woodlands, arable lands and hedges (Wang and Grimm, 2007). However this also makes the species more susceptible to the use of insecticides.

Birds of Prey, including owls regurgitate the indigestible remains of their prey in the form of a pellet. These pellets can contain the remains of several prey items of different species - if the prey items were consumed within a few hours of one and other (Dodson & Wexlar, 1979). The formation and egestion of pellets is a gastrointestinal phenomenon (Rea, 1973), by which the pellet is formed in the bird's stomach from the indigestible bones, hair or feathers of prey (Reed & Reed 1928, Grimm & Whitehouse 1963, Rhoades & Dukes 1977). In owls, the prey eaten fills the stomach and lower esophagus, within 20-30 minutes the meal moves into the muscular stomach (Rhoades & Duke, 1977) for pellet formation followed by egestion (Fuller & Duke, 1978).

Pelleting behaviour in raptors provides a source of information about their prey which can be sampled non-invasively via morphological analysis. Barn Owls are not selective in their prey choice; meaning pellets are not only a random sample of their diet but also of prey availability in the area. With this in mind the analysis of Barn Owl pellets a suitable method to characterize small mammal communities from different eco regions (Yom-Tov & Wool, 1997). The proportions of small mammals in their diet are generally representative of the proportions of the species in the environment (Andrade *et al*., 2016). Despite the Barn Owls preference for some prey species, dietary analysis has previously recorded more species than extensive trapping efforts alone (Avenant, 2005).

Study area

This study uses data collected from Anglesey (central grid reference SH405804), an island off the coast of North West Wales. The island covers 444 square kilometers, much of which is used for relatively intensive cattle and sheep farming. The British Trust for Ornithology (BTO) has 499 sites with nest boxes located throughout Anglesey, there are approximately 130 known Barn Owl box sites used and records show that in the mid-1970s there were 110 known Barn Owl box sites used. This suggests that any variation found in reproductive success from previous years is not due to changes in Barn Owl box density. Twenty-six nest locations were used in this study (Figure 1.2). The boxes were monitored throughout the year by volunteers (William Williams and Stephen Roddick), details of the reproductive season were recorded and all nestlings are individually marked with numbered metal rings where possible.

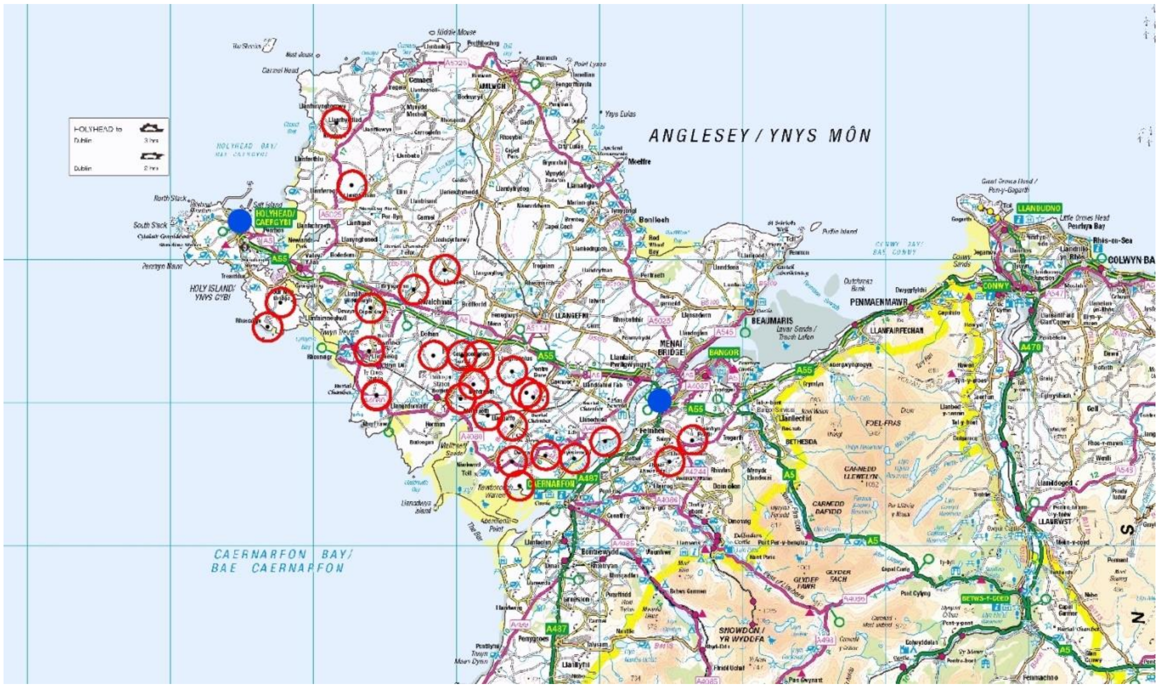


Figure 1.2 A map of the study area, Anglesey, showing the 26 British Trust for Ornithology (BTO) nest/roost sites used in Chapter 2. Each site is represented by a black dot, and the red ring around each dot represents the 1km home range of the Barn Owls occupying the site, during the breeding season. All Barn Owl sites in the area were not used in the study due to limitations such as safe access, landowner permission and limited resources. The Barn Owl road casualty sites and randomly generated sites used in Chapter 3 where positioned along the A55 running from Menai Bridge and Holyhead, represented by blue markers.

Figure 1.3. A map of the study area outlining the section of the A55. The red dots represent the road casualty sites provided by the North and Mid Trunk Road agency. In total 117 Barn Owl road casualty sites were reported, as a result numerous red dots are layered as more than one owl was found in the area.

Inhabitants of the nest boxes include Barn Owls, Kestrels, Jackdaws and Peregrine Falcons. Some of the sites include more than one box and there have been various reports of multiple species occupying the same site in extremely close quarters. For example, in the 2018 breeding season one site was found to have Kestrels nesting inside the box, Jackdaws on top of the box and Barn Owls roosting on a beam in the corner of the building.

The North Wales expressway (A55) is a dual carriageway primary route, running from Chester to Holyhead. The length of the A55 on Anglesey is 35.24km, running from Menai Bridge to Holyhead (Figure 1.3) and is largely surrounded by agricultural grasslands its entire length. The North and Mid Trunk Road Agency, is an agency delegated by the Welsh Government with the responsibility of operating and maintaining trunk roads. The agencies ecologist, Jill Jackson, works with the BTO volunteers and members of the public to record incidences of wildlife killed after collisions with vehicles. While the A55 was not searched systematically for road kill, all sightings of dead Barn Owls were recorded when reported (Figure 1.3). The date and grid reference were recorded for the sites where dead Barn Owls where found.

Aims

The study focuses on the ecology of Barn Owls in Anglesey particularly: diet, reproductive success, habitat and road mortality. The reason for this is that these factors are expected to be interlinked. The habitat surrounding the nest box may differ in species richness and abundance - as a result this could influence the owl's diet. An owl that can catch profitable prey more frequently is expected to successfully fledge more chicks and as a result have greater reproductive success (Charter, 2015b). Land used for intense agricultural practices has lower species richness and abundance however, road side grass verges has been found to have an increased availability and abundance of voles (Grilo *et al*., 2012), which is an important prey of the Barn Owl (Glue, 1974; Brown, 1981; Love et al., 2000). This makes grass verges increasingly important yet a potential risky foraging habitat for Barn Owls (Hindmarch *et al*., 2012). Birds that are heavy relative to their wing size and have a lower take-off trajectory, such as owls, have been suggested to be more susceptible to wildlife-vehicle collisions than other birds (Kociolek & Clevenger, 2011). Barn Owls hunt relatively low to the ground therefore the presence or absence of continuous low flight obstructions is a likely factor contributing to Barn Owl vehicle collisions, as obstructions force the bird to fly up and over the roadway.

The aim of this study is therefore, to explore the impact of land-use on two aspects of Barn Owl ecology: diet - as assessed by pellet analyses - and road mortality as assessed through reports of Barn Owls road kills. First the study quantified the variation in Barn Owl diet in relation to season and habitat within the breeding and wintering ranges of the birds. It also explored the relationship of diet and habitat with reproductive success (Chapter 2). Second, the study explores how Barn Owl mortality due to road traffic collisions varies with season, habitat and population density, using records provided by the North and Mid Trunk Road Agency (Chapter 3). Finally, chapter 4 discusses the overall conclusion and the general links between habitat diet and population ecology in the Barn Owl.

Chapter 2. The effects of habitat and season on the diet and reproductive success of the Barn Owl

Abstract

The Barn Owl population decline in the UK has been attributed to agricultural intensification and urbanization. This shift in farming practices has resulted in reduced habitat diversity and homogenization of the landscape, overall reducing small mammal diversity and abundance, and causing ecological shifts in predatory species such as the Barn Owl.

The objectives of the study were to analyze the diet of the Barn Owl using prey remains from regurgitated pellets, to investigate variation in diet due to season and habitat, and to quantify the effect of diet variation on reproductive success. The study was conducted in Anglesey in northwest Wales, where 377 pellets were collected and dissected from 26 nest/roost locations, within the breeding season and the wintering roost season.

Of the prey items identified form regurgitated Barn Owl pellets, 12 species of vertebrates were found. Of the 12 species identified the three most abundant were the Field Vole (60.52%), Common Shrew (16.31%) and Wood Mouse (8.65%). The results of the study found the mean Field Vole weight per pellet was higher outside the Barn Owl breeding season (64.65g) when compared to during (53.53g). And the mean Wood Mouse weight

per pellet was lower outside the breeding season (4.06g) when compared to inside (7.16g). The Barn Owl home range habitat composition was found to vary from 14-99% agriculturally improved grassland, 0-43% arable horticulture and 0-9% fen marsh swamp; all of which were found to have a negative association with the number of successful fledglings per nest.

In conclusion, in areas of intense agriculture maintaining species rich diverse habitats is important for the success of Barn Owls. The results of this study suggest conservation efforts should be focused on the restoration of habitats to provide biodiversity, habitats of different management levels, which contain a wider variety of vegetation, should allow predatory birds to exploit habitats at different times of the year depending on food abundance.

Introduction

The dietary composition of a species is influenced by a variety of factors such as prey abundance (Love *et al.*, 2000; Taylor, 1994; Tores *et al.*, 2005; Durant *et al.*, 2013), habitat (Dahl & Patterson, 2014; Cancio *et al*., 2017; Eisenberg *et al.*, 2017) and season (Gonzalez-Fischer *et al.*, 2011; Burger *et al.*, 2012; Gormezano & Rockwell, 2013; Gryz & Krauze-Gryz, 2015; Hodora and Poggio, 2016). The habitat occupied has been shown to largely influence the diet consumed across a range of species; in predators such as the Lionfish (Dahl & Patterson, 2014) and the Red Fox (Cancio *et al*., 2017), diet was shown to vary according to habitat and landscape features over food availability. Similarly in Amazon River Turtles, water type influenced the volume of vegetation matter consumed (Eisenberg *et al.*, 2017). However, habitat does not appear to influence diet composition in predatory birds. The Peregrine Falcon, Barn Owl and Common Kestrel have been found to maintain the same diet irrespective of habitat variation (Kross *et al.*, 2012; Teta *et al.*, 2012; Navarro-Lopez & Fargallo, 2015), but this may because predatory birds are generalist and not specialists, allowing them to change their prey preference depending on abundance and profitability.

As well as habitat, season has also been found to influence diet across species. The Pied Flycatcher shows a seasonal decline in caterpillar consumption when occupying oak habitats (Burger *et al.*, 2012) and Polar Bears show a shift in their hunting behaviour by becoming opportunistic during the ice free season (Gormezano & Rockwell, 2013). Variation in diet throughout the season, especially in predatory species, is indicative of changes in the abundance of prey available at different times of the year. For example, in the Long-eared Owl, birds, anurans and insects are consumed more in summer (Gryz & Krauze-Gryz, 2015), probably because these prey items become more abundant in warmer months.

The reproductive success of a species can be affected by diet composition, rather than simply the total food availability and this is particularly important in birds. Diet diversity has been shown to influence reproductive success in Egyptian Vultures (Margalida *et al.*, 2012) and Golden Eagles (Whitfield *et al.*, 2009), whilst food quality was more important in determining success in the House Sparrow (Seress *et al.*, 2012) and the Barn Owl (Charter *et al.*, 2015b).

The diet of the Barn Owl

The Field Vole is the primary prey species in the diet of Barn Owls in the UK, but Wood Mice, Common Shrews and Brown Rats, are important secondary prey items (Glue 1974; Brown, 1981; Love *et al.*, 2000). Barn Owl diet varies in relation to prey abundance and profitability (Love *et al.*, 2000; Taylor, 1994; Tores *et al.*, 2005; Durant *et al.*, 2013). For example, the Wood Mouse is a more valuable food source in comparison to the Common Shrew, because Wood Mice provide twice the mass per capture, however, when mice are scarce, Barn Owls will increase the proportion of smaller prey, such as shrews, in their diet (Love *et al.*, 2000).

Despite being able to adapt their diet in regards to prey abundances and profitability (Love *et al.,* 2000; Taylor, 1994; Tores *et al.*, 2005; Durant *et al.,* 2013), the Barn Owl population is to a degree dependent on the population numbers of their primary prey the Field Vole, as vole population size has been found to influence reproductive success in the Barn Owl (Fajardo, 2001; Klok and de Roos, 2007; Charter et al. 2015). During bad vole years, especially in closed populations, low reproductive rates and low rates of vole survival led to such a decline in the number of resident predators - the population cannot benefit optimally from the good voles years and as a consequence cannot maintain itself (Klok and de Roos, 2007). This suggests the food level in the bad compared to the good vole years has a much higher impact on the persistence of the Barn Owl population. However, in Western Europe years of high vole abundance were often followed by massive emigration of mainly juvenile owls over large areas (Honer, 1963), suggesting Anglesey's population could be rejuvenated in good voles through the emigration of owls from natal ground outside of Anglesey. Variation in the abundance of small mammal species, such as the Field Vole, can be erratic, periodic or annual (Krebs & Myers, 1974). These changes have been found to largely depend in the length and severity of winter, with small mammal fluctuations being influenced by seasonality (Stenseth *et al.,* 2003), resulting in changes in Barn Owl diet throughout the year based on prey availability.

Numerically the most important prey within the Barn Owl breeding season (summer) has been identified as the Common Shrew and outside the breeding season (winter) the Field Vole (Brown, 1981), which is likely due to the Common Shrew spending its winter underground (Brown, 1981). Additionally, an increased abundance of Wood Mice in autumn was found and an increased abundance of Field Voles in spring (Broughton *et al.*, 2014). Wood Mice populations decreased during the breeding season of Barn Owls, thus resulting in proportionally fewer Wood Mice in the diet during summer (Tores *et al*., 2005).

Variation in Barn Owl reproductive success has been linked to rodent availability (Wilson *et al*., 1986; Taylor *et al.*, 1992). In the UK, Hen Harrier population numbers was found to correlate strongly with vole abundance as did clutch size (Redpath et al., 2002). Similarly, the reproductive success of Barn Owls has been found to increase with the proportion of voles in their diet (Charter *et al.*, 2015b), with more fledglings and double brooding occurring more in good vole years (Jackson & Cresswell, 2017). Reproductive success has been found to be negatively associated with the proportion of mice in the Barn Owl diet (Charter *et al*., 2015b).

How habitat change and farming intensity has affected the Barn Owl

Many of the changes in the Barn Owl diet during the 20th century can be attributed to habitat changes brought about by changes in agricultural practice, which have resulted in the loss of many habitats suitable for small mammal communities and other potential prey species (Love *et al*., 2000). Dietary shifts in predatory species are indicative of low rodent numbers, resulting from rapid farming intensifications (Hodora and Poggio, 2016). Recent attention to environmentally friendly farming, such as the introduction of field margins and set aside schemes has been found to enhance small mammal communities (Broughton *et al*., 2014). However, the habitat requirements of the Barn Owls primary prey, voles, differ from those of other important arable wildlife (Tattersall *et al*., 2000). Additionally, the small mammals consumed by Barn Owls have differing relationships with their environment and sometimes opposing habitat requirements (Hansson, 1994; Tattersall *et al*., 2000; Wang and Grimm, 2007). Tattersall et al., (2000), found no Field Voles were captured on set asides for the first 9 months after establishment, whereas many ground nesting birds and game birds require open disturbed habitats which an annually relocated set aside can provide. With many farmland species being of conservation concern, it is important to provide a variety of habitats of different management levels which are tailored to local conservation requirements, in order to increase local biodiversity. This could also provide Barn Owls with an alternative food source during bad vole years.

Aims

The study aims to investigate factors affecting the diet of the Barn Owl such as seasonality and habitat, as well as the role this plays in reproductive success. One of the aims was to test the hypothesis that the proportion of different small mammal species in the diet of Barn Owls will vary inside to outside the breeding season (Brown, 1981). Furthermore, the study will explore how the proportion of small mammal species varies with habitat composition inside the home range of Barn Owls, as well as how habitat composition may vary between seasons. Another aim was to test the hypothesis that there is a relationship between the diet consumed and habitat surrounding the nest site and the reproductive success of the Barn Owl.

Methods

Pellet collection

The diet of Barn Owls was characterized by collecting and analyzing regurgitated pellets from their winter roosts and nest sites. Pellets were collected from inside nest boxes and on the ground underneath boxes. Pellets were collected alongside British Trust for Ornithology (BTO) volunteers from nest boxes within the study area between April 2017 and January 2018. Fresh pellets were collected when possible; fresh pellets are identifiable as they are dark in colour, glossy on the outside and wet. As many pellets as possible were removed from inside and around the nesting boxes to ensure pellets from during the breeding season would not be collected in the following January. However, fresh pellets were not always accessible or present therefore pellets were dated before dissection using the method described below. The pellets were stored in labeled plastic bags and frozen. The label included the date of collection, location name and grid reference of the nest box.

Barn Owl pellets were collected from 26 locations, on two separate occasions where possible, once within (March to September) and once outside the breeding season. A total of 377 pellets were dissected, 190 from the breeding season and 187 from the winter roosting season.

Pellet dissection

The mean number of pellets dissected was 14.5 pellets per nest site, SD = 8.7. Only pellets that were less than 8 months old were dissected. The pellets were aged based on their water content, colour and texture using a standard guide (Available at: https://www.barnowltrust.org.uk/barn-owl-facts/barn-owl-pellet-analysis/, Figure 2.1). As the pellet ages it lightens in colour, becomes dull and loses form. Only pellets that could accurately be assigned to a season where dissected. Also pellets that were more than 8 months old were not analyzed as they could also not be confidently assigned to a season within the year. For example, the bones from each pellet were extracted and stored separately in labeled sealed containers. The remainder of the pellet content, such as matrix, fur, larvae and plant matter was disposed of. The dry dissection method was used and pellets that were not intact were not analyzed. Skulls, jaws and pelvis bones were counted to estimate the quantity of prey items in each pellet and were then used to identify prey to species level when possible, using guides produced by The Barn Owl Trust (The Barn Owl Trust, 2018) and The Royal Society for the Protection of Birds (RSPB) (The Royal Society for the Protection of Birds, 2018).

Figure 2.1 A resource used to estimate the age of owl pellets based on their appearance. The resource was taken from The Barn Owl Trust website.

The estimated median weight of primary prey (Field Vole, Wood Mouse and Common Shrew) was calculated using the recorded weights of species by The Mammal Society, UK (Field Vole 30g, Wood Mouse 20g and Common Shrew 9.5g; Corbet & Harris, 1991). This was then used in the statistical analysis of pellet content.

Reproductive success

Reproductive data were provided by Stephen Roddick and William Williams who survey and ring the Barn Owls on Anglesey, and Kelvin Jones the BTO representative. The data provided included: date of site visited, location name, grid reference and the number of eggs/hatchlings/fledglings.

Habitat analysis

Habitat data were extracted using the buffer tool and tabulate area tool in GIS ArcMap 10.4. A 1km radius around the nest box was created using the buffer tool to represent the hunting range of Barn Owls inside the breeding season and a 4km radius was used to represent the hunting range of Barn Owls outside the breeding season. The home range of Barn Owls, although not typically circular, extends 1-2.5km in radius around the nest site during summer (Taylor, 1994), and 4-5 km radius around the nest site during winter (Taylor, 1994). Due to the location of the nest boxes, being close to the coast, it was decided to use the smallest homerange of 1km and 4km as the predicted homerange radius. Ordnance Survey maps and habitat maps were downloaded from Digimap (University of Edinburgh, 2018). The tabulate area tool in ArcMap calculates the habitat composition inside each buffer zone, providing each habitat present in m^2, which was then calculated as a percentage of land cover.

Statistics

All statistical tests were run on IBM SPSS Statistic 24.

To test the first prediction, that there was a relationship between diet and reproductive success of Barn Owls nesting in BTO nest boxes on Anglesey, a Poisson generalized linear model was conducted for the main prey items. Following this, an additional Poisson generalized linear model was conducted to test if there was a relationship between habitat within the Barn Owl home range and reproductive success. Reproductive success was based on the number of fledglings which successfully fledged the nest.

To test the second prediction, that the diet of Barn Owls varied with season (breeding versus non-breeding), an independent t-test was used for each of the main prey types.

