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BARN OWL *TYTO ALBA* NESTBOX OCCUPATION AND BREEDING SUCCESS IN RELATION TO PREY AVAILABILITY AND VEGETATION CHARACTERISTICS IN THE SOUTH DOWNS NATIONAL PARK

A technical report prepared from an MRes Wildlife Conservation project, Marwell Wildlife & University of Southampton

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September 2016

ABSTRACT

Around the world, agricultural intensification is correlated with habitat loss, simplification of the landscape, loss of diversity across extensive areas and increased addition of chemicals. Its expansion has been associated with biodiversity losses and it is a major threat to birds. Barn owl populations are exposed to these threats and drastically decreased in the past decades. However, barn owls have the ability to adapt and coexist in human-environments where proper management and mitigation, such as implementation of nest-boxes in regions where significant habitat loss has occurred. The research aimed to examine Barn owl breeding success in South Down National park and its relation with suitable prey habitat, by assessing breeding success of barn owls utilizing nest boxes, quantifying small mammal abundance related to different landscapes and evaluating if these are a predictor of breeding success, and finally, informing the wider conservation management of this species, through governing bodies such as the South Downs National Park Authority (SDNPA), and provide evidence and guidance for the placement of new nest boxes when assessing the suitability of location regarding availability of prey and habitat type. It was hypothesized that: a) Breeding success of Barn Owls in nest boxes is determined by small mammals abundance, richness, diversity, and the vegetation parameters litter layer depth and vegetation height; and b) Nest boxes occupation is influenced by small mammals abundance, richness, diversity, litter layer depth and vegetation height. Taking in account weather features, as temperature, rainfall and sunlight. The outcome for the GLM model apply for all these explanatory variables revealed no significant effect on nestbox occupancy and breeding success. However, the results shed a light towards which direction to focus on future researches, including increasing the number of nest-boxes monitored and addition of pellets analysis for comparison with small mammal capture-recapture abundances.

Target Journal: Functional Ecology

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INTRODUCTION

Threats to Barn Owls

Within the UK, the development and intensification of agriculture has encouraged the uniformity of vegetation, reducing habitat quality and diversity. Intensification has also resulted in sparse hedgerows, which lower foraging efficiency (Whittingham and Evans, 2004). Loss and degradation of habitat through changes in landscape management has caused population declines in farmland Birds (Evans and Smith, 1994; Green et al, 2001; Peach et al, 2001).

Birds have been great indicators of the effects of anthropogenic interference on biodiversity, contributing to a value ble history of scientific research and tracked record in conservation management (Hoyo, 1999; Bruford, 2002). Bird indexes, eg. “The wild bird index”, are used by the UK government to measure the progress of the country towards sustainable development (Gregory et al, 2004).

In the 1990s, studies started to reveal the extent of problems that lowland farmland birds in the UK are facing (Marchant et al. 1990, Gibbons et al. 1993, Fuller et al, 1995). Status reviews of a range of bird species showed similarities in pattern and time of declines across population size and geographical range (Fuller et al, 1995), placing relatively widespread and common birds in a category of conservation concern in a revision of the Red List in 1996, due to strong population declines (Gibbons et al, 1993).

Open grasslands with longer vegetation are known to sustain a greater diversity of plants and animal species, enhancing food supply of various farmland bird species (McCracken et al. 1995; Jacob & Brown 2000). Some of this birds also benefit from shorter vegetation, therefore, a mosaic of both long and short vegetation are very likely to provide the most advantageous conditions for their benefit (Benton et al. 2003, Atkinson et al. 2004, Buckingham et al. 2004). Agri-environmental schemes that contributes to the access to healthy invertebrate and small mammals populations are probably inclined to aid in farmland bird conservation (Whittingham and Evans, 2004).

Habitat loss of open grassland due to the development in modern agriculture and cessation of traditional practices is one of the various factors threatening Barn

Owls that are adapted to this type of habitat (Taylor 1994, Love et al. 2000). The intensification of monocultures brought serious consequences to those species whose natural habitat have been destroyed to give place to agriculture,not just by decreasing natural nesting and hunting sites, but also contaminating the environment with pesticides (Newton 1979, Newton & Wyllie 1992, Donald et al. 2001).