To test the third prediction, that diet was related with habitat within the home range, a general linear model (GLM) was used. The home ranges of Barn Owls varies from 1km inside the breeding season (during summer) to 4km outside of the breeding season (during winter) (Taylor, 1994), so habitat is recorded as a percentage to account for this change. Habitats where Barn Owls were unable to hunt (e.g. sea) were removed from the analysis, along with habitats that made up less than 1% of the home range. The habitat analysis consisted of the following categories: broadleaved woodland, arable horticulture, agriculturally improved grassland, neutral grassland, fen marsh swamp, urbanized land, saltmarsh, saltwater and freshwater, making up 92.4% of Barn Owl home ranges. First, an exploratory multivariate GLM was used to investigate all prey types (Field Vole, Common Shrew and Wood Mouse) in relation to all habitats. Following on from this, a univariate GLM was used to analyze a reduced set of habitats and prey types that were shown to be significant in the previous test.

Additionally, an exploratory univariate GLM was used to investigate the difference in habitats within the home ranges of breeding and non-breeding seasons, a univariate GLM was used which included habitat types making up 92.4% of the home range, as previously stated. To confirm these results further, independent t-tests were used to identify differences in the home range habitat composition within and outside the breeding season.

Results

The annual diet of the Barn Owl

A total of 1226 prey items were identified from the 377 pellets that were collected from 26 locations. Of the prey items identified, 12 species of vertebrates were identified through the morphological analysis of bones extracted from regurgitated Barn Owl pellets. By count, rodents were the most abundant prey item contributing to 72.66% of the diet, with prey belonging to the order Eulipotyphla (shrews and moles) making up 27.08% and birds making up 0.24% of the diet. Of the 12 species identified, the three most abundant were the Field Vole (60.52%), Common Shrew (16.31%) and Wood Mouse (8.65%), making up the primary prey items. This was followed by the secondary prey items: Pygmy Shrew (7.01%), Water Shrew (3.67%), Bank Vole (2.68%) and the least abundant prey item was the Harvest Mouse (0.08%) (Figure 2.2).

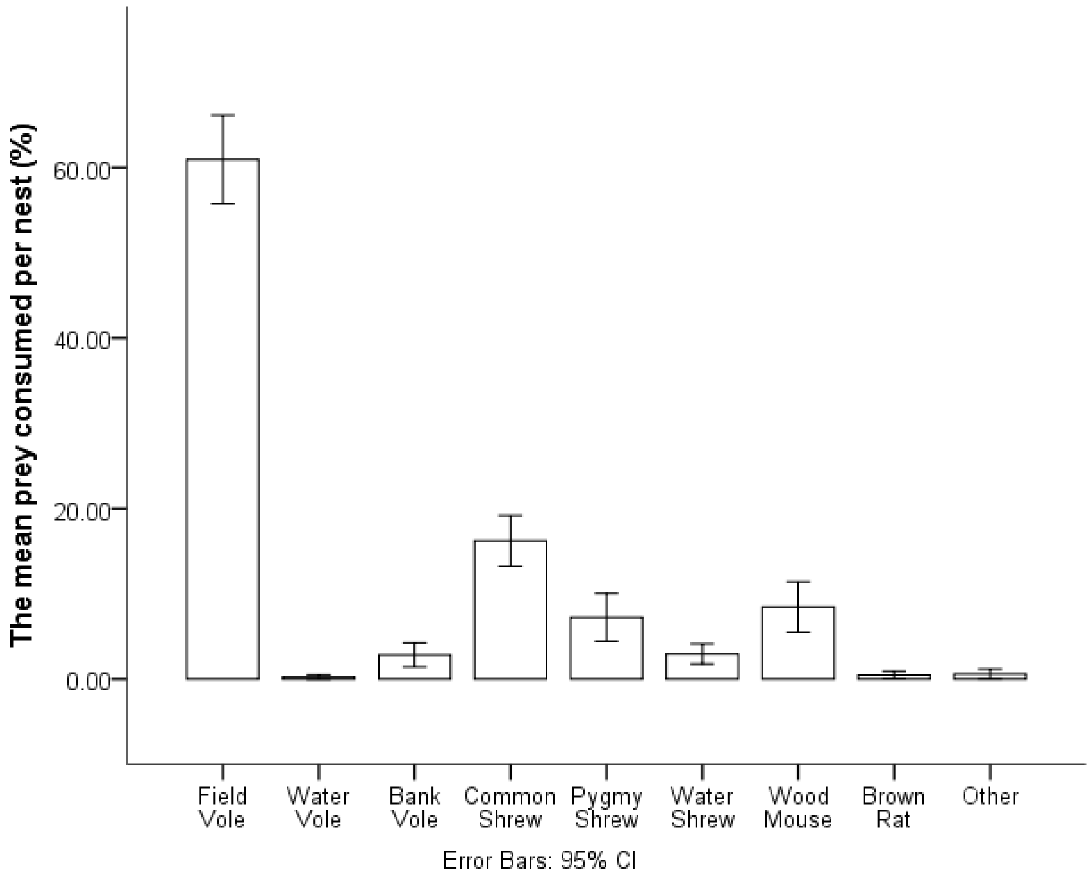


Figure 2.2 The combined mean percentage of prey consumed per nest by count from inside and outside the breeding season. The category 'other' includes Thrush, Wren, Harvest Mouse and Mole.

In terms of percentage (of number of prey items), the Common Shrew (16.31%) was found in larger proportions in comparison to the Wood Mouse (8.65%), when using the total percentage of prey from all pellets. However, when considering the biomass of the three primary prey species in the diet, the Wood Mouse contributed to a larger proportion of biomass to the Barn Owls diet than did the Common Shrew (percentage biomass of primary prey: Field Vole = 84.70%, Common Shrew = 7.23% , Wood Mouse = 8.07%). The estimated weight of the primary prey items was used to analyze these proportions further: Field Vole (30g), Common Shrew (9.5g) and Wood Mouse (20g). When considering the estimated weight of each prey species Field Voles averaged at 59.05g per pellet, with a maximum of 180g (6 Field Voles) in one pellet. The Common Shrew averaged 5.04g per pellet, with a maximum of 38g (4 Common Shrews) per pellet. The Wood Mouse averaged 5.62g per pellet, with a maximum of 100g (5 Wood Mice) per pellet (Figure 2.3).

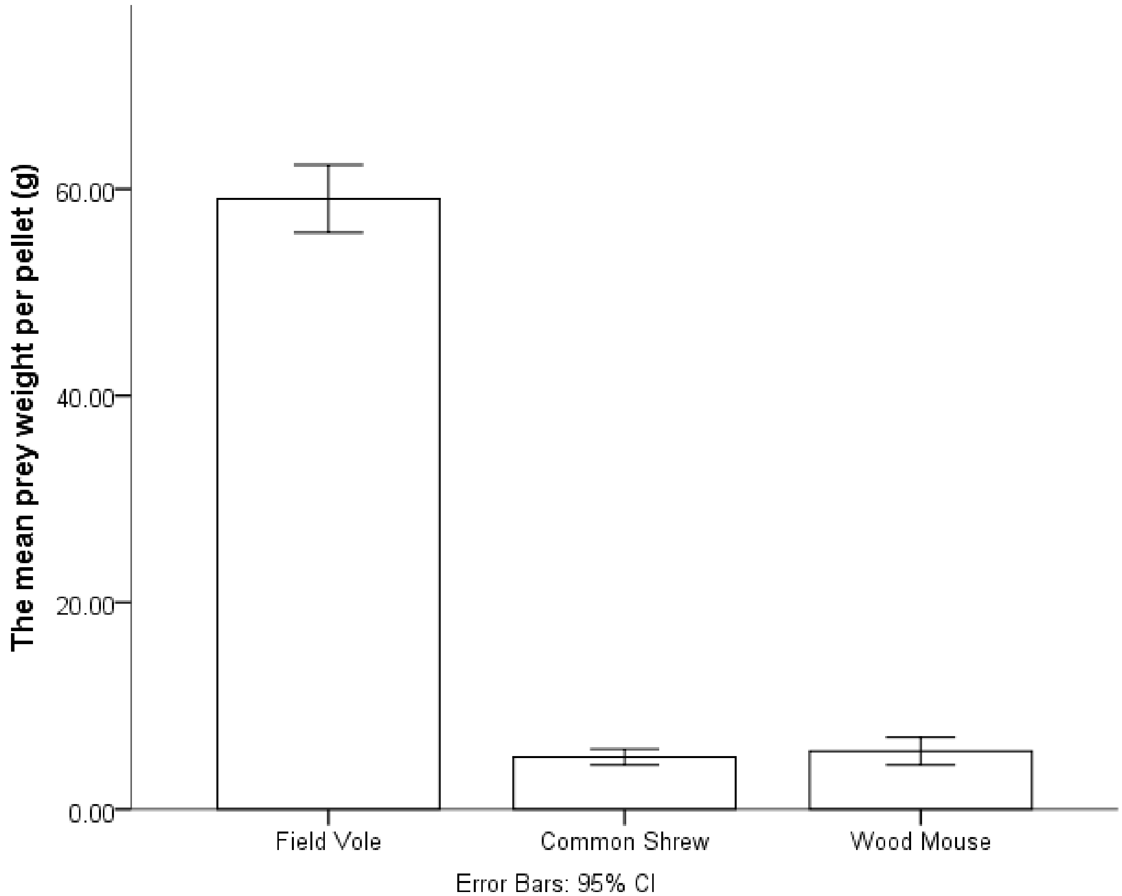


Figure 2.3 Prey weight per pellet of primary prey consumed. Prey weight was estimated using the median of prey weight recorded by The Mammal Society (Corbet & Harris, 1991). The estimated weight of primary prey: Field Vole 30g; Wood Mouse 20g; Common Shrew 9.5g.

How diet and habitat influence the reproductive success of the Barn Owl

A mean of 1.5 nestlings per nest (range 0-4, total 39 fledglings) survived to fledge from the 26 nests for which there were diet data. Twelve out of 26 nests produced no fledglings. The number of fledglings per nest showed no significant variation with the proportion of the main prey species in the diet: Field Voles, Common Shrews and Wood Mice (Table 2.1). This suggests there is no relationship between the proportions of prey consumed by the Barn Owl and the number of hatchlings they successfully fledged.

Table 2.1 Summary of three Poisson generalized linear models with the number of Barn Owls successfully fledged as the dependent variable and prey weight per pellet (g) as the predictor variables for the three primary prey species.

Model 1.	B	χ^2	df	P
Intercept	0.508	38.949	1	<0.001
Field Vole (g)	0.001	0.698	1	0.403
Omnibus Test	P = 0.405	Deviance	df = 375	
Model 2.	**B**	χ^2	**df**	**P**
Intercept	0.523	122.291	1	<0.001
Common Shrew(g)	0.008	2.952	1	0.086
Omnibus Test	P = 0.091	Deviance	df = 375	
Model 3.	**B**	χ^2	**df**	**P**
Intercept	0.547	166.722	1	<0.001
Wood Mouse (g)	0.003	1.525	1	0.217
Omnibus Test	P = 0.228	Deviance	df = 375	

Agriculturally improved grassland in the home range varied from 14% to 99%, arable horticulture varied from 0 to 43% and fen, marsh, swamp varied from 0 to 19%. A total of 15 out of the 26 locations analyzed were found to have 0% neutral grassland in the home range. Despite this, a positive association was found between the number of fledglings per nest and the proportion of neutral grassland in the home range (Table 2.2) (Figure 2.6). A negative association was found with the number of fledglings per nest and the proportion of agriculturally improved grassland (Figure 2.4), and arable horticulture (Figure 2.5) in the home range (Table 2.2). This suggests Barn Owl nest boxes placed in areas within an increased percentage of neutral grassland are likely to produce more fledglings and as a result increase the population of Barn Owls on Anglesey.

Table 2.2 Summary of four Poisson generalized linear models with the number of Barn Owls successfully fledged as the dependent variable and habitat percentage (%) within the home range as the predictor variables.

Model 1.	B	χ^2	df	P
Intercept	0.348	43.412	1	<0.001
Neutral Grassland	5.042	49.982	1	<0.001
Omnibus Test	P = <0.001	Deviance	df=375	
Model 2.	**B**	**χ^2**	**df**	**P**
Intercept	1.142	62.390	1	<0.001
Agriculturally Improved Grassland	- 0.824	16.310	1	<0.001
Omnibus Test	P = <0.001	Deviance	df=375	
Model 3.	**B**	**χ^2**	**df**	**P**
Intercept	0.636	188.977	1	<0.001
Fen Marsh Swamp	- 2.886	6.337	1	0.12
Omnibus Test	P = 0.008	Deviance	df=375	
Model 4.	**B**	**χ^2**	**df**	**P**
Intercept	0.742	285.886	1	<0.001
Arable Horticulture	- 4.191	38.901	1	<0.001
Omnibus Test	P= <0.001	Deviance	df=375	

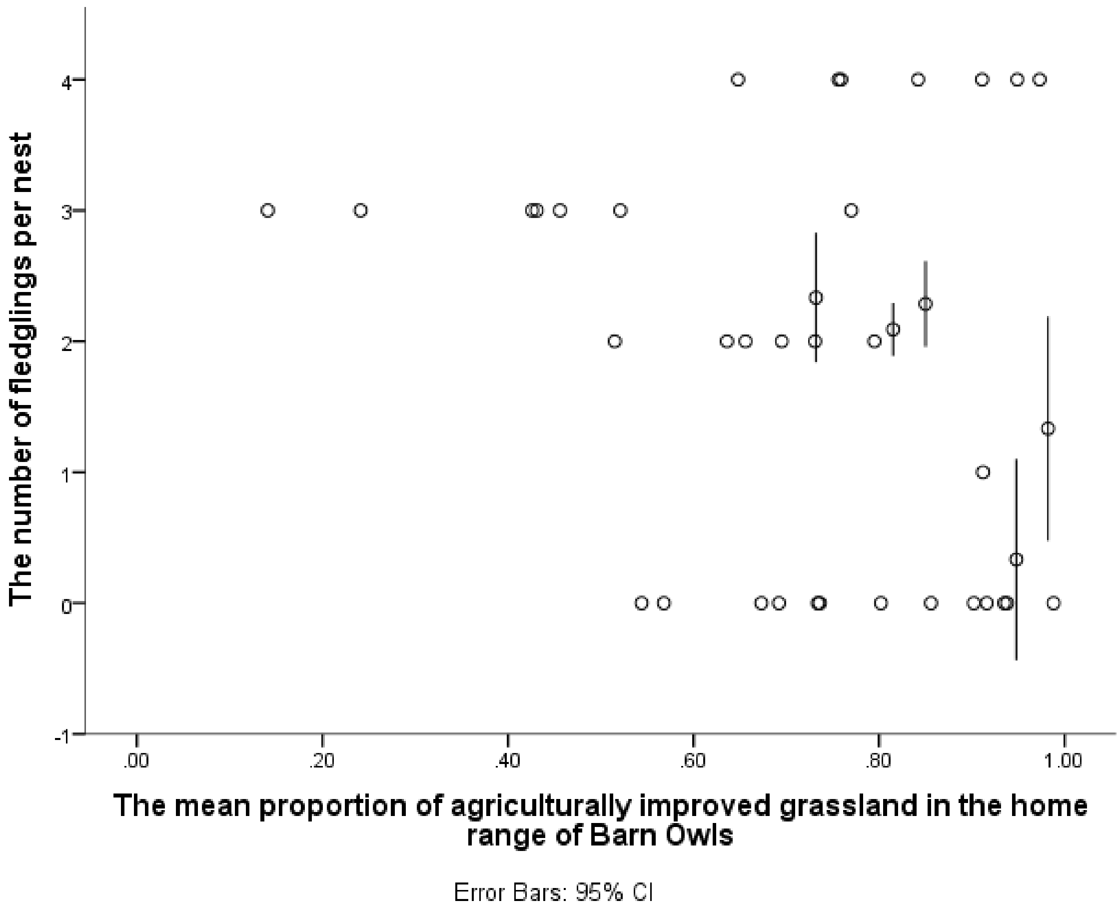


Figure 2.4 The mean proportion of agriculturally improved grassland in the home range of Barn Owls in relation to the number of Barn Owl fledglings per nest.

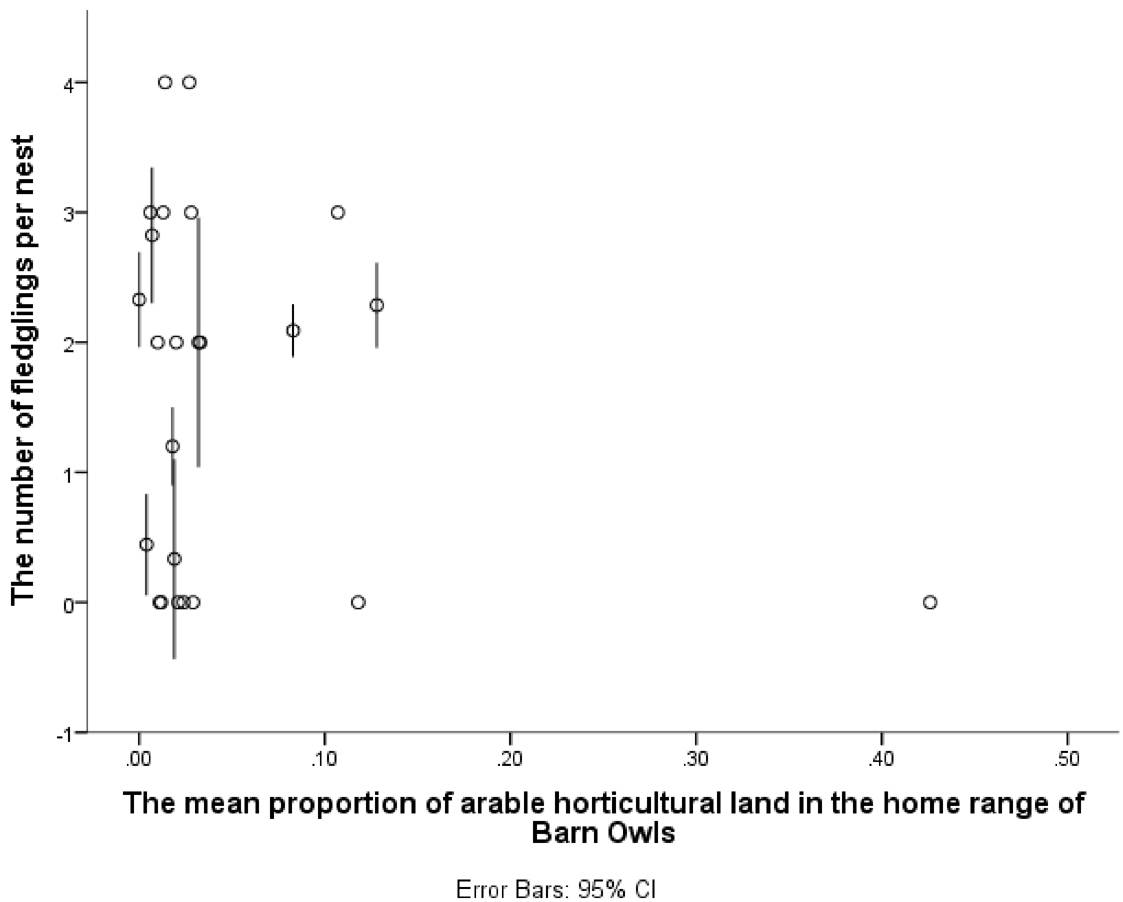


Figure 2.5 The mean proportion of arable horticultural land in the home range of Barn Owls in relation to the number of Barn Owl fledglings per nest.

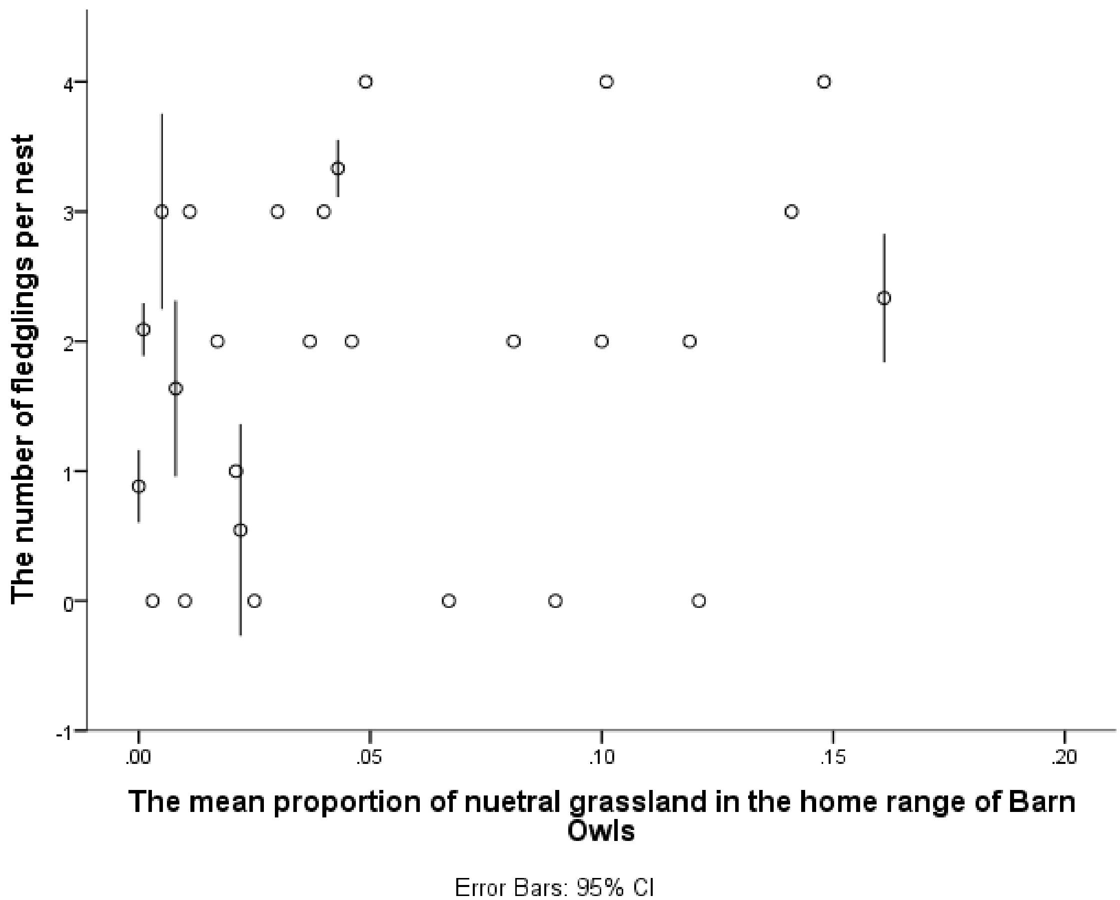


Figure 2.6 The mean proportion of neutral grassland in the home range of Barn Owls in relation to the number of Barn Owl fledglings per nest.

Habitat composition inside the predicted home range of Barn Owls

The habitat composition was calculated for the home range of Barn Owls using the BTO nest box grid reference as the center of the home range. Home range was calculated as a circle of 1 km radius during the breeding season (Figure 2.9), and 4 km circle outside the breeding season (Figure 2.9), despite home ranges not being typically circular.

Agriculturally improved grassland accounted for 14% to 99% of home ranges, averaging 99% inside the breeding season and 92% outside the breeding season. This is closely followed by: arable horticulture, averaging 43% inside the breeding season and 8% outside the breeding season; saltmarsh, averaging 20% inside the breeding season and 6% outside the breeding season; freshwater makes up the lowest percentage of the home range, averaging 0% inside the breeding season and 2% outside the breeding season.

In rare occasions the Barn Owl has been known to feed on anurans when prey abundance is low, however no anurans were found in the diet of the Barn Owl in this study?. Therefore, freshwater has minimal biological relevance to the diet of the Barn Owl and as a result has been removed from the analysis.

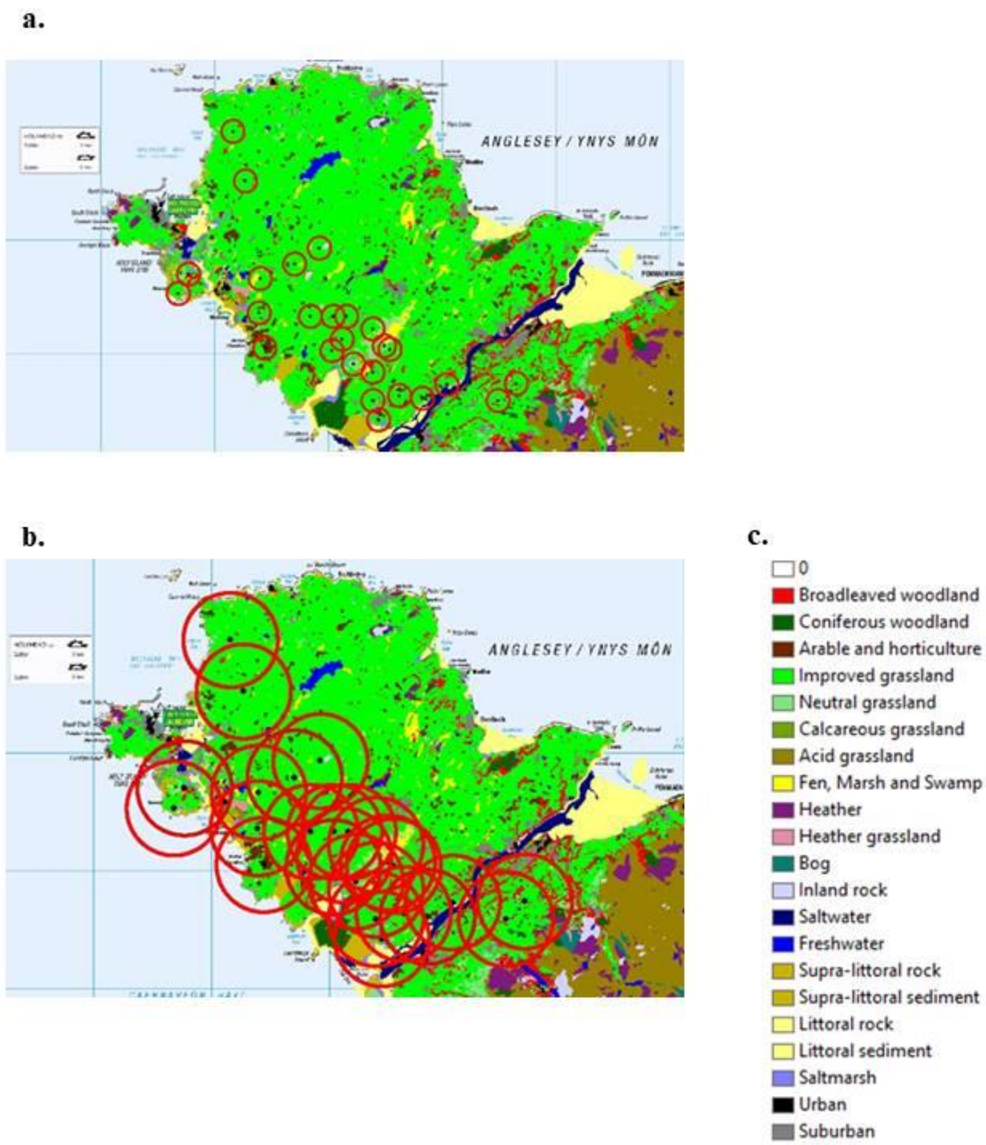


Figure 2.7 The 26 Barn Owl box locations on a habitat map. The graph shows: a) 26 Barn Owl nesting locations (black dot) with a 1km predicted home range (red ring) around them; b) The 26 Barn Owl winter roost locations (black dot) with a 4km predicted home range (red ring) around them; c) The habitat key used in the habitat analysis of Barn Owl box locations.

How season influences the habitat composition inside the predicted home range of Barn Owls

A significant difference was found between the mean proportion of arable horticultural land (Figure 2.8), urbanized land (Figure 2.9) and saltwater (Figure 2.10) in the home range of Barn Owls during and outside the breeding season (Table 2.3).

Arable Horticulture increased inside the breeding season, which could indicate site selection during the breeding season. Urbanized land and saltwater increased outside the breeding season - this is likely due to homeranges increasing from 1km to 4km in winter which is outside the breeding season and not site selection.

Table 2.3 Independent T-test results comparing habitat features of Barn Owl home ranges inside versus outside the breeding season.

Habitat	Mean habitat percentage inside the breeding season.	Mean habitat percentage outside the breeding season.	t	df	P
Arable Horticulture	9.2%	2.4%	6.314	375	<0.001
Urbanized Land	1.1%	3.4%	12.504	375	<0.001
Saltwater	0.7%	3.0%	6.302	375	<0.001

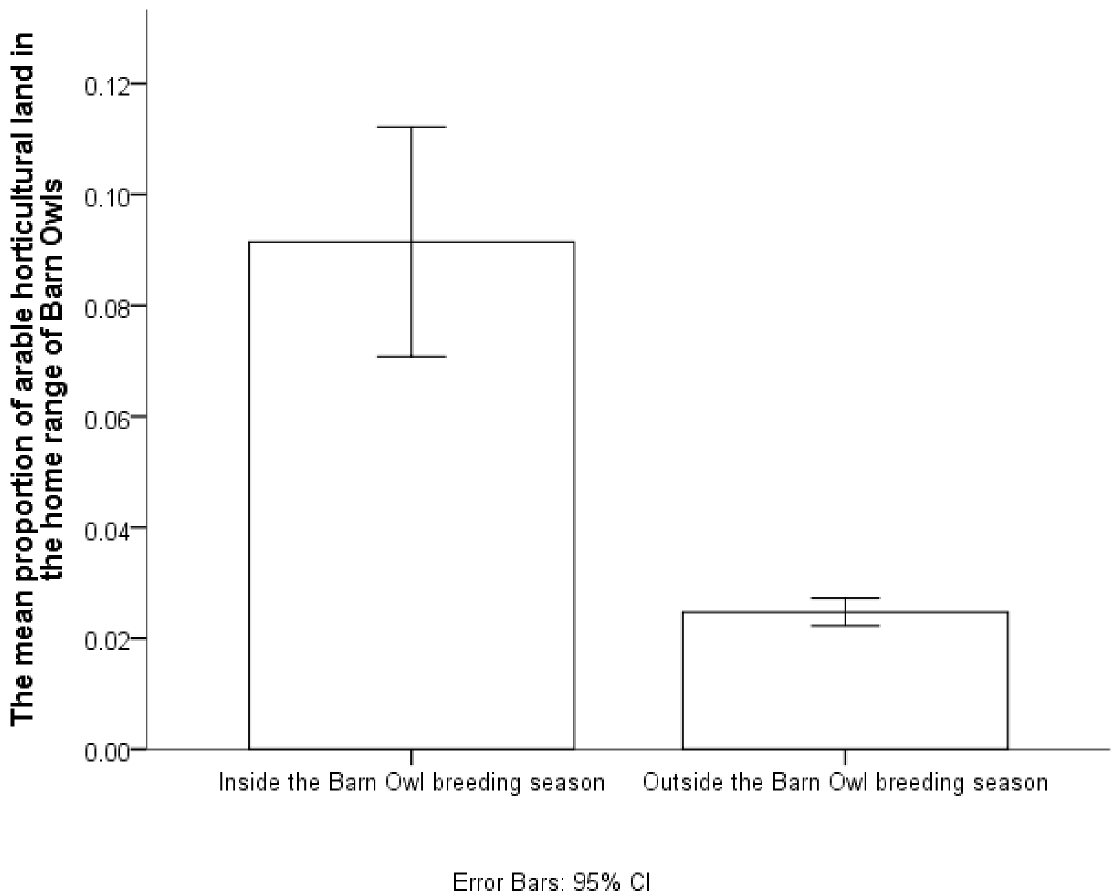


Figure 2.8 The difference in the proportion of arable horticulture land in the home ranges of Barn Owls at different times of the year.

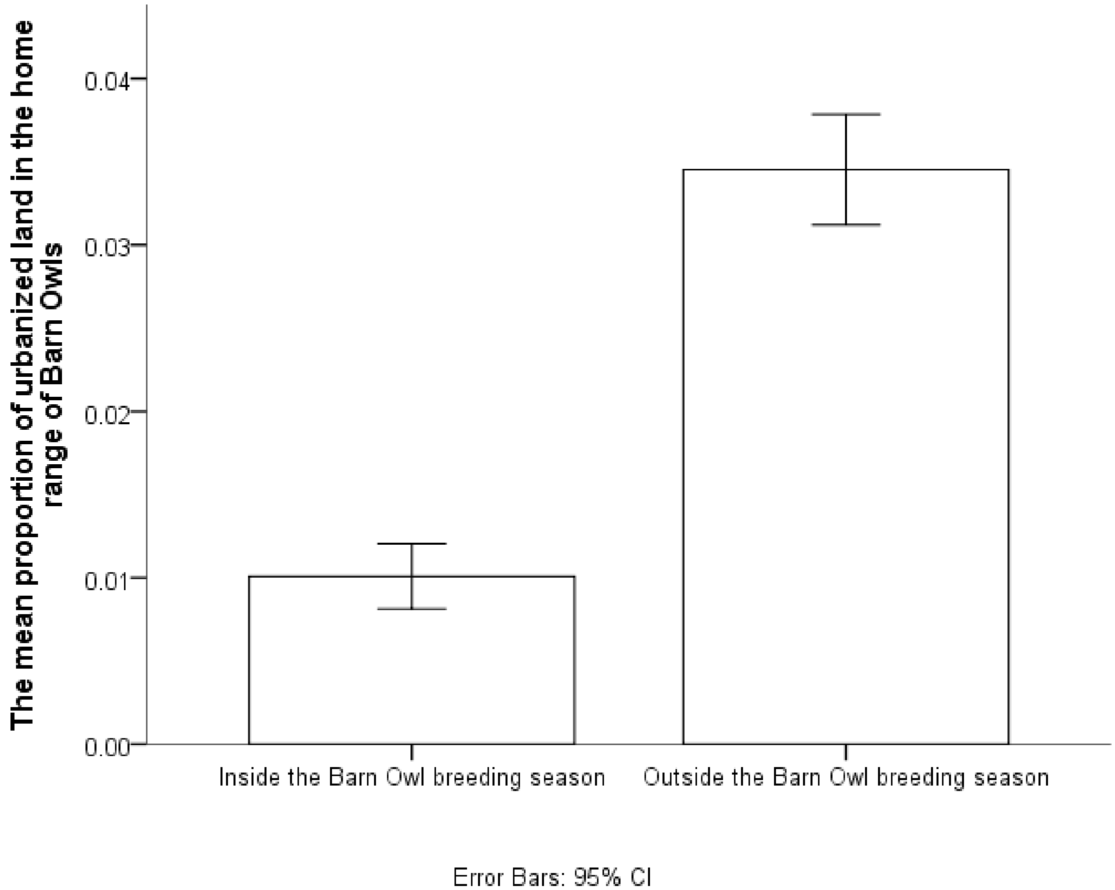


Figure 2.9 The difference in the proportion of urbanized land in the home range of Barn Owls at different times of the year.

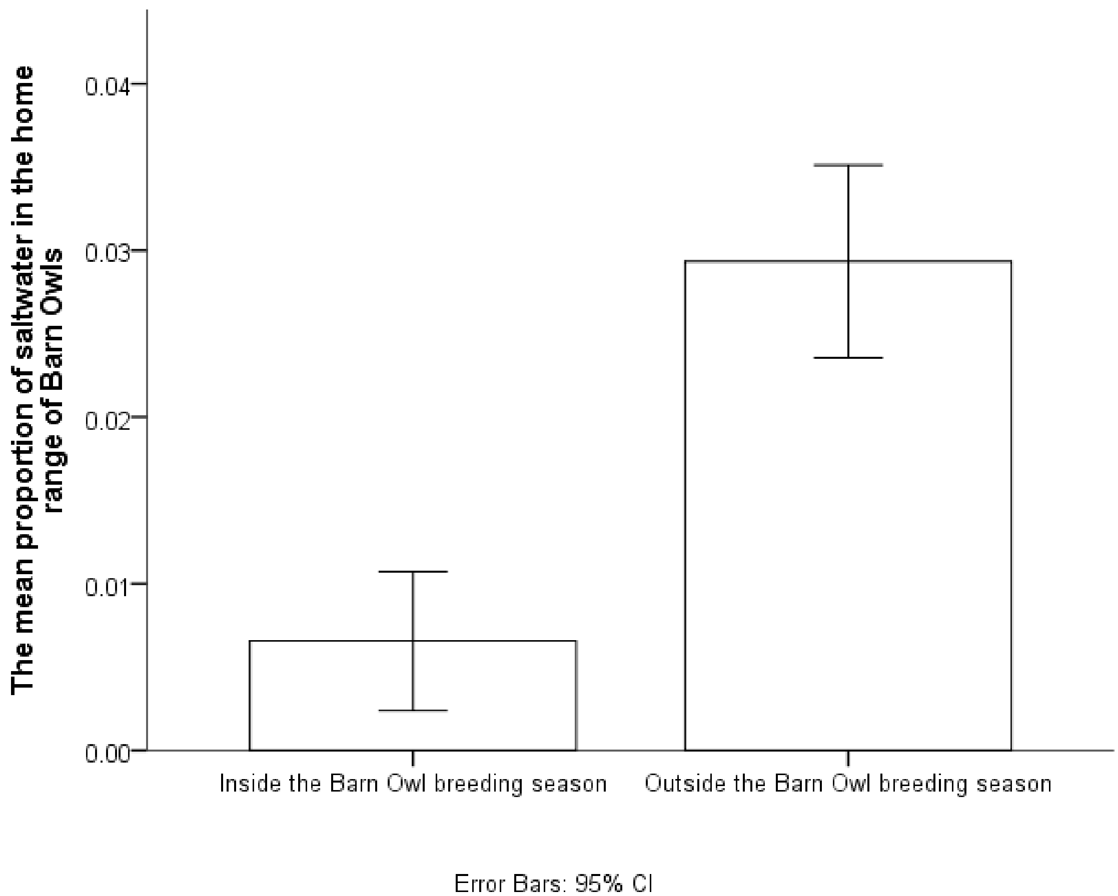


Figure 2.10 The difference in the proportion of saltwater in the home ranges of Barn Owls at different times of the year.

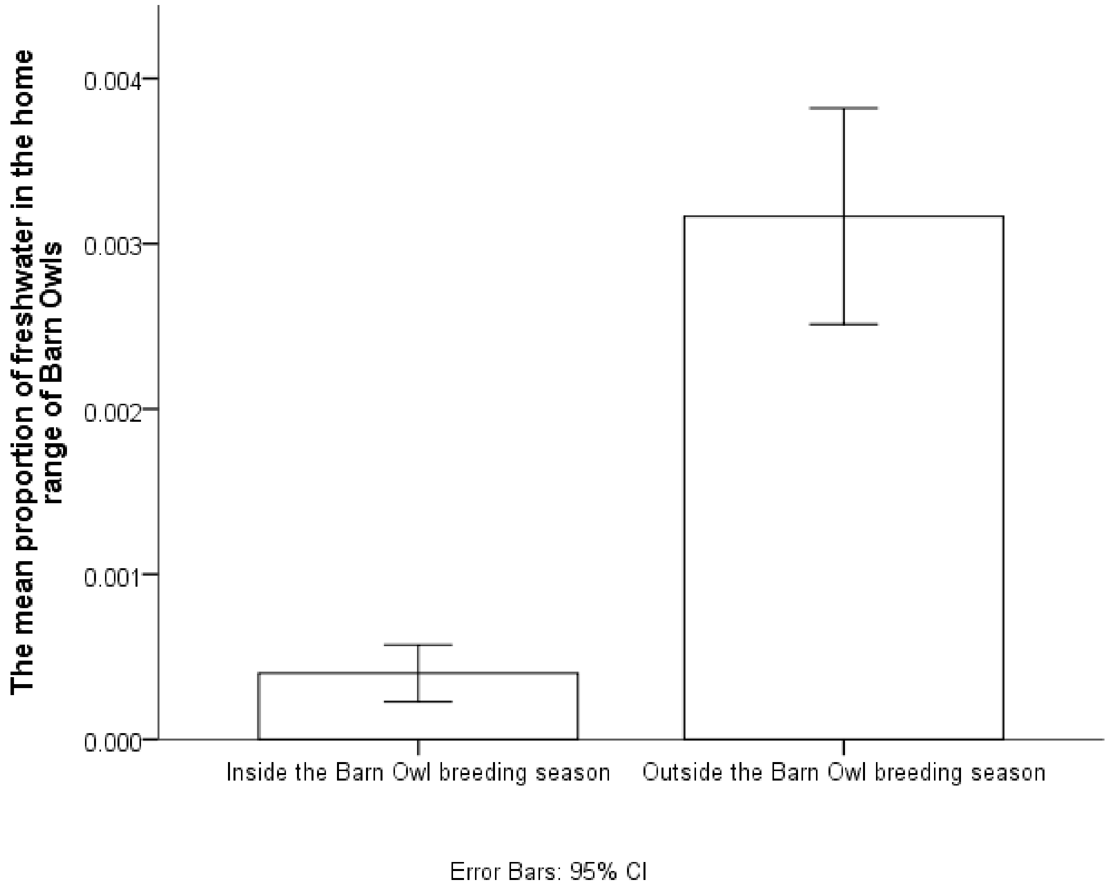


Figure 2.11 The difference in the proportion of freshwater in the home range of Barn Owls at different times of the year.

How season influences prey consumed by the Barn Owl

Of the 377 pellets collected, 190 pellets were collected during the breeding season and 187 pellets were collected during the winter roosting season. The primary prey species showed little change between seasons. In the breeding season, the diet consisted of Field Voles (66.15%), Common Shrews (15.67%) and Wood Mouse (6.69%) mean prey per pellet. Outside the breeding season the diet consisted of Field Voles (65.63%), Common Shrews (11.84%) and Wood Mouse (6.69%) mean prey per pellet.

The highest number of a prey items found in one pellet was 6 Field Voles in a pellet collected outside of the breeding season. This was followed by: 5 Field Voles per pellet inside the breeding season; 5 Water Shrews per pellet outside the breeding season and 5 Wood Mouse per pellet outside the breeding season.

Table 2.4 Independent T-test results comparing the prey weight per pellet (g) from Barn Owl pellets collected inside versus outside the breeding season.