The Barn Owl

Barn Owls are considered Birds of Prey and are classified in the Tytonidae family, which together with the Strigidae family form the Strigiformes Order, that are mainly nocturnal animals, hunting at night, dawn or dusk hours (Hoyo, 1999; Chittenden et al, 2004). They are medium-size birds with a characteristic pale heart-shaped facial disc (Figure 1), being one of the most charismatics Birds in Britain (Cramp 1985; Taylor, 1994).

Figure 1. Drawing of Barn Owl by Davina Falcão extracted from Lopes, 2009.

In the wild, the Barn Owl would be totally dependent on tree holes, cracks in ravines or other species' abandoned nests, however, as this species is adapted to human environments, they take advantage of old barns, chimneys, churches, houses and holes in the walls as nest and roost sites (Cramp, 1985; Taylor 1994, Martin 2008).

Although Barn owls are globally one of the most widely distributed bird species (Taylor, 1994), the size of their population and distribution range is becoming smaller (Barn Owl Trust, 2012). In the UK, there was once 12,000 breeding pairs in the 1930's which have declined to about 4000 pairs in 60 years (The Project Barn Owl Report, 2000), due to habitat loss, which results in less prey availability, and fewer roosting and nesting sites, among other reasons, such as road mortality and rodenticides (The Barn Owl Trust, 2012).

The estimate of breeding pairs range from 3000 to 5000 in the UK and 111000 to 230000 in Europe (European Red List, 2015). In a short term the population trend seems to have increased, although long term trend shows a moderate decrease from 20 to 49% in the UK according to the European Red List (2015). The "State of the UK Barn Owl Population" is an initiative from The Barn Owl Trust assessing breeding success since 2013, which showed a decrease of 26% in nesting occupancy and 18% in mean brood size comparing all-years average and 2015 (State of the Barn Owl Population, 2015).

Barn owl prey availability

The biggest cause of death for Barn Owls is believed to be starvation, as food supply is controlled by habitat quality, which in turn affects small mammal's availability, that are the Barn owl's main source of food, accounting for 80% of their diet, and more specifically in the UK their preference is for field voles (Glue, 1974; Taylor, 1994).

Field voles (*Microtus* agrestis), Wood mouse (*Apodemus sylvaticus*), Yellow-necked mouse (*Apodemus flavicollis*) and Common shrews (*Sorex araneus*) are found in open habitats in mainland Britain, occurring widely in rough grassland with thick grass cover and marginal habitats, such as scrubs, hedgerows, grass lays, wet and marsh ground and moorland. Usually building underground burrow systems to move around and make their nest (Glue, 1974; Aulagnier et al, 2008). From 3 to

5 years Field vole population density peaks can occur, increasing their numbers to a level where they cause damage to crops and pastures (Glue, 1974; Aulagnier et al, 2008).

Barn Owls also prey on other small mammals depending on the availability of the most preferred prey and opportunity, such as Bank vole (*Clethrionomys glareolus*), Brown rat (*Rattus norvegicus*), House mouse (*Mus musculus*), Pygmy Shrew (*Sorex minutus*), Water Shrew (*Neomys fodiens*), Water vole (*Arvicola amphibious*), Harvest mouse (*Micromys minutus*), among others (Glue, 1974; Taylor, 1994).

In addition to small mammals, Barn Owls can prey on other small Birds, Bats, Amphibians and Invertebrates in smaller numbers for short periods of time (Glue, 1974; Cramp, 1985; Taylor, 1994; Love et al. 2000; Roque, 2003; Martin, 2008). It has been noticed that Barn Owls occurring in unproductive, hot and dry parts of the globe have a tendency to rely less on small mammals while those from moist temperate zones have a tendency to specialize on them (Taylor, 1994).

To be able to successfully hunt on small mammals in rough grassland, Barn Owl flight and hearing are highly developed and have a very important role in foraging, making them a skilled predator at dawn and dusk periods. Their low wing loading enables them to fly through great periods of time without stalling, besides making the flight slower, it does increase their perception of finding their prey in deep grasslands and tussocks (Taylor, 1994; The Barn Owl Trust, 2012).