Prey	Mean primary prey weight per pellet inside the breeding season	Mean primary prey weight per pellet outside the breeding season	t	df	P
Field Vole	53.52g	64.65g	3.391	375	0.001
Common Shrew	5.35g	4.72g	0.803	375	0.422
Wood Mouse	7.15g	4.06g	2.291	375	0.023

There were significant differences between breeding and non-breeding seasons for the mean Field Vole weight per pellet (Figure 2.12) and the mean Wood Mouse weight per pellet (Figure 2.13) (Table 2.4). However, there was no significant seasonal difference in the mean Common Shrew weight per pellet (Table 2.4).

The mean Field Vole weight per pellet increased outside the breeding season from 53.52g to 64.65g, suggesting this prey source is more important in the colder months. Whereas the mean Wood Mouse weight per pellet decreased from 7.15g to 4.72g outside the breeding season, suggesting this prey is less important as a prey choice during the colder months.

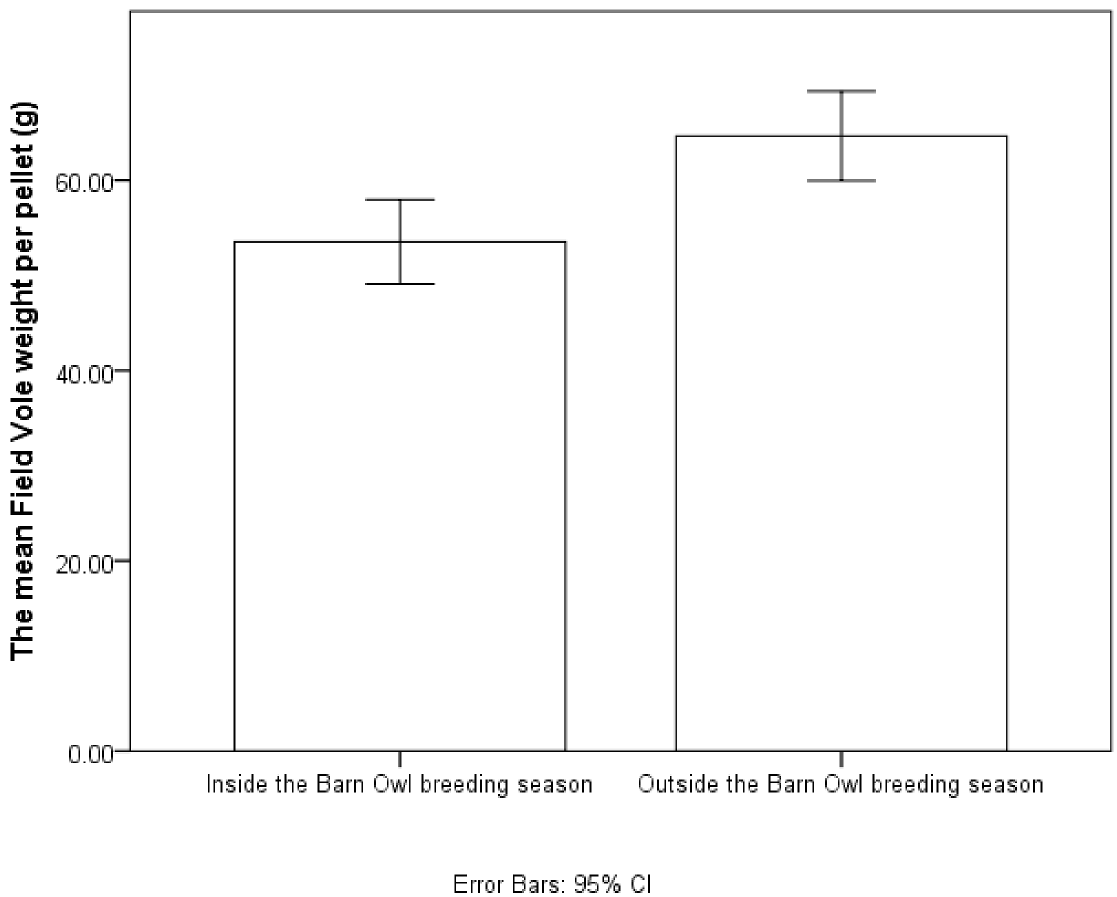


Figure 2.12 The proportion of Field Voles consumed by Barn Owls at different times of the year.

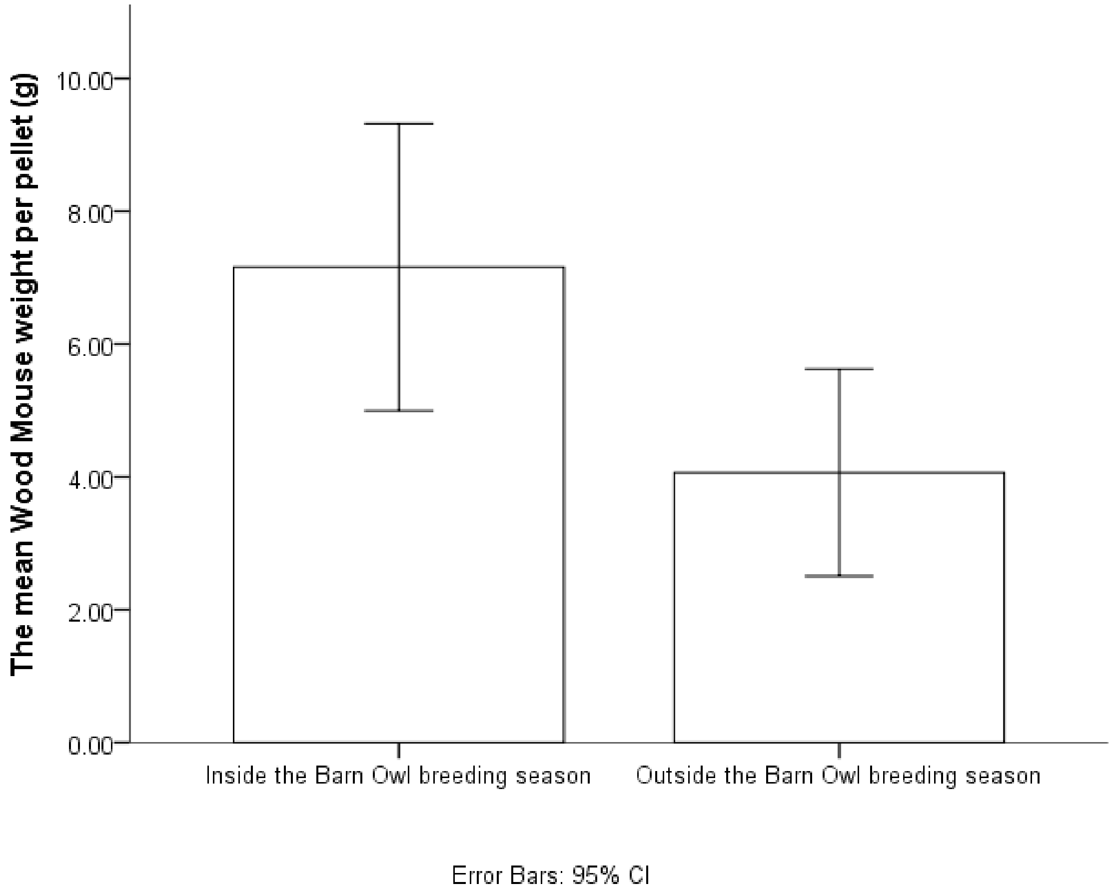


Figure 2.13 The proportion of Wood Mice consumed by Barn Owls at different times of the year.

Habitat and diet

Field Vole weight per pellet showed no statistically significant relationship with the mean proportion of neutral grassland and agriculturally improved grassland in the home range (Table 2.5). No significant relationship was found between the mean Wood Mouse weight per pellet and the proportion of arable horticulture in the home range (Table 2.6). Additionally, Common Shrew weight per pellet showed no statistically significant relationship with the mean proportion of arable horticulture, agriculturally improved grassland and neutral grassland (Table 2.7), but a significant relationship was found between mean Common Shrew weight per pellet and the proportion of broadleaved woodland in the home range (Figure 2.14) (Table 2.7). The mean Common Shrew weight per pellet was higher in areas with a low percentage of broadleaved woodland within the homerange.

Table 2.5 Summary of two general linear models with the Field Vole weight per pellet (g) as the dependent variable and habitat percentage (%) within the Barn Owl home range as the predictor variable.

Model 1.	df	F	P
Intercept	1	62.367	<0.001
Agriculturally Improved Grassland	1	0.821	<0.365
Error	375	-	-
Adjusted R Squared	< 0.001		

Model 2.	df	F	P
Intercept	1	721.304	<0.001
Neutral Grassland	1	3.833	>0.051
Error	375	-	-
Adjusted R Squared	=0.007		

Table 2.6 Summary of general linear model with the Wood Mouse weight per pellet (g) as the dependent variable and habitat percentage (%) within the Barn Owl home range as the predictor variable.

Model 1.	df	F	P
Intercept	1	53.068	<0.001
Arable Horticulture	1	0.002	0.965
Error	375	-	-
Adjusted R Squared	= 0.003		

Table 2.7 Summary of four general linear models with the Common Shrew weight per pellet (g) as the dependent variable and habitat percentage (%) within the Barn Owl home range as the predictor variable.

Model 1.	df	F	P
Intercept	1	130.650	<0.001
Arable Horticulture	1	0.009	0.926
Error	375	-	-
Adjusted R Squared	= 0.003		
Model 2.	df	F	P
Intercept	1	4.335	0.038
Agriculturally Improved Grassland	1	1.338	0.248
Error	375	-	-
Adjusted R Squared	= 0.001		
Model 3.	df	F	P
Intercept	1	113.367	<0.001
Neutral Grassland	1	0.547	0.460
Error	375	-	-
Adjusted R Squared	= 0.001		
Model 4.	df	F	P
Intercept	1	84.115	<0.001
Broadleaved Woodland	1	4.449	0.036
Error	375	-	-
Adjusted R Squared	= 0.009		

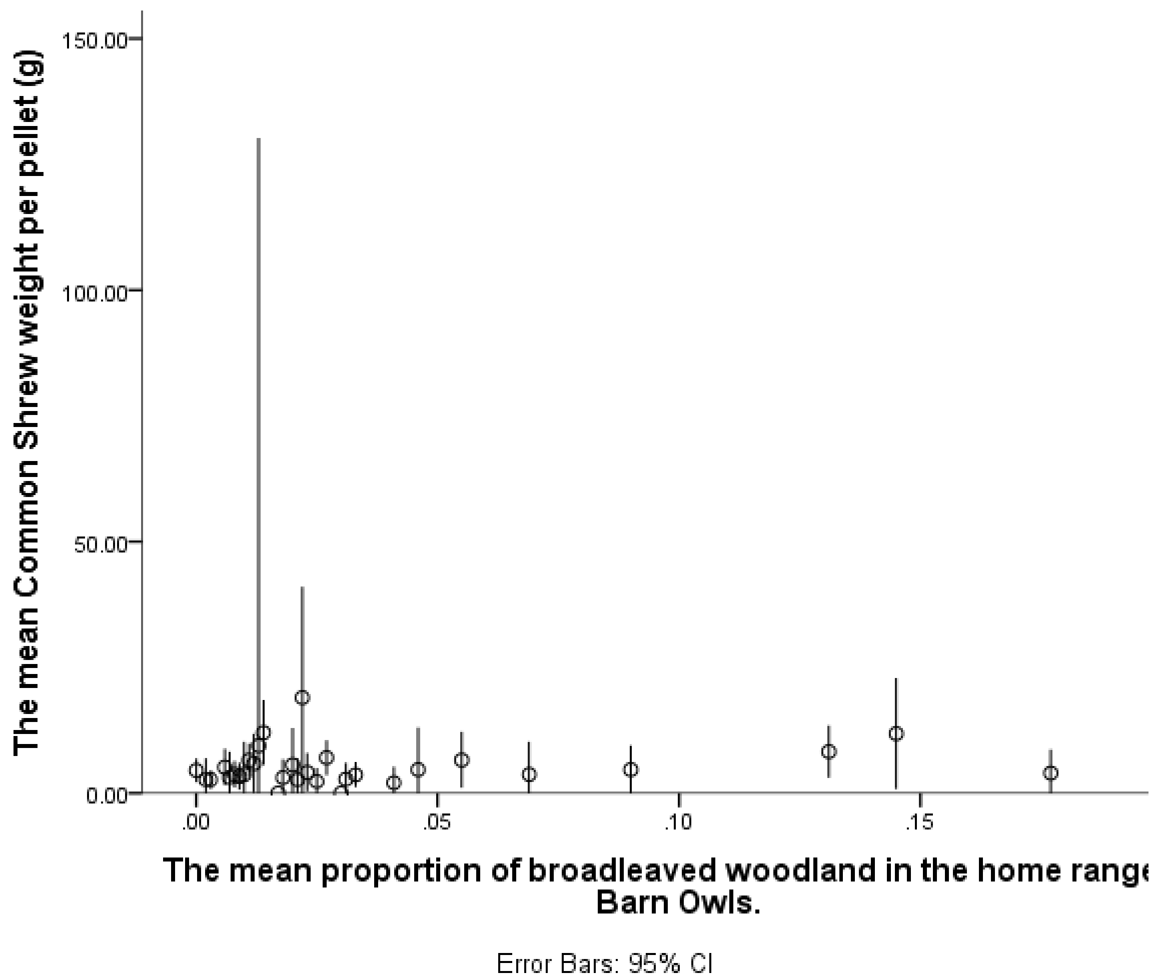


Figure 2.14 The relationship between Common Shrews weight per pellet and the proportion of broadleaved woodland in the home range of Barn Owls.

Summary

In summary, 12 species were identified in the diet of the Barn Owl, by biomass the three most abundant were the Field Vole (84.70%), Common Shrew (7.23%) and Wood Mouse (8.07%). The diet of the Barn Owl is known to change according to prey abundance and profitability, which can be influenced by season. The study found mean Field Vole weight per pellet was higher outside the breeding season compared to inside the breeding season, suggesting more Field Voles are consumed outside the breeding season during colder months. Wood Mice weight per pellet was higher inside the breeding season compared to outside, suggesting fewer Wood Mice were consumed outside the breeding season during colder months.

Additionally, the results of the study found no relationship between diet and reproductive success however, a positive association was found between the number of successful fledglings per nest and the proportion of neutral grassland in the homerange. A negative association was also found between the number of successful fledglings per nest and agriculturally improved grassland, arable horticulture and fen, marsh, swamp. This could suggest habitat is more important in nest box site selection than available prey, however nest boxes are provided by the BTO thus limiting Barn Owl choice.

Within the homerange of the Barn Owl, agriculturally improved grassland averaged 99% inside the breeding season and 92% outside the breeding season. Agriculturally improved grassland is known to have low biodiversity and species richness, such a high percentage of this habitat within the homerange of Barn Owls suggests boxes are placed in areas of poor owl hunting habitats. This could explain why no relationship was found between diet and reproductive success, as owls are either hunting in habitats of low species richness or traveling outside their homerange to find suitable hunting grounds, such as roadside verges. This may also explain why no significant relationship was found between primary prey and the proportion of neutral grassland, agriculturally improved grassland and arable horticulture.

Discussion

The findings show that rodents and shrews made up over 99% of prey consumed by the Barn Owl, with Field Voles, Common Shrews and Wood Mice making up the bulk of the diet. As a result, these species were classed as primary prey items and became the focus prey species in the study.

In the study, primary prey eaten showed no significant relationship with the reproductive success of Barn Owls. Yet, habitat within the home range was shown to have a relationship with reproductive success. Specifically, the proportion of neutral grassland in the home range was found to be positively related to reproductive success. This could suggest habitat is more important in nest box site selection than available prey, however nest boxes are provided by the BTO thus limiting the Barn Owls choice of suitable nesting sites.

Seasonality was shown to affect both prey consumption and habitats occupied. Barn Owls consumed fewer Field Voles and more Wood Mice inside the breeding season. Additionally, sites occupied during the breeding season included higher proportions of arable horticultural land inside the home range and less urbanized land, saltwater and freshwater.

Lastly, habitat within the home range was shown to affect prey consumed, specifically in home ranges with freshwater and broadleaved woodland.

Diet of the Barn Owl

The results of the present study showed that the proportion of the Barn Owl diet that was made of Field Voles (60.52%), was higher than that of previous studies. Glue (1974), found that Field Voles made up 43.7% of the Barn Owls diet in Wales and Brown (1981), recorded 42% of Field Voles in pellets collected from Gwynedd, Wales. The increase in the percentage of Field Voles could indicate a reduction in the biodiversity of small mammal species within Anglesey, assuming that Barn Owls consume prey in a similar proportion to their availability in the field (Andrade *et al*., 2016). Taking into consideration the limits of prey consumed by the Barn Owl, the distribution of prey in the diet could be indicative of the population structure of the mammal community the diet derived from (Yom-Tov & Wool, 1997). However, an increased proportion of Field Vole in the diet of the Barn Owl may also be a result of vole population cycles. Variation in the abundance of small mammal species, such as the Field Vole, can be erratic, periodic or annual (Krebs & Myers, 1974). These changes have been found to largely depend on the length and severity of winter, with small mammal fluctuations being influenced by seasonality (Stenseth *et al.*, 2003), resulting in changes in Barn Owl diet throughout the year based on prey availability and from year to year. Therefore, an increase in the percentage of Field Voles consumed when compared to previous studies could be indicative of the present study taking place during a good vole year. Future research could use data on Field Vole population numbers to confirm this.

As predicted, with an increase of Field Voles in the diet, the study has identified a decrease in the percentage of Common Shrew. In this study, the diet by number of items contained 16.31% Common Shrews; however, Glue (1974) found 30.3% Common Shrews, almost double the percentage. A reduction in the percentage of Common Shrew could be due to an increased use of insecticides. As an insectivorous small mammal (Churchfield, 1982), the Common Shrew is likely to be directly affected by the use of insecticides through the food chain, either resulting in a decrease in food availability or death through the accumulation of insecticide contaminated prey consumed.

Additionally, Glue (1974), recorded 9.8% of prey belonged to the Apodemus genus, which includes the Wood Mouse. The present study identified 8.65% of the Barn owl prey as being Wood Mouse and 0.08% Harvest Mouse but without knowing the percentage of Wood Mice in the previous study it is difficult to identify an increase or decrease in the presence of the Wood Mouse in the Barn Owl diet.

The Common Shrew (16.31%) and the Wood Mouse (8.65%) were the two most important species in the diet of the Barn Owl after the Field Vole (60.52%). In terms of the percentage of prey consumed, the Common Shrew appears to be more important in the Barn Owl diet than the Wood Mouse, however, when the weights of these species are considered this is not the case. The Mammal Society UK recorded the average weight of these species as followed: Field Vole (30g), Common Shrew (9.5g) and Wood Mouse (20g) (Corbet & Harris, 1991). Using these mean values, the present study estimated the mean weight of Field Voles per pellet as 59.05g, with a maximum of 180g per pellet; the mean weight of Common Shrews per pellet as 5.05g per pellet, with a maximum of 38g per pellet; and the mean weight of Wood Mouse per pellet as 5.62g, with a maximum of 100g per pellet. Considering this, the Wood Mouse contributes a greater mass of food per capture than the Common Shrew, as the Barn Owl would need to spend twice the time hunting if they were catching Common Shrews than if they were catching Wood Mice.

The lighter morph Barn Owl found in the UK is primarily adapted for capturing fast moving prey such as mice, due to the owl possessing shorter wings and a shorter tail in comparison to the darker morph Barn Owl found in other parts of Europe (Roulin, 2004 & Charter *et al.*, 2015a). The greater mass per capture of prey may therefore explain why UK Barn Owls which are adapted to hunt mice are found to feed on a diet comprised of majority voles, as voles are a more energy efficient food source in comparisons to mice and shrews.

How season influences prey consumed by the Barn Owl

The most important prey in winter has been found to be Field Voles (Brown, 1981); the gradual decrease in Field Vole availability throughout winter leads to an increase in the abundance of Common Shrews found in the diet of Barn Owls during summer (Bose & Guidali, 2001 & Cichocki *et al*., 2008). This is supported by the results of the present study, as a significant difference was identified between breeding and non-breeding seasons for the mass of Field Voles, per pellet, in the diet. The mean Field Vole weight per pellet was approximately 17% lower inside the breeding season than it was outside the breeding season, supporting the previous statement that Field Voles are a more important prey during winter.

However, the reproductive success of Barn Owls has been found to increase with the proportion of voles consumed (Charter *et al.*, 2015b), suggesting voles are an important food source during the breeding season which coincides with the summer months. The abundance of voles in the diet has been identified as an important factor influencing reproductive success in coastal areas (Solonen and Karhunen, 2002), which Anglesey is. Despite this, Meek *et al.* (2003) identified that the Barn Owl replaced Field Voles as prey with the less habitat-specific Wood Mouse, making Field Vole availability a less important factor in the reproductive success of Barn Owls.

A significant difference was found between the Wood Mouse weight per pellet during the breeding versus the non-breeding season. The Wood Mouse population decreases throughout the breeding seasons of the Barn Owl, resulting in lower availability during summer (Torres *et al.*, 2002) and an increase in availability during the autumn (Broughton *et al.*, 2014). In studies that did not account for the weight of prey, it was found that the proportion of rodents consumed by the Barn Owl higher in autumn and winter, likely because this is when abundance of the species peaked (Gonzalez-Fischer *et al*., 2011). However, the results of the present study found the mean Wood Mouse weight per pellet was higher during the breeding season (7.16g) than it was outside the breeding season (4.06g).

How habitat influenced the diet of the Barn Owl

Previous studies have found that Field Vole abundance tend to be highest in non-intensively farmed grassland (Aschwanden *et al.*, 2007), such as neutral grassland. A small mammal trapping study found Field Voles were not captured on set asides for the first 9 months after establishment (Tattersall *et al*., 2000), suggesting they prefer habitats that are not frequently disturbed. This suggests that Field Vole abundance would be negatively associated with agriculturally improved grasslands. Additionally, vole abundance has been found to be lower in habitats used to graze cattle (Wheeler, 2008), which is a common practice in Anglesey. However, the results of the present study showed that Field Voles weight per pellet had no relationship with neutral grassland or agriculturally improved grassland. Anglesey's landscape is dominated by agriculturally improved grassland; this may affect the relationship small mammal prey, such as the Field Vole, has with differing habitats as wildlife corridors may be sparse, preventing small mammals moving between habitats in a homogenized landscape. Fragmentation of the landscape through major roads may also be contributing factor to this, however they do provide a habitat for voles in the form of grass verges (Grilo et al., 2012).

The Wood Mouse is a generalist that occupies a variety of habitats and is adaptable to the homogenization of the landscape (Love *et al.*, 2000). The species has a preference for agricultural land (Tattersall *et al.*, 1997), where they can be abundant (Rodriguez and Peris, 2007). However, the results of the present study showed no relationship between Wood Mice weight per pellet and arable horticultural land.

Research has shown that there is a weak relationship between the population density of Common Shrews and land use (Rodriguez and Peris, 2007), likely because of their insectivorous nature (Churchfield, 1982), which enables them to occupy habitats such as grassland, woodland and arable land (Wong and Grimm, 2007). The present study found no relationship between the occurrence of shrews in the Barn Owl diet and the proportion of home range habitat that was arable horticulture, agriculturally improved grassland and neutral grassland. A significant relationship was found between Common Shrew weight per pellet and the percentage of broadleaved woodland in the homerange; the higher the percentage of broadleaved woodland in the homerange, the lower the Common Shrew weight per pellet. This is expected as Barn Owls do not hunt in woodlands, they hunt in open spaces such as meadows. This could suggest Barn Owls on Anglesey are not hunting further from their homerange however; further research needs to be conducted to determine this.

How season influenced the habitat composition inside the predicted home range of Barn Owls

The present study compared differences in the habitat composition of the home range during the Barn Owl breeding season and during their non-breeding season. The percentage of agriculturally improved grassland did not differ between seasons, likely because that habitat type is the most frequent habitat encountered on Anglesey. The percentage of arable horticulture in the home range was high during the breeding season, whereas the percentage of urbanized land, saltwater and freshwater was found to be lower during the Barn Owl breeding season. Barn Owls cannot hunt over the sea and despite being recorded to occasionally prey on frogs (Hodara & Poggio, 2016), they do not use freshwater habitats as a regular hunting habitat. Populations of urban owls are becoming ever more common however these owls need to travel further to locate suitable hunting habitats, which is indicated by the larger home ranges of urban owls (Hindmarch *et al*., 2017). This being considered, the present study did not account for the larger home ranges of urban owls which should be accounted for in future studies.

Habitats that increased in percentage as the size of the home range increased were an expected result in the study. As the home range expands from 1km to 4km, there was a greater chance of habitat diversity occurring especially as home ranges become closer to the coast. Considering this, a decrease in arable horticulture was not expected, this may be due to Barn Owl nest selection but the available nesting boxes are provided by humans. This in turn may cause human nest site selection and whilst increasing potential nesting sites, this may decrease an owl's ability to exploit particular foraging habitats by not providing a nest box. Despite the results of the present study, habitat composition changes between seasons cannot be concluded in the time period available for the present study.

How diet influences reproductive success in the Barn Owl

The results of the present study found no relationship between reproductive success and prey eaten, despite reproductive success being linked to rodent availability in previous studies (Wilson *et al*., 1986; Taylor *et al.*, 1992). Reproductive success has been found to be positively associated with the proportion of voles in the diet and negatively associated with the proportion of mice (Charter *et al*., 2015b). Despite this, the present study showed that the number of successful fledglings had no significant association with biomass of Field Voles, Wood Mice or Common Shrews consumed. Meek *et al.* (2003), found that the consumption of Field Voles was a less important factor in the reproductive success of Barn Owls, as the predator replaced voles with Wood Mouse. The results of the present study may be suggesting a similar behaviour in the Barn Owls on Anglesey; however, Anglesey's landscape is dominated by agriculturally improved grassland which has poor species richness and biodiversity. Barn Owls are known to increase their home ranges in order to locate suitable hunting habitats when nesting in areas of low prey abundance (Hindmarch *et al*., 2017), however this would involve owls expending more energy to hunt further away from the nest which could be disadvantageous. Future studies could investigate differences in Barn Owls dietary preferences, reproductive success and habitat use in areas of rich and poor biodiversity.

How habitat influences reproductive success in the Barn Owl

Barn Owls select nest boxes as a response to landscape scale composition, preferring wooden nest boxes surrounded by grassland (Wendt & Johnson, 2017) and having greater reproductive success when nesting within semi-natural grasslands (Leech *et al.,* 2009) and unimproved grassland (Kitowski, 2013 and Salek *et al*., 2016).

The present study found a positive association between the number of fledglings per nest and the proportion of neutral grassland in the Barn Owls' predicted home range. This reaffirms the importance of species rich habitats which have been lost through the intensification of farming practices (Love *et al*., 2000).

A negative association was found with the number of fledglings per nest and the proportion of agriculturally improved grassland in the home range. This is supported by Bond *et al.* (2005) and Salek *et al.* (2016), who found unsuccessful broods nested in areas of agriculturally improved grassland. Habitats such as agriculturally improved grassland are managed by humans to improve agricultural yield, however such improvements result in lower species diversity and homogenization of the landscape. On Anglesey, agriculturally improved grassland was found to make up to 99% of some Barn Owl home ranges suggesting there is little habitat diversity in the study area.

Additionally, previous studies have found unsuccessful broods nested in wetland areas (Bond *et al.*, 2005 and Salek *et al.,* 2016). The result of the present study found an association with the proportion of fen, marsh and swamp (a wetland habitat) in the home range and the number of fledglings per nest.

However, the present study also found that reproductive success was negatively associated with arable horticultural land, suggesting nests within these areas do not produce large broods. This contradicts the findings that Barn Owls have more reproductive success when nesting within arable land (Kitowski, 2013 and Salek *et al*., 2016). The intensive farming practices used across most of Anglesey could explain the lack of relationship found between reproductive success and the percentage of arable horticultural land within the home range of Barn Owls. Intense farming practices produce habitats which have poor biodiversity; lower species richness and lower small mammal abundance. Additionally, many of the farms on Anglesey have grazing sheep and cattle, this means vegetation will be short in length and regularly disturbed which is not ideal for small mammal species such as the Field Vole.

Conclusion

Despite the importance of diet being discussed in previous studies, the result of the present study found no relationship between prey weight per pellet and owl reproductive success, however habitat was found to have a positive relationship with reproductive success. Agriculturally improved grassland dominated the study area, making up to 99% of the habitat composition of some home ranges. The study found that increased proportions of agriculturally improved grassland within the Barn Owls homerange had negative effects on reproductive success, however a positive association between fledglings and the proportion of neutral grassland in the home range was found. This highlights the importance of maintaining species rich, undisturbed habitats such as dry hay meadows in areas of intense agriculture. Conservation efforts should focus on habitat restoration to provide a landscape with diverse habitats of different management levels, plant species and as a result differing prey species.

It could be argued that diet does play an important role in reproductive success and population success of Barn Owls, as the study also found that habitat was shown to affect prey consumed. The relationship was only found between the Field Vole and Wood Mouse with the proportion of freshwater in the home range; and between the Common Shrew and the proportion of broadleaved woodland in the home range. Despite this, it could be argued that the true relationship between habitat and prey cannot be deduced from pellet analysis, as Barn Owls are known to travel long distances to find suitable hunting grounds (Hindmarch *et al*., 2017).

The observed changes in farming practices have led to the loss of many suitable foraging habitats, resulting in habitats of low small mammal abundance and diversity (Love *et al*., 2000). The presence of species rich, undisturbed habitats within the home range of Barn Owls is an important factor to consider when implicating conservation strategies, to increase population success of the species.

Barn Owl's nests often occur in close proximity to one another as they are typically not territorial; yet breeding densities have no effect on either foraging or breeding success (Meek *et al.*, 2003). Therefore placing multiple nest boxes within neutral grassland, or any other area where species rich habitats cover a considerable proportion of the predicted home ranges during the breeding season, could prove to be a way of increasing reproductive success. Multiple nest boxes within a home range has the potential to encourage double broods, which could accelerate Barn Owl population growth in Anglesey.

Chapter 3. The factors influencing the occurrence of Barn Owl vehicle collisions

Abstract

The Barn Owl population decline has been attributed to increased agricultural intensity and urbanization. The expansion of road networks to accommodate more vehicles on the road, has led to habitat fragmentation and ecological traps. Barn Owls are the most frequent bird species encountered on road casualty surveys, with over half of Barn Owls deaths being a result of wildlife-vehicle collisions.

The objectives were to identify characteristics of Barn Owl road mortality hotspots and investigate factors influencing the occurrence of Barn Owl vehicle collisions. The study was conducted on a 35.24km section of the A55 running from one end of Anglesey to the other. Barn Owl road mortality hotspots were investigated using data provided by the North & Mid Trunk Road Agency; the date the casualty was reported and the grid reference of the casualty location. Additionally, the British Trust for Ornithology provided data on reproductive success.

There were 117 Barn Owl road casualties on the A55 Anglesey recorded by the North Trunk Road Agent between 2001 and 2017, this equate to 0.196 Barn Owls/year/km. The month in which the most deaths occurred was April with 18 deaths, and the least was August with only 1 death, however no relationship was identified between the time of

year and the number of Barn Owl road casualties. Additionally, no relationship was found between habitat and owl road mortalities, however, a relationship was found between the presence of grass slope verges at the side of the A55 and bi-monthly road mortality. The number of deaths in areas with grass sloping verges was recorded as 29 and in none grass slope area was 87.

Introduction

The presence of roads is a fundamental part of human society, providing many economic and social benefits. However the presence of roads, and the vehicles on them, can have negative implications on the surrounding wildlife. They fragment, disturb and reduce habitats as well as increase human disturbance especially through light and sound pollution (Brumm, 2004; Fuller *et al*., 1995; Parris & Schneider, 2008; Fahrig & Rytwinski, 2009; Barber *et al*., 2010; Summers *et al*., 2011; Berthinussen & Altringham, 2012; McClure *et al*., 2013; Strasser & Heath, 2013; Barthelmess, 2014; Ware *et al*., 2015). As a result, millions of vertebrates are killed each year through wildlife-vehicle collisions (Brown & Brown, 2013). However, vehicle animal collisions also has detrimental effects on humans, as wildlife put motorists at risk of vehicle damage, injury and even death (Kociolek *et al*., 2011).

Understanding the impact roads have on wildlife behaviour and their population densities can mitigate the negative effects (Sadleir & Linklater, 2016). It is estimated that one million vertebrates are killed annually on UK roads (Slater, 1994), with seasonal changes in animal activity, such as natal dispersal, being the most likely cause (Sadler & Linklater, 2016). The increase in animal road kill is so high in some areas it is suppressing populations of migrating and dispersing species, as well as residential species such as in the Grizzly Bear (Boulanger & Stenhouse, 2014) and in Spotted Salamanders (Gibbs & Shivers, 2005).

The presence of roads acts as a barrier to dispersing wildlife, affecting movements and behaviour (Taylor & Goldingawy, 2010) in very different ways. Interestingly, populations of herbivorous mammals such as rodents and ungulates have been found to increase in response to roads (Rytwinski & Fahrig, 2015), carrion eating species such as the Raven and Black Kite have shown no population response (Palomino & Carrascal, 2007), whereas carnivorous mammals have been shown to decrease in response to the presence roads (Rytwinski & Fahrig, 2015).

Wildlife collision preventative measures typically focus on ungulates, which are often the cause of many highway problems, meaning birds are often overlooked (Kociolek *et al*., 2015). Despite this, it is estimated that 89-340 million birds die annually from vehicle collisions on U.S roads (Kociolek & Clevenger, 2011). The Barn Owl is the most numerous bird species encountered on road casualty surveys in France (Baudvin, 2004) and in the USA (Boves & Belthoff, 2012). Birds that are heavy relative to their wing size and have a lower take-off trajectory, such as owls, have been suggested to be more susceptible to wildlife-vehicle collisions than other birds (Kociolek & Clevenger, 2011). Barn Owls hunt relatively low to the ground therefore the absence of continuous low flight obstructions is a likely factor contributing to Barn Owl vehicle collisions, as obstructions force the bird to fly up and over the roadway.

The decline of Barn Owls has been suggested to be largely due to land use change, habitat loss and pesticide use but with road traffic casualties rising and becoming ever more relevant as a cause (Fajardo, 2001). Death from wildlife-vehicle collisions is a major mortality factor in Barn Owl ecology and can account for 56-70% of known deaths (Taylor, 1994; Fajardo *et al*., 2000). The number of Barn Owl deaths caused by traffic collision has increased from previous years (Glue, 1971; Newton *et al*., 1991), with 0.64 owls/km/year recorded in Great Britain (Taylor, 1994).

The majority of Barn Owls encountered in road casualty surveys are juveniles (Grilo *et al*., 2014), likely due to the fact young birds are naive and have less experience living in proximity to roads. Juvenile birds also undertake natal dispersal movements during their first year of life (Taylor, 1994) and this could increase the likelihood of encountering roads and suffering greater rates of mortality (Boves and Belthoff, 2012). However, the increased number of juvenile road casualties could reflect the natural age structure of the population (Marti, 1997), as after the breeding season there is an increase in the number of juveniles that make up the population and as a result more juveniles come into contact with vehicles.

Traffic noise has been shown to reduce the hunting efficiency of acoustic predators (Siemers & Schaub, 2010). Therefore, Barn Owls should avoid areas where noise and disturbance negatively influences foraging efficiency (Hindmarch *et al*., 2012). Yet Barn Owls have frequently been observed hunting on the grass verges of busy roads and therefore do not actively avoid these habitats (Hindmarch *et al*., 2012; Hindmarch *et al*., 2017), with owl vehicle collisions seeming to result from individuals ignoring traffic (Grilo *et al*., 2014).

The time of year has been found to influence the occurrence of Barn Owl road casualties, as fewer deaths are recorded from May to July which coincides with the main period of the breeding season - the time when food is plentiful and the females are confined to incubation at the nest (Newton *et al*., 1991). The rise in mortality from September to November likely results from the population reaching its annual peak after the breeding season has ended (Newton *et al*., 1991) and an influx of recently fledged juvenile birds into the population.

Increased winter mortality has been suggested to be linked to physiological characteristics which require Barn Owls to hunt more in cold winter months to avoid starvation (Boves and Belthoff, 2012), which coincides with peak traffic volume. During winter there are more cars on the road at dawn and dusk, as the shorter day lengths result in an earlier dawn and dusk - preferred Barn Owl hunting times - which coincide with rush hour traffic, people traveling to and from work.

It has been suggested that the condition of the Barn Owl may influence its likelihood of being killed in a road traffic collision. For example, poor condition such as starvation may lead owls to spend more time hunting in places where accidents are likely, such as road verges and make them less able to avoid collisions (Newton *et al*., 1991). Therefore, because of these physiological traits and being ground prey dependent with a narrower range of prey items than other owls, the Barn Owls may have to expand their hunting areas to fulfill their energetic needs of the upcoming reproductive season which corresponds to a dramatic reduction of prey abundance (Taylor, 1994).

Grass road verges have been shown to support a high abundance of small mammals, making them attractive habitats and important hunting grounds for Barn Owls (Grilo *et al*., 2012). A study in Spain found Barn Owls killed on roads were recovered from areas where vole numbers where at maximum (Fajardo, 2001), resulting in owls becoming more tolerant to roads (Grilo *et al*., 2012). This could make grass verges increasingly important yet a potential risky foraging habitat for Barn Owls (Hindmarch *et al*., 2012).

In order to understand the impact of roadway mortality on Barn Owls populations, immigration must also be considered (Boves and Belthoff, 2012). Despite for the most part being considered non-migratory (Marti, 1988), Barn Owls do undergo post juvenile dispersal and have been recorded traveling over 1900 km from their natal sites (Taylor 1994 and Marti, 1988).

The volume of traffic, speed and size of vehicles, road design and density are the most frequent factors thought to contribute towards bird mortality on roads (Massemin & Zorn, 1998; Clevenger *et al*., 2003; Erritzoe *et al*., 2003; Baudvin, 2004; Holm & Laursen, 2011; Kociolek *et al*., 2011). Barn Owl mortality has been found to be higher near grassy verges than shrub verges (Hodora and Poggio, 2016), with Barn owls using nesting sites in proximity to busy roads suffering higher mortality (Hindmarch *et al*., 2012). The occurrence of owl vehicle collisions is also higher in areas with low slopes (Baudvin, 1997; Massemin & Zorn, 1998; Lode, 2000; Arnold, 2016), water features such as streams (Gomes *et al*., 2009; Boves & Belthoff, 2012; Grilo *et al*., 2012; Arnold, 2016), and a high percentage of crop fields (Arnold, 2016).

A previous study found the number of Barn Owl road kills decreased with the presence of secondary roads, human structure such as houses and the presence of dairy farms (Arnold, 2016). These three characteristics can be explained as Barn Owls are known to follow straight lines (Develey and Stouffer, 2001; Riley *et al*., 2006; Grilo *et al*., 2012), such as roads and hedges, therefore may use secondary roads to avoid contact with major roads. Human structures such as houses and buildings may prevent owls from coming in contact with major roads, causing them to avoid low flight zones as they would need to fly up above the human structure to get to the road and as a result are more likely to fly up over the major road or to use the human structure as a border for their homerange (Develey and Stouffer, 2001; Riley *et al*., 2006; Grilo *et al*., 2012). The presence of dairy farms is likely due to prey abundance, dairy farms do not make ideal owl hunting habitats as grazing cattle results in short grass which is a poor habitat for small mammals, suggesting Barn Owls would not use this habitat to forage in and thus wouldn’t come into contact with roads in areas with an increased presence of dairy farms.

Habitat also plays an important role in influencing Barn Owl road mortality. Barn Owls in both urban and agricultural landscape have been found to select roadside grass verges significantly more than other habitat types, based on availability within their home range (Hindmarch *et al*., 2017). Mortality has been found to be the most common where agricultural land borders the roadway, predominantly cultivated crops, pasture and hayfields (Boves and Belthodd, 2012). The population of Barn Owls that occupy urban areas is lower (Hindmarch *et al*., 2017) and these urban owls need to travel longer distances to locate suitable hunting habitats (Hindmarch *et al*., 2017). Urban owls nest in industrial structures and under highway bridges, radio-tagged Barn owls have frequently been observed hunting at grass road verges (Hindmarch *et al*., 2017).

Dispersal seems to play an important role in explaining mortality mainly for tawny and little owls; however diet type seems to be the key role in Barn Owl vulnerability to roads rather than dispersal itself (Grilo *et al*., 2014). Barn Owls in both urban and agricultural landscapes have been found to select roadside grass verges more than other habitat types, with Field Voles being the main prey item for all Barn Owls irrespective of land use (Hindmarch *et al*., 2017). Ascenao *et al*., (2012), found high prey availability in highway verges with cattle exclusion fences. Additonally, a previous study showed that Barn Owls tend to move towards road verges with herbaceous cover where small mammals are abundant (Grilo *et al*., 2012).

Barn Owls do not appear to avoid roads (Grilo *et al*., 2012), flying at the same height as cars is likely the resulting cause of mortality (Arnold, 2016). Also, turbulence caused by large vehicles is likely to increase owl road mortality deaths (Ojeda *et al*., 2015).

Aims

The study aims to investigate the seasonal and habitat effects associated with Barn Owl vehicle collisions. I was also interested in examining the influence population numbers and breeding success have on the occurrence of owl vehicle collisions was also examined. To do so, I used records of owl vehicle collisions to identify: owl casualty hotspots, seasonal variation in owl vehicle collisions, and road and habitat features associated with mortality. Reducing wildlife collision risk for Barn owls in Anglesey is an important step in ensuring the successful conservation of the population.

Methods

Study Area

The study area was located in Anglesey, an island off the coast of North West Wales, using data collected from 2001 to 2017. The island covers 444 square kilometers, much of which is used for relatively intensive cattle and sheep farming. Alongside agricultural farming, Anglesey relies on tourism for much of its economy, as Holyhead port handles more than 2 million passengers each year. Tourist visit Anglesey for the wildlife and scenery; historical relics and recreational activities such as cycling and surfing.