Suitable habitats and nest-boxes for barn owls

Past planning decisions has had an adverse impact on Barn Owls, often because land owners and government bodies involved did not have enough information nor knowledge about relevant planning policies and guidance. The decrease in roost and nesting sites due to demolition and unsympathetic conversion results in population declines and lack of suitable sites can limit population recovery (The barn Owl Trust, 2012).For a habitat to meet the needs of an individual or a species, it should provide not only the direct needs, but also the intricate interactions with other organisms in the ecosystem, ideally being suitable at a broad landscape scale and at a microhabitat scale (Mayor et al. 2009; Whyle, 2015).

These changes in the agricultural system led to a decline in suitable old farm buildings and hollow trees as roost and nesting sites for Barn Owls populations, as they make use of several roost sites and one nest site within their breeding range (Taylor, 1994; Barn Owl Trust, 2012; Hindmarch et al, 2012). As a consequence of these considerable losses, the British population of Barn Owls are highly dependent of the availability of man-made nest boxes (Shawyer, 2011; The Barn Owl Trust, 2012).

Supplementation with nest boxes has become an essential device for barn owl conservation in the UK, proven to be successful in promoting local populations numbers (Johnson, 1994; Taylor, 1994). However, to aid population growth, the habitat around nest boxes have to be able to sustain breeding and hunting (Taylor, 1994).

Barn owls in South Downs National Park

In the western region of South Downs National Park, there is an active monitoring programme of Barn Owl nest-boxes, where several land managers work together with the local governing Authority through Environmental Stewardship Programmes to aid with improvement of habitat quality and wildlife conservation, such as the Barn Owl nest monitoring program, which include the set-up and monitoring of various boxes in the National Park (South Downs National Park, 2016).

This region has a temperate maritime climate, created by the merging of moist maritime and dry continental air. Monthly, the average of bright sunshine and temperature varies from 61 hours and 4°C in January to 261 hours and 17°C in July, respectively. The coldest night might reach -7.5°C and an average 58 days per year fall below 0°C. At Winchester, the average annual rainfall is 823mm and the wind speed for the most part is not higher than a mean of 6.8 mph.

In the South Downs National Park, chalk is the common geology along with greensands and clays. Soils are well drained, as the chalk absorbs a great quantity of water, having a distinct effect over grassland characteristics (Wilkie et al, 2014; South Down National Park, 2016).

A previous study has shown that eleven out of sixteen nest boxes were being used by Barn Owls in South Down National Park, and five of them were confirmed to support breeding (Whyle, 2015). Nest boxes are commonly used in Europe and North America to provide suitable nesting sites for hole-nesting birds, indicating positive correlations between breeding success and their use for several species (Karlsson and Nilsson, 1977; Hamerstrom et al, 1973; Marti et al, 1979; Korpimaki, 2006; Griffith et al, 2008; The Barn Owls Trust, 2012).

Study Aims

This study is part of a long-term examination of barn owl breeding success, evaluating habitat features, vegetation structure and prey habitat suitability (Whyle, 2015). Continuing the research, this study sets out to assess breeding success through small mammal communities' population dynamics.

The research aimed to examine Barn owl breeding success in South Down National park and its relation with suitable prey habitat, by assessing breeding success of barn owls utilizing nest boxes, quantifying small mammal abundance related to different landscapes and evaluating if these are a predictor of breeding success, and finally, informing the wider conservation management of this species, through governing bodies such as the South Downs National Park Authority (SDNPA), and provide evidence and guidance for the placement of new nest boxes when assessing the suitability of location regarding availability of prey and habitat type.

Quantifying small mammals community within different landscapes in South Downs National Park and adding this information to the previous study results about microhabitat characteristics, will provide better understanding about Barn Owls population dynamics and its environment, facilitating decision making regarding the species conservation.

Where the hypothesis being tested were: a) Breeding success of Barn Owls in nest boxes is determined by small mammals abundance, richness, diversity, and the vegetation parameters litter layer depth and vegetation height; and b) Nest boxes occupation is influenced by small mammals abundance, richness, diversity, litter layer depth and vegetation height.

In this way, informing conservation management authorities where best to focus mitigation efforts; where to enhance habitats in areas that are already acceptable for Barn Owls can aid to maintain or boost populations levels, as