However, Anglesey is home to various species under conservation concern therefore it has many sites of significant ecological interest such as coastal areas, wetlands and lakes. These habitats are given greater protection through both UK and European designation because of their conservation value supporting wildlife such as Peregrine Falcons, Harbor Porpoises and Marsh Fritillary.

The North Wales expressway (A55), is a dual carriageway primary route, running from Chester to Holyhead. The length of the A55 on Anglesey is 35.24km, running from Menai bridge to Holyhead and is largely surrounded by agricultural grasslands its entire length.

The North and Mid Trunk Road Agency, is an agency delegated by the welsh government with the responsibility of operating and maintaining trunk roads. The agency's ecologist Jill Jackson works with British Trust for Ornithology (BTO) volunteers and members of the public to record incidences of wildlife-vehicle collisions. The A55 is not scoured periodically looking for road kill, however all sightings of road kill reported are recorded.

Barn Owl Road Casualty Data Collection

The occurrence of Barn Owls found as road kill was reported to the North & Mid Trunk Road Agent, who provided data for the present study. The grid reference of the location where the road kill was found, the date the road kill was found and who recorded the data were all provided. In total, 117 Barn Owls were recorded as road kill from 2001-2017. The rate of death was then calculated by dividing the total number of deaths by the number of years and the length of the A55 Anglesey (35.244km).

Habitat Analysis

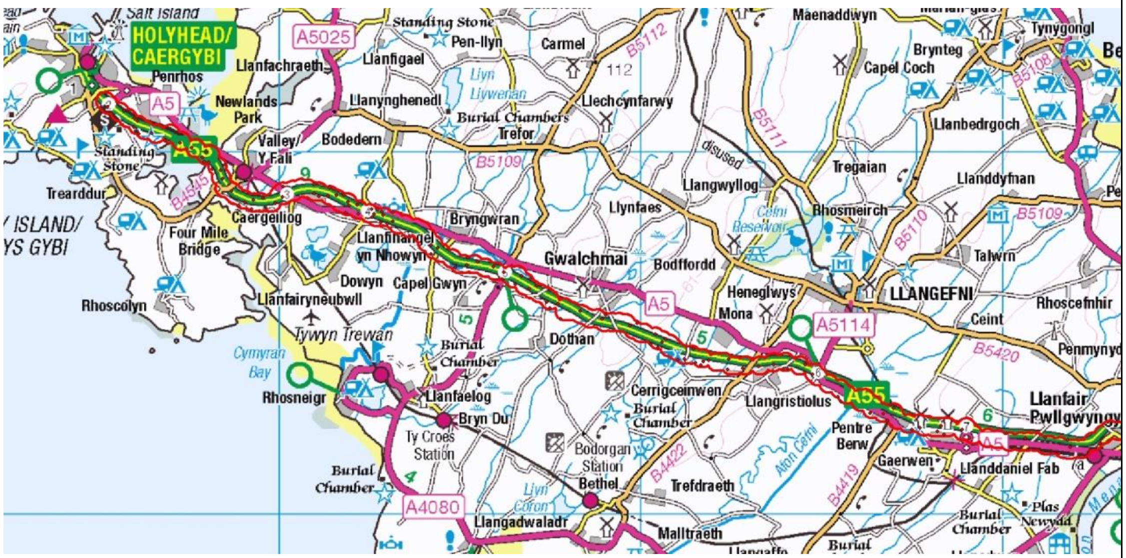
The program ArcMap 10.4 was used to determine the habitat within a 1km radius around the site where the Barn Owl was found.

A National Land Cover Database Raster Layer which contained 21 land cover types was accessed through Digimap and used to determine the percentage of each land cover category in each buffer zone. The land cover types where: sea; broadleaved woodland; coniferous woodland; arable horticulture; agriculturally improved grassland; neutral grassland; calcareous grassland; acid grassland; fen, marsh, swamp; heather; heather grassland; bog; inland rock; saltwater; freshwater; supra-littoral rock; supra-littoral sediment; littoral rock; littoral sediment; saltmarsh; urban; sub-urban.

Using the National Land Cover Database Raster Layer, habitat data was extracted using the Buffer tool and the Tabulate Area tool in ArcMap 10.4. The Tabulate Area tool calculates the habitat composition inside each buffer zone providing each habitat present within the zone in meters squared. This information was then converted into percentages using the total area of a 1km circle as a proxy, with any land not accounted for being classed as sea.

In order to compare the sites where Barn Owl road casualties' occurred and sites where they did not, a sequence of randomly generated points was created as a means of comparison. The program ArcMap 10.4 was used to create 117 random points distributed along the A55 in Anglesey (Figure 3.1). This was done by merging 250m buffers around the existing points and then using the Create Random Points Tool (Random Generator ACM 599) to generate points within the zone created.

a.



b.

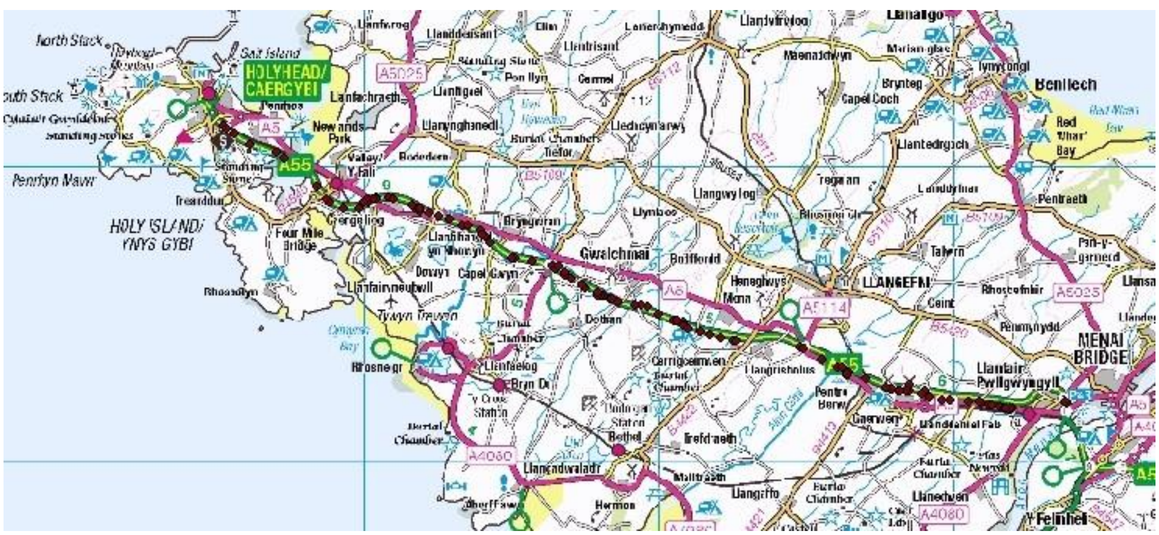


Figure 3.1 A map of the study area showing the A55 running from Holyhead to Menai bridge. The figure shows: a) The red dots along the A55 are the randomly generated sites used in the analysis. B) The pink dots along the A55 are the Barn owl road casualty sites provided by the Mid North and Mid Wales Trunk Road Agency from 2001-2017.

Road Characteristic Data Collection

Observational data were collected at each mortality site and each randomly generated site through the use of Google Earth Street View. A preliminary survey was conducted to compile a list of characteristics to examine based on observations at mortality and randomly generated sites. Additional characteristics were also taken from previous studies such as Arnold (2016). Characteristics were then recorded on a presence and absence basis and only those that could be seen on street view were recorded. The characteristic included was the presence/absence of: buildings, secondary roads (including bridges), street lights, grass verges, stone wall/cement wall, hedges, shrubs, trees, stone slope and grass slope verge (Figure 3.2).

Figure 3.2 An image taken from one of the randomly generated sites via Google Earth to illustrate a sloping grass verge.

Breeding Data

In order to investigate whether population size has an influence on road mortalities, a proxy for population size in each year needed to be assigned. The British Trust for Ornithology (BTO) provided data on the number of fledglings from BTO nest boxes each year. There were a total of 2351 hatchlings from 2004-2017. This information was then used to calculate the number of fledglings each year and the mean number of fledglings per nest each year.

Statistical Analysis

All statistical tests were run on IBM SPSS Statistics 24. A multivariate general linear model and a univariate general linear model were conducted with the mean number of fledglings per nest each year and the mean number of deaths each year, the year after. A multivariate general linear model was used to assess all road characteristics recorded. A univariate general linear model was used to assess if there was a relationship between the presence of grass slopes at the side of the roads and bi-monthly mortality. A multivariate general linear model was used to look at all habitat types and the presence of recorded Barn Owl road mortalities. Following this, habitat was put into two groups. Group 1 (Urbanized Land) contained the percentage of urban land plus the percentage of sub-urban land. Group 2 (Non-Urbanized Land) contained the sum of the percentages for the remaining habitats: sea; broadleaved woodland; coniferous woodland; arable horticulture; agriculturally improved grassland; neutral grassland; calcareous grassland; acid grassland; fen, marsh, swamp; heather; heather grassland; bog; inland rock; saltwater; freshwater; supra-littoral rock; supra-littoral sediment; littoral rock; littoral sediment; saltmarsh. An Independent T-test was then conducted comparing the means of the two groups for mortality and randomly generated sites.

Results

Barn Owl Population Size

The British Trust for Ornithology (BTO) recorded 2351 fledglings from BTO nest boxes on Anglesey from 2004 to 2017 (Figure 3.3). The highest number of fledglings produced in one year was 470 in 2014 whilst the fewest were 61 in 2004. Figure 3.1 shows a gradual increase in the number of fledglings up until 2014 followed by a decrease after 2015.

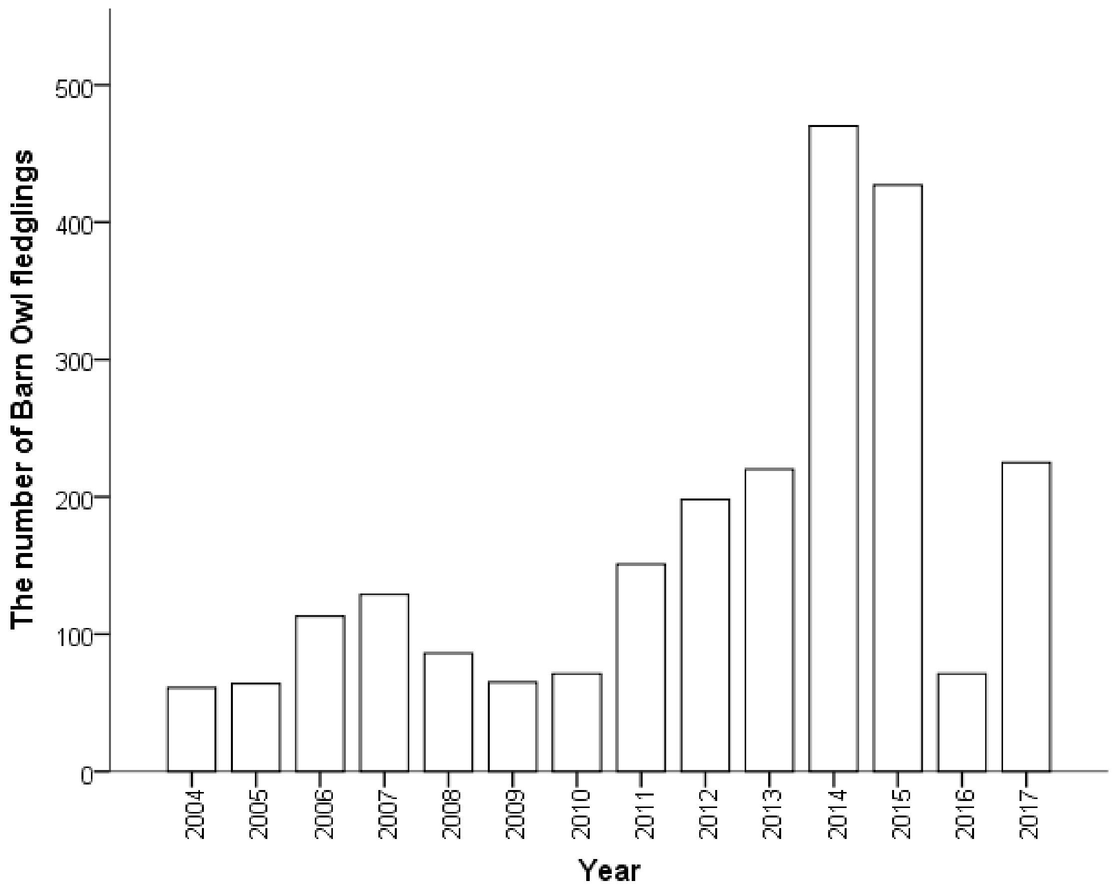


Figure 3.3 The number of Barn Owl fledglings from BTO nest boxes in Anglesey and Gwynedd each year from 2004-2007.

Barn Owl Road Casualties

There were 117 Barn Owl road casualties on the A55 Anglesey recorded by the North & Mid Truck Road Agent between 2001 and 2017 (Figure 3.4). This equates to 0.196 Barn Owls/year/km. A total number of 10 of these casualties occurred before 2004, equaling 107 deaths from 2004 to 2017. This equates to 0.217 Barn owls/year/km.

The highest occurrence of Barn Owl road casualties recorded on the A55 by the North & Mid Truck Road Agent was 18 deaths in 2008. There was a decrease in the number of Barn Owl casualties after 2009 of 8 deaths. The least number of Barn Owl casualties was 2 in 2011 (Figure 3.4).

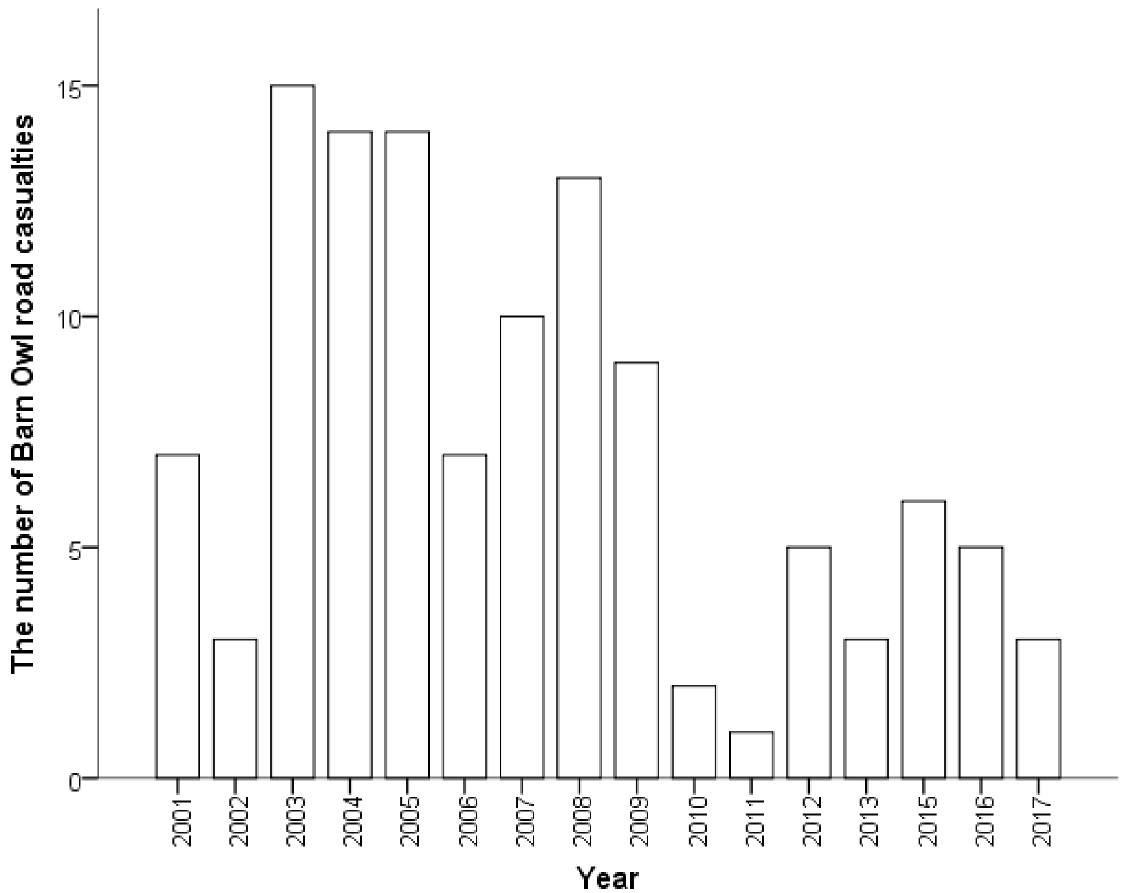


Figure 3.4 The number of Barn Owl road casualties recorded by the North and Mid Wales Trunk Road Agency from 2001-2017.

Average fledglings per nest fluctuate yearly in accordance to a variety of factors. The highest occurrence of fledglings per nest was 3.95 in 2014 and the least was 2.54 in 2016. The results of a univariate general linear model showed no significant relationship between the mean number of fledglings per nest per year and the number of Barn Owl road casualties that occurred the following winter (Figure 3.5) (Table 3.1).

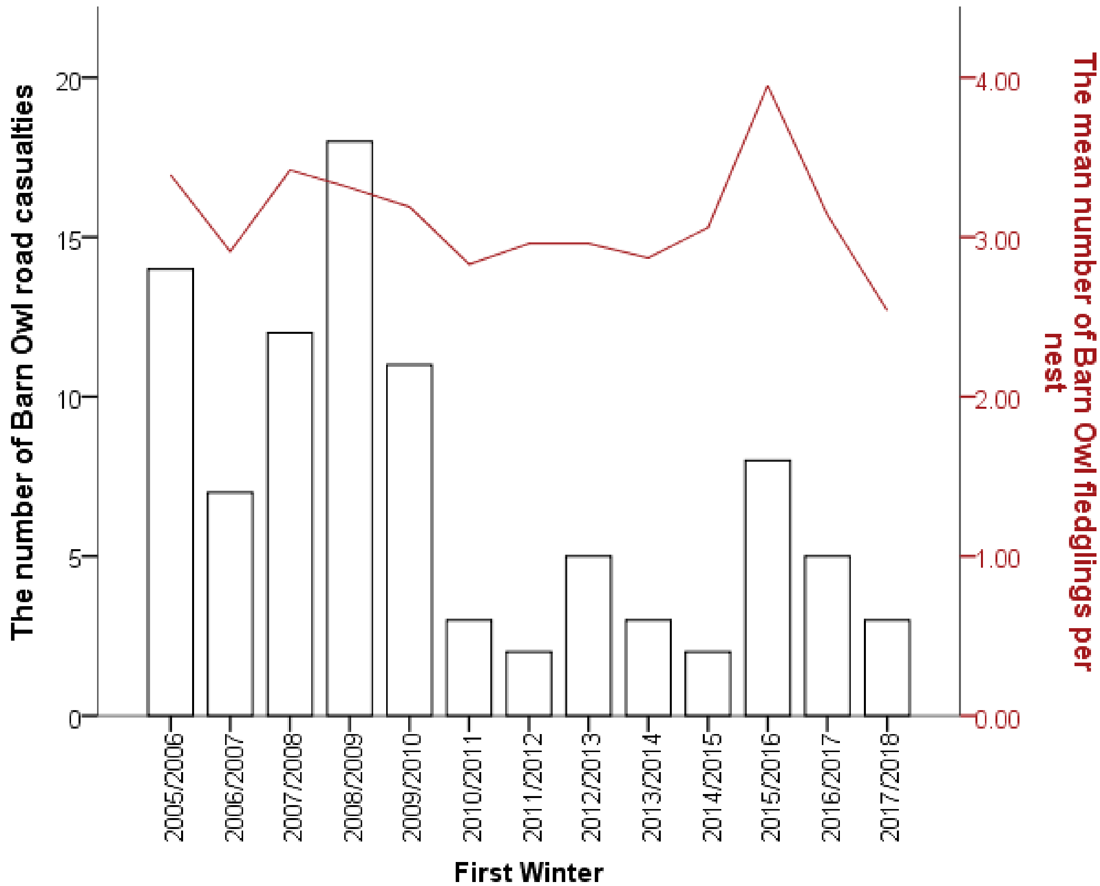


Figure 3.5 The number of Barn Owl road casualties on the A55 recorded by the North & Mid Trunk Road Agency, the winter in which the death occurred and the mean number of fledglings from BTO nest boxes each year from 2005-2017.

Table 3.1 Univariate general linear model comparing the number of Barn Owl road casualties which occurred during the first winter as the dependent variable and the mean number of fledglings per nest as the predictor variable.

Model 1.	df	F	P
Intercept	1	0.002	0.966
Mean Fledglings Per Nest	1	0.148	0.708
Error	12	-	-
R Squared	= 0.012		
Adjusted R Squared	= 0.070		

Seasonal Variation

The month in which to most deaths occurred was April with 19 deaths and the month with the fewest deaths was August, with only 2 death (Figure 3.6). Peak deaths occurred in April from 13 deaths in March to 19 deaths in April, potentially due to dispersal movements from winter roost sites to nesting grounds meaning owls are coming into contact with roads.

Fewer deaths occurred May-August, this coincides with peak prey availability resulting in less need to hunt at the road side verges. Additionally, May-August coincides with the Barn Owls breeding season, as during this time female Barn Owls will be sat on eggs or with chicks meaning there are less Barn Owls hunting therefore less chance of Barn Owl road casualties.

There is a decline in the number of deaths from 17 deaths in December to 6 deaths in January, which needs to be investigated further to understand why. However, no significant relationship was found between the time of year (season, bi-monthly, monthly) and the number of Barn Owl road casualties.

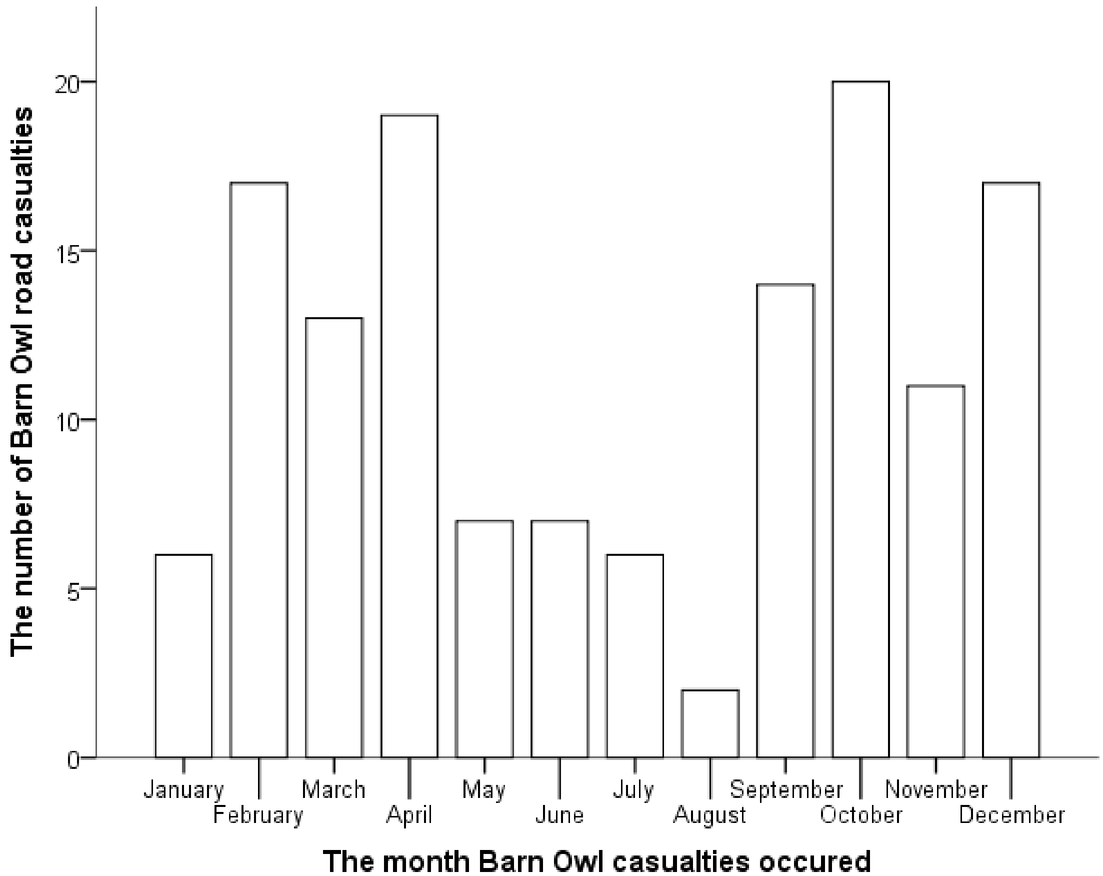


Figure 3.6 The number of Barn Owl road casualties that occurred each month.

Table 3.2 Univariate general linear model to compare the number of road casualties which occurred at sites grass slope verges as the dependent variable with bimonthly road casualties as the predictor variable.

Model	df	F	P
Intercept	1	0.345	0.558
Mortality	1	6.548	0.012
Error	115	-	-
Adjusted R Squared	= 0.046		

No significant relationship was found between habitat and the time of year (season, bi-monthly, and monthly) that Barn Owl road casualties occurred, but a significant relationship was found between the presences or absences of grass slope verges at the side of the A55 and bi-monthly Barn Owl road casualties, (Table 3.2) (Figure 3.7). Grass slope verges are wide areas of long grass and shrubs sloping down towards the road which provides habitats for small mammal communities and as a result provide Barn Owl hunting habitats away from the roads edge. More Barn Owl road casualties were recorded in locations without grass slope verges than in areas with grass slope verges.

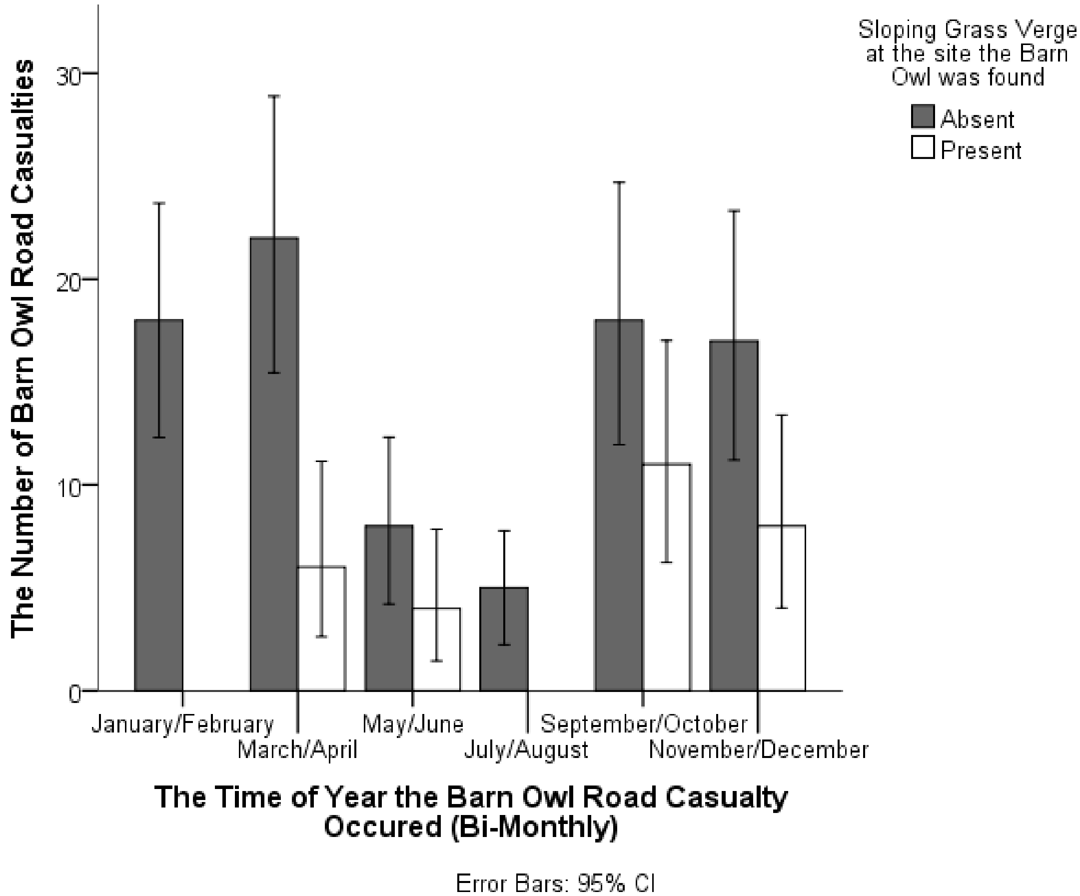


Figure 3.7 How the presence of sloping grass verges influences the occurrence of Barn Owl road casualties at different times of the year.

The number of deaths in areas with grass slope verges at the side of the A55 was recorded as 29 and in none grass slope areas was 87 (Figure 3.7). When grouping data bi-monthly the most deaths occurred in September/October (11 deaths in areas where grass slope verges were present and 18 deaths in areas where grass slope verges were absent). This is the bi-monthly group with the lowest difference between deaths in areas with and without grass slope verges. However, it coincides with the time of year when young owls will be dispersing away from natal grounds and would be likely to come into contact with roads for the first time. The largest difference between bimonthly deaths in areas with and without grass verges occurred within January/February; 0 deaths in areas where grass slopes verges were present and 18 deaths in areas where grass slope verges were not present.

Habitat

Agriculturally improved grassland made up an average of 75.8% of the 1km radius around Barn owl road casualty sites, with sites varying from 0% to 100% (Figure 3.8). This was similar to the 70.4% cover of agriculturally improved grassland for the 1km radius around randomly generated sites, which also varied from 0% to 100% (Figure 3.8).

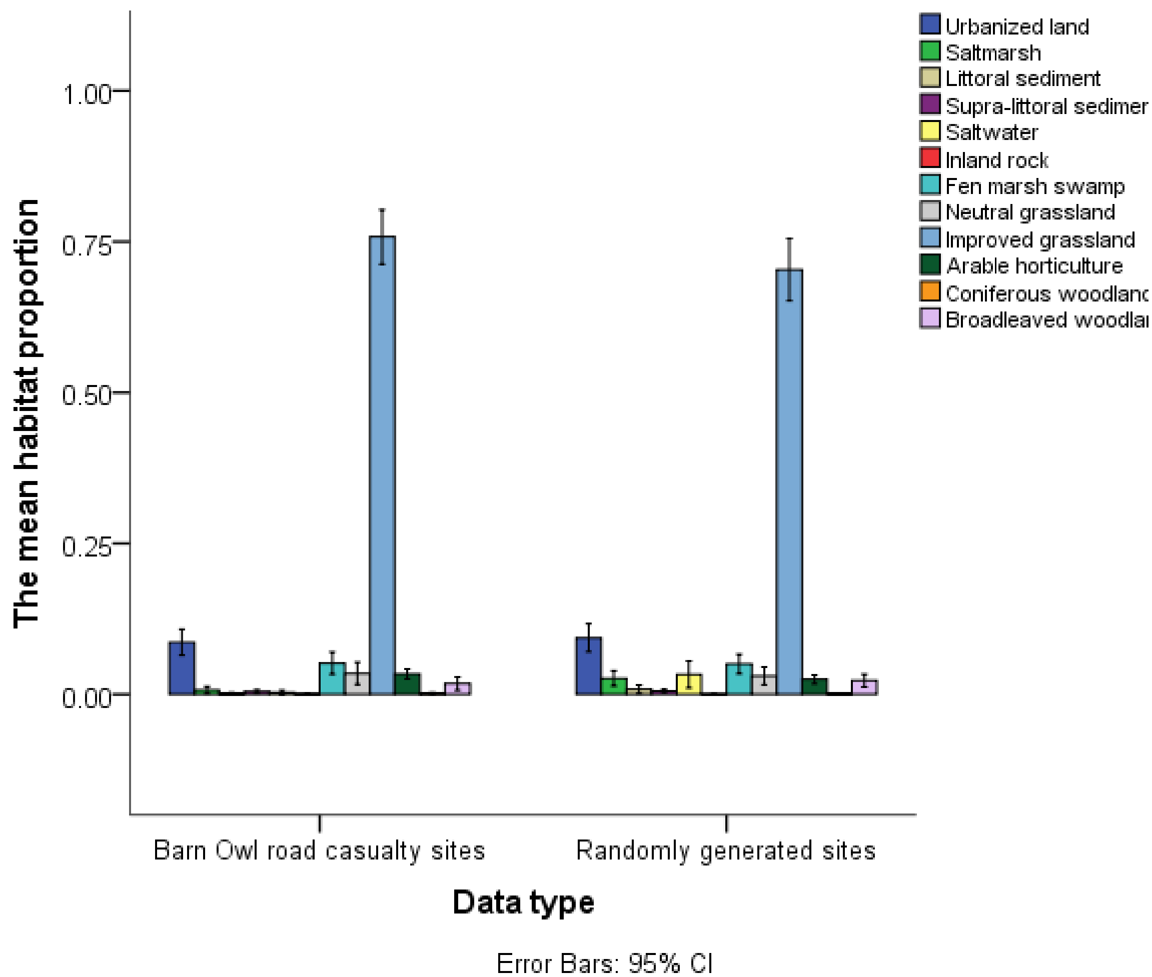


Figure 3.8 The habitat surrounding Barn Owl road casualty sites. Habitat composition was calculated using a 1km circular buffer zone around each casualty site.

Table 3.3 Independent T-test results comparing habitat composition (%) within a 1 km buffer zone around Barn Owl road casualty sites versus randomly generated sites. The category non-urbanized land contained the sum percentage of: broadleaved woodland, coniferous woodland, arable horticulture, agriculturally improved grassland, neutral grassland, fen marsh swamp, inland rock, saltwater, supra-littoral sediment, littoral sediment and saltmarsh.

Habitat	Mean habitat percentage at Barn Owl road casualty sites	Mean habitat percentage randomly generated sites	t	df	P
Urbanized Land	91.3%	90.6%	-0.443	232	0.658
Non-urbanized Land	8.6%	9.3%	0.442	232	0.659

Urbanized land makes up an average of 8.7% of the 1km radius around Barn Owl road casualty sites; however sites vary from 0% to 75.5% in some areas of the A55. This number is similar to 9.4% urbanized land in the 1km radius of randomly generated sites, varying from 0% to 65.4%.

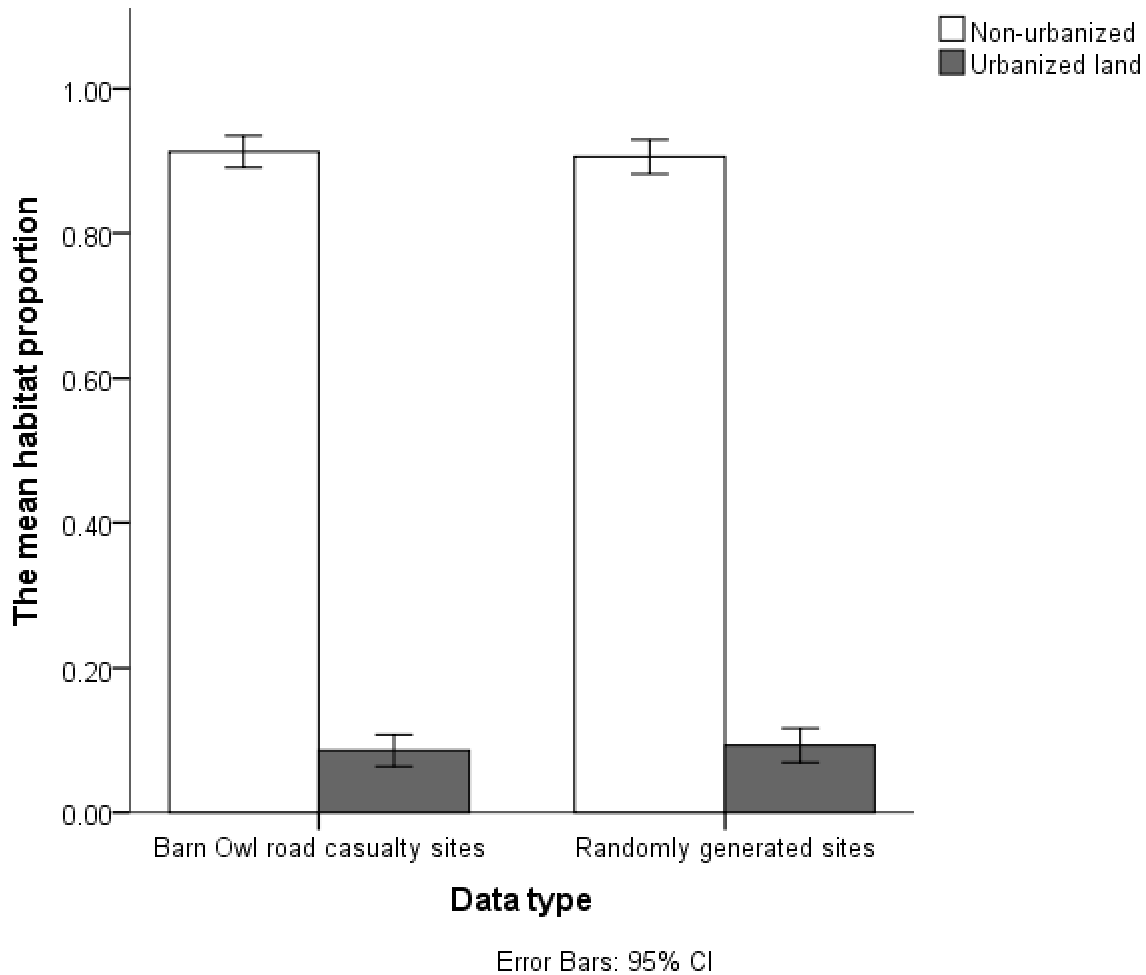


Figure 3.9 The proportion of urbanized land and non-urbanized land surrounding Barn Owl road casualty sites. Habitat composition was calculated using a 1km circular buffer zone around each casualty site.

No significant difference was found between the proportion of urbanized land and non-urbanized land (Figure 3.9) around Barn Owl road mortality sites and randomly generated sites, (Table 3.3).

Discussion

Barn Owl Population Size

The results of the study showed that the rate of which Barn Owls are being hit by vehicles on the A55 Anglesey is 0.217 Barn Owls/year/km from 2004 to 2017 - 107 deaths in total. In contrast, Taylor (1994) found the rate of which Barn owls were being hit by vehicles in Great Britain was 0.64owls/km/year. This suggests the problem of Barn Owl road casualties in Anglesey is not as severe as that in Great Britain as a whole, as fewer Barn Owls are being hit on the A55 Anglesey per km per year than in other areas. However, this does not take into consideration the effect such deaths could have on the population of Barn Owls in Anglesey. Additionally, comparisons between the present study and Taylor's (1994) should take into consideration changes in Barn Owl population numbers over that past 24 years.

The highest occurrence of Barn Owl road casualties recorded on the A55 was 18 deaths in 2008 and the least was 2 deaths in 2011. There was a decrease in the number of Barn Owl casualties after 2009 from 11 to 3. This could be a result of changes in the presence road characters such as more lights on the side of the road (Arnold, 2016), a good vole year leading to Barn Owls hunting closer to the nest or a decline in the Barn Owl population leading to less Barn Owls to be killed in general.

The month in which the most deaths occurred was April with 18 deaths and the least was August with only 1 death. The occurrence of deaths decreases from May to August, which is expected as this is during the main part of the breeding season, when food is plentiful, female Barn Owls will be confined to their nest, fewer Barn owls will be hunting and as a result fewer Barn Owls will be coming into contact with roads. Similarly, Newton *et al*. (1991), found fewer recorded deaths from May to July which again coincides with the main period of the breeding season.

There was an increase in the number of Barn Owl casualties in September which remained high throughout the winter, with the exception of January. The rise in Barn Owl deaths from September could result from the population reaching its annual peak after the breeding season has ended (Newton *et al*., 1991). Additionally, this increase was possibly due to increased Barn Owl hunting activity while food was scarce (Newton *et al*., 1991; Arnold, 2016) and the extension of their hunting range during winter to find more food (Taylor, 1994). Grass road verges have been shown to support a high abundance of small mammals, making them attractive habitats and important hunting grounds for Barn Owls (Grilo *et al*., 2012). Additionally, a study in Spain found Barn Owls killed on roads were recovered from areas where vole numbers where at maximum (Fajardo, 2001). This results in owls becoming more tolerant to roads, (Grilo *et al*., 2012) and as food abundance coincides with peak traffic activity and fewer daylight hours, the occurrence of owl road traffic collisions is higher during the winter months. Therefore, increased winter mortality has been suggested to be linked to physiological characteristics which require Barn Owls to hunt more in cold winter month to avoid starvation (Boves and Belthodd, 2012).

Increased mortality rates occurring during late autumn and winter (Grilo *et al*., 2014), have also been suggested to be due to juvenile dispersal movements (Taylor, 1994). Juvenile dispersal movements increase the likelihood of owls coming in contact with roads, with lack of experience being an explanation for the relatively high proportion of juvenile Barn Owls killed on roads (Boves and Belthodd, 2012).

The British Trust for Ornithology (BTO) recorded 2351 fledglings from BTO nest boxes on Anglesey between 2004 to 2017. The most fledglings were 470 in 2014 and the least was 61 in 2004. The gradual increase in the number of fledglings up until 2014, is likely due to an increased effort in Barn Owl conservation and the introduction of more nest boxes. However, there was a decrease in 2015, this could be due to a crash in the Field Vole population, as vole population size has been found to influence reproductive success in Barn Owls in other studies (Fajardo, 2001; Klok and de Roos, 2007; Charter *et al*., 2015b).

Average fledglings per nest fluctuate yearly in accordance to a variety of factors. The highest occurrence of fledglings per nest was 3.95 in 2014, and the least was 2.54 in 2016. The results of the study found deaths were fewer after 2009, whereas more owl successfully fledged after 2010, suggesting a negative relationship between the two factors. This could be a result of male Barn Owls being killed whilst hunting to feed the female and fledglings, as the hunting capacity of male Barn Owls has been found to have a strong influence on the success of fledglings (Durant *et al*, 2013). It could also be argued that more Barn Owl casualties lead to fewer owls in the population, resulting in fewer eggs being hatched the next breeding season or that more mortality in the winter reduces competition, resulting in survivors doing better. Despite this, the univariate general linear model found no significant relationship between average fledglings per nest and the number of casualties the following winter. This could suggest population size has little influence on the occurrence of owls deaths from road traffic casualties. On the other hand it could also suggest owl road casualties has little impact on the reproductive success of the species. Further analysis needs to be conducted to investigate the true relationship between road traffic casualties and reproductive success in the Barn Owl. The current data is taken from only one road in Anglesey (the A55). In order to investigate this further all road casualties must be considered on all roads within the study area, as well as a methodic way of recording such collisions - one which does not rely on the general public recording road kill sightings.

Season and Road Feature

No relationship was found between the number of Barn Owl road casualties and the time of year (season, bi-monthly or monthly). However, a significant difference was found between sites with and without grass slope verges and bi-monthly mortality. A grass slope verge is a wide area of land running alongside the road, which slopes toward the roads edge and is covered in grass or shrubs. Grass slope verges provide an undisturbed habitat for small mammals in an area of agriculturally improved grassland unsuitable for voles. Field Voles favor undisturbed areas of long vegetation (Tattersall et al., 2000), which agriculturally improved grassland cannot provide due to frequent harvesting or grazing of livestock. The number of deaths in areas with grass slope verges at the side of the A55 was recorded as 29 and in none grass slope areas was 87. This contradicts the results of Arnold (2016), who found characteristics such as low slopes increased mortality due to vehicle collisions. The results also suggest that the presence of grass slope verges could prevent Barn Owl road casualties, likely due to Barn Owls hunting less than 3m above the road, or above car height, and away from the side of the road.

When grouping data bi-monthly the most deaths occurred in September/October (11 deaths in areas where grass slope verges were present and 18 deaths in areas where grass slope verges were absent). This is the bi-monthly group with the lowest difference between deaths in areas with and without grass slope verges, however, this coincides with the time of year juvenile owls will be dispersing away from natal grounds (Taylor, 1994). Juveniles lack experience and many will be encountering roads for the first time during their dispersal, this increases the likelihood of Barn Owls being killed by vehicles during September/October (Boves and Belthodd, 2012). An influx in juvenile Barn Owls could also explain the low difference between sites with and without grass verges at this time of year, as lack of experience will likely mean these owls are not selecting foraging sites from experience.

The largest difference between bimonthly deaths in areas with and without grass verges occurred within January/February (0 deaths in areas where grass slopes verges were present and 18 deaths in areas where grass slope verges were not present). During this time of year food is scarce; during cold weather, Barn Owls require more food to prevent starvation (Newton *et al*., 1991; Arnold, 2016). Grass road verges are habitats with a high prey availability of small mammals due to their vegetation diversity and unmanaged state, this makes them important hunting grounds for predators especially during the winter when food is scarce (Ascenao *et al*., 2012; Grilo *et al*., 2012). The results of the study could suggest, desperation for food results in Barn Owls hunting in habitats where they are in a higher risk of casualty, due to the abundance of small mammals present, leading them to hunt close to road edges despite the threat of vehicles. This would explain why fewer Barn Owls were killed at areas with grass slope verges, as these sites allow owls to hunt further away from the roads edge.

Habitat Composition

The results of the study showed no significant relationship between the occurrence of Barn Owl road casualties and habitat, despite studies having found mortality is most common where agricultural land borders the roadway (Boves and Belthodd, 2012).

The habitat category 'agriculturally improved grassland' makes up the largest proportion of habitat within a 1km radius around Barn Owl casualty sites and randomly generated sites. Anglesey has a largely homogenized landscape dominated by agriculturally improved grassland, meaning there is little variation in habitat composition along the A55 to influence the occurrence of road deaths.

Arnold (2016), found that certain road features decreased road mortality such as secondary roads and human structures. However, the results of the present study found no significant relationship between the number of deaths and the presence of buildings, secondary roads or street lights. Urbanized areas makes up on average 8.7% of the 1km radius around Barn Owl road casualty sites and 9.4% of randomly generated sites; however this number increases to 75.5% in some areas of the A55. Barn Owls that occupy urban areas need to travel further to locate suitable hunting habitats, indicated by the larger home ranges of urban owls (Hindmarch *et al*., 2017). Radio-tagged urban Barn Owls have been observed hunting at grass road verges and nesting under highway bridges (Hindmarch *et al*., 2017). This suggests urban owls are more likely to come into contact with roads and as a result it is expected that urbanized land would have a relationship with Barn Owl road casualties unlike the results the study has shown.

Conclusion

The results of the present study found fewer Barn Owl-vehicle collisions occurred during the breeding season of Barn Owls. Similarly, Newton *et al*. (1991) found fewer recorded deaths coinciding with the breeding season of Barn Owls, when food is plentiful and females are confined to their nest. More casualties in winter coincide with peak traffic volume (Massimini *et al*., 1998), with more cars on the road during periods of darkness. Increased winter casualties can also be linked to physiological traits, by which Barn Owls hunt more to maintain energy requirements (Boves & Benthodd, 2012), and to the exploitation of prey-rich habitats located close to roads (Grilo *et al*., 2012). However, this does not explain why fewer deaths occur in January.

Additionally, fewer Barn Owl road casualties occurred at locations with grass slope verges. It could be suggested that grass slope verges encouraged Barn Owls to hunt away from the road and above vehicle height. Despite this, mortality was found to be higher near flat grass verges (Hodora & Poggio, 2016) and low slopes (Arnold, 2016).

Previous research has shown Barn Owl road casualties are higher in areas were agricultural land borders the roadway (Boves & Belthodd, 2012). Additionally, urban and agricultural owls have been found to select roadside grass verges more than other habitat types to hunt in (Hindmarch *et al*., 2017). However, the results of the present study suggest habitat has no effect on the occurrence of Barn Owl road casualties. This is possibly due to the homogenization of Anglesey’s landscape. The A55 is bordered invariably by agriculturally improved grassland its almost entire length making habitat an unlikely contributing factor in the occurrence of Barn Owl road mortalities.

Research into the effects of population on Barn Owl road casualties is limited; however the study showed that, the mean number of fledglings per nest from BTO boxes showed no relationship with the number of Barn Owl road casualties recorded on the A55 Anglesey. However, the BTO nest boxes are not representative of the entire Anglesey Barn Owl population, leaving room for further investigation. Additionally, using nest boxes as a proxy for population numbers does not account for juvenile Barn Owls dispersing into and out of Anglesey.

Previous research has suggested the introduction of obstructions on the side of roads to encourage low flying birds such as the Barn Owl to fly up above vehicles and over roads. Low flight barriers such as screen, closely placed shrubs and trees could prevent Barn Owls from flying less than 3m above the road. The result of the present study found fewer deaths related to vehicle collisions occurred in locations with grass slope verges. This suggest grass slope verges could be used as a preventative measure to reduce the number of Barn Owl road casualties on busy roads, whilst also providing important foraging habitats in areas of poor small mammal abundance.

Chapter 4. Final discussion and conclusion

The prey consumed by the Barn Owl has remained the same from previous studies (Glue, 1974), with Field Voles, Common Shrews and Wood Mice being important prey items but Brown Rats being considerably lower in proportion than previously reported. However, the relative proportion of primary prey items differs from previous studies; a higher percentage of Field Voles was found, ecological shifts in the diets of predators, such as the Barn Owl, are indicative of changes in prey abundance in the surrounding landscape (Avenant, 2005 and Andrade *et al*., 2016).

The importance of prey weight was outlined in the study, as the proportion of prey consumed differed depending on whether data was presented as the percentage of prey items consumed per nest or as prey weight per pellet. For example, the Wood Mouse proved to be a more important prey item when compared to the Common Shrew, despite making up a lower percentage of the Barn Owls diet. The Wood Mouse is a more valuable food source in comparison to the Common Shrew, because the Wood Mouse provides twice the mass per capture (Corbet & Harris, 1991), however when mice are scarce Barn Owls will increase the proportion of smaller prey items such as shrews in their diet (Love *et al*., 2000). This demonstrates how Barn Owls adapt their dietary preferences depending on prey abundance and profitability.

Seasonal variation in diet has been observed across species: Pied Flycatchers consumed fewer caterpillars in colder months (Burger *et al.*, 2012); Polar Bears became more opportunistic during the ice free season (Gormezano & Rockwell, 2013); and the Long-eared Owl consumed more birds, anurans and insects in summer (Gryz & Krauze-Gryz, 2015). Such dietary changes are indicative of variation in prey abundance at different times of the year.

The results of the present study showed that primary prey species did not change throughout the year; the Field Vole, Common Shrew and Wood Mouse remained the most numerous preys consumed regardless of season. However, relatively fewer Field Voles were consumed during the Barn Owls breeding season (March-September), which supports the finding that the Field Voles are not the most important prey during the Barn Owl breeding season (Brown, 1981).

The results of the present study showed the Common Shrew showed no variation with season, as the Common Shrew weight per pellet did not differ between seasons suggesting the proportion of the Barn Owl diet that is made up of Common Shrews does not vary between seasons. This contradicts the finding that the Common Shrew is the most important prey species during the breeding season (Brown, 1981), additionally seasonal variation in the consumption of Common Shrews is expected as the Common Shrew spends its winter underground (Brown, 1981), making it increasingly unlikely for them to be caught by Barn Owls. However, the present study showed no variation in the consumption of Common Shrews at different times of the year. This could reflect the shrew population on Anglesey potentially suggesting a consistently low shrew population or limited habitats for shrews to occupy; yet further long term investigation is needed particularly with reference to small mammal oscillations.

The present study also found relatively fewer Wood Mice were consumed outside the breeding season, this is unexpected as Wood Mice have been showed to increase in abundance during the autumn (Broughton *et al.*, 2014), which is after the Barn Owl breeding season thus resulting in proportionally fewer Wood Mice in the diet during summer (Tores *et al*., 2005). However, fewer Wood Mice may be consumed outside the breeding season as these months are relatively colder, the proportion of Wood Mice are likely replaced in the Barn Owls diet by an increase in Field Voles, a more profitable prey by mass per capture.

The move away from mixed farming which has occurred since the 1970s has resulted in reduced habitat diversity and the homogenization of the landscape (Love *et al.,* 2000), this is demonstrated in the results of the present study. Anglesey is largely used for relatively intensive cattle farming; as a result the landscape is dominated by agriculturally improved grassland. The home range of Barn Owls as a result was found to be comprised of mostly improved grassland, with arable horticulture and saltmarsh being the next most prevalent habitats.

The habitat surrounding Barn Owl road casualty sites was also mostly comprised of agriculturally improved grassland. Additionally, the results of the study showed habitat did not influence the occurrence of Barn Owl road traffic casualties, despite previous studies finding Barn Owl road casualties were higher in areas where crop fields (Arnold, 2016), and agricultural land borders the roadway (Boves & Belthodd, 2012).

Agriculturally improved grassland is land used mostly for cattle grazing which is managed by humans. These management practices typically result in decreased vegetation diversity, resulting in fewer small mammal species. A lack of diverse hunting habitats available for the Barn Owl, due to landscape homogenization, highlights the importance of ecological traps. Barn Owls exploit the potentially risky but increasingly important habitats located close to roads which are abundant in small mammal species (Grilo *et al.*, 2012 and Hindmarch *et al.*, 2012). For example, Barn Owls in both urban and agricultural landscapes have been found to select roadsides grass verges more than other habitat types (Hindmarch *et al.*, 2017).

An association was found between the presence of grass slope verges at the side of the A55 and the occurrence of bimonthly Barn Owl road traffic casualties. Despite previous studies showing casualties have been found to be higher near grassy verges (Hodora & Poggio, 2016), and low slopes (Baudvin, 1997; Massemin & Zorn, 1998; Lode, 2000; Arnold, 2016), fewer Barn Owls were killed at locations with grass slope verges. The width of grass slope verges provides hunting habitats at a safe distance from the road, preventing owls from coming into contact with vehicles.

The September/October group showed the smallest difference between the occurrences of casualties which is expected, as Barn Owls are more likely to be killed during September/October, regardless of location. This is because at this time of year juvenile birds will be dispersing from their nest - juvenile dispersal increases the chance of owls being hit by cars as birds dispersing away from their natal grounds will inevitably need to cross roads. Juvenile owls are more likely to be hit by vehicles for a variety of reasons, for example juvenile birds are not wary of the dangers of moving vehicles, additionally they are not accustomed to their surroundings and it is likely that they do not know where the best hunting habitats are. It could also be argued that juvenile birds are still learning how to hunt, being a less experienced hunter suggests the birds are hungry, having to spend more time hunting which increases their exposure to vehicles on the road and likelihood of being hit.

Despite no overall association being found between habitat and diet, the result of the present study did find proportions of Field Voles and Wood Mice consumed was found to have an association with the proportion of freshwater in the homerange. The Common Shrew also showed an association with broadleaved woodland, suggesting that habitat composition within the home range does have an effect on the proportion of prey consumed. This supports the findings that diet varies according to habitat and landscape features over food availability in the Lionfish (Dahl & Patterson, 2014) and the Red Fox (Cancio *et al*., 2017), yet contradicts those that suggest habitat does not appear to influence diet composition in predatory birds (Kross *et al.*, 2012; Teta *et al*., 2012; Navarro-Lopez & Fargall0, 2015). However, the results of the present study only found associations between diet and habitats that make up a small proportion of the Barn Owls homerange, some of the homeranges consisted of up to 99% agriculturally improved grassland suggesting any variation in diet due to habitat is masked due to agriculturally improved grassland dominating Anglesey's landscape. Additionally, Barn Owls are known to travel long distances to find suitable hunting grounds (Hindmarch *et al.*, 2017), suggesting the true relationship between diet and habitat cannot be established from pellet analysis alone.

Further research could look at expanding the study area to incorporate more diverse habitats, different regions, as well as areas of differing agricultural intensity. For example a comparative study between the diet of Barn Owls in Anglesey and in Bowland Forest; Anglesey being a lowland, coastal areas of intense agricultural practices and Bowland Forest being an upland area of traditional mixed farming practices.

Diet diversity has been found to influence reproductive success in a variety of species such as the Egyptian Vulture (Margalida *et al*., 2011) and the Golden Eagle (Whitfield *et al*., 2009), whilst food quality is shown to be more important in the House Sparrow (Seress *et al*., 2012) and the Barn Owl (Charter *et al.*, 2015). In the Barn Owl, reproductive success was found to increase with the proportion of voles consumed (Charter *et al*., 2015b and Jackson & Cresswell, 2017), and decrease with the proportion of mice consumed (Charter *et al*., 2015b). However, the result of the present study showed no relationship between diet and brood success.

The results suggest habitat is more important than diet in influencing reproductive success. A positive relationship was found between fledglings and the proportion of neutral grassland in the home range of Barn Owls, and a negative relationship was found with the proportion of fen marsh swamp, arable horticultural land and agriculturally improved grassland in the home range of Barn Owls. Interestingly, the habitat composition of the Barn Owls homerange during the breeding season was found to have a greater proportion of arable horticultural land when compared to the homerange outside the breeding season. This is unexpected as arable horticultural land was found to have a negative relationship with the number of fledglings produced by Barn Owls, therefore by selecting nest sites with an increased proportion of arable horticultural land could decrease a Barn Owls reproductive success. Considering this, the increase in arable horticultural land during the breeding season could be a result of human selection bias, as humans select where Barn Owl boxes are installed. Additionally, less urbanized land, saltwater and freshwater was found in the home range of Barn Owls during the breeding season.

Previous studies have found similar results. Barn Owls showed greater reproductive success when nesting in semi natural grassland (Leech *et al*., 2009) and unimproved grassland (Kitowski, 2013 and Salek *et al*., 2016), unsuccessful broods were found to be nesting in areas of agriculturally improved grassland (Bond *et al.* 2005 and Salek *et al.* 2016). This highlights the importance of maintaining species rich, undisturbed habitats such as dry hay meadows in areas of intense agriculture.

Despite the results of the study suggesting habitat is more important than diet to reproductive success, it is likely that habitat appears to be more important because dietary information established from pellet analysis alone is not indicative of total prey consumed or prey availability in the surrounding habitat. Further research into the relationship between diet and reproductive success could use small mammal trapping to establish prey availability within the Barn Owls home range. Additionally, past records of annual vole population cycles could be analyzed alongside nest box occupancy and breeding date, to establish whether vole numbers do have an effect on reproductive success.

Research into the effects of population on Barn Owl road casualties is limited, however the study showed that the number of successful fledglings from BTO nest boxes had a positive relationship with the number of Barn Owl road casualties recorded, however this relationship was found to be insignificant during the univariate analysis. A large proportion of Barn Owl road casualties found on the A55 are not ringed, indicating they did not come from BTO nest boxes. It is not possible to know whether the Barn Owls hit by cars are owls from Anglesey that are not nesting in BTO nest boxes, or whether they are owls dispersing from outside of Anglesey.

Further research into factors influencing Barn Owl road casualties could use road kill data to establish whether casualties are ringed, from this the effects of age, sex and dispersal on the occurrence of Barn Owl road casualties can be investigated further. Helpful information could include how juvenile Barn Owls interact with roads; this could be investigated using telemetry to establish the true effects of juvenile dispersal on the occurrence of road casualties.

The conservation of the Barn Owl in the UK has been directed at: increasing the number of nesting sites - in the form of BTO nest boxes on Anglesey - and decreasing the number of Barn Owl mortalities caused by illegal killings, such as shooting, poisoning or trapping. However, the results of the present study demonstrate how in areas of intense agriculture maintaining species rich diverse habitats is important for the success of Barn Owls. Since the move away from mixed farming practices, habitat diversity has decreased, resulting in reduced prey abundance particularly in small mammals. The introduction of hedgerows was found to be beneficial in increasing small mammal abundance, especially for the Wood Mouse; however such habitats are not suitable for the Field Voles (Quinn *et al.*, 2000). Conservation efforts should therefore be focused on the restoration of habitats to provide biodiversity, such as mosaic-like landscapes with rough grasslands, habitats of different management levels, made up of a wide variety of vegetation, which will allow predatory birds to exploit habitats at different times of the year depending on food abundance.

The actions to improve Barn Owl hunting habitats should therefore focus on increasing prey abundance, as in regions where Barn Owls depend on fluctuating vole populations - low vole years restricts the growth of the Barn Owl population (Klok and de Roos, 2007). Therefore, conservation actions should aim to increase the prey abundance in such a way that especially in low vole years there are alternative prey present to replace the vole such as stable populations of mice, shrews and small birds. Additionally, supplementary feeding in low vole years could also be used to help sustain a struggling population of Barn Owls.

Additionally, preventative measures have been suggested such low flight barriers to assure wildlife-vehicle collisions do not occur. However, many studies have outlined the importance of grass verges as foraging grounds for Barn Owls, as adaptable predators they can compensate for the loss of reduced available hunting habitats by increasing foraging attempts in lower quality habitats such as grass verges (Taylor, 1994 and Bolger *et al.*, 2001). Instead of removing these important foraging grounds and introducing manmade structures, conservation efforts could focus on making these foraging grounds safer. The findings of the present study found fewer Barn Owl road casualties occurred at grassslope verges, therefore the introduction of grass lope verges could be used as a wildlife-vehicle collision preventative measure. The introduction of wider grass verges would likely reduce the number of Barn Owl casualties whilst still preserving this important habitat; this would involve cutting back verges directly next to the road but leaving natural hunting habitats at a safer distance away from the road.

Acknowledgements

This research would not have been possible without the support of a number of people. First, I would like to thank my supervisor Dr Ian Hartley at Lancaster University who provided guidance and support throughout the project. I would also like to thank Kelvin Jones, William Williams and Stephen Roddick from the BTO for their assistance throughout the collection of owl pellets, and their contribution of shared resources and data, which made the project possible. Thank you to Jill Jackson, ecologist at the North and Mid Wales Trunk Road Agency, for sharing her data on Barn Owl road mortality sites. Lastly, I would like to thank Gemma Davies for her support using Arcmap GIS in the habitat analysis.

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Appendix 1. Scientific names of species mentioned in the thesis.

Species Name	Scientific Name
Amazon River Turtle	*Podocnemis unifilis*
Bank Vole	*Myodes glareolus*
Barn Owl	*Tyto alba*
Brown Rat	*Rattus norvegicus*
Common Shrew	*Sorex araneus*
Egyptian Vulture	*Neophron percnopterus*
Field Vole	*Microtus agretis*
Golden Eagle	*Aquila chrysaetos*
Grizzly Bear	*Ursus arctos*
Harbor Porpoise	*Phocoena phocoena*
Harvest Mouse	*Micromys minutus*
Hen Harrier	*Circus cyaneus*
House Sparrow	*Passer domesticus*
Jackdaw	*Corvus monedula*
Kestrel	*Falco tinnunculus*
Red Lionfish	*Pterois volitans*
Long-eared Owl	*Asio otus*
Mole	*Talpa europaea*
Peregrine Falcon	*Falco peregrinus*

Pied Flycatcher	*Ficedula hypoleuca*
Polar Bear	*Ursus maritimus*
Pygmy Shrew	*Sorex minutus*
Red Fox	*Vulpes vulpes*
Skylark	*Alauda arvensis*
Song Thrush	*Turdus philomelos*
Spotted Salamander	*Ambystoma maculatum*
Water Shrew	*Neomys fodiens*
Water Vole	*Arvicola amphibious*
Wood Mouse	*Apodemus sylvaticus*
Wren	*Troglodytes troglodytes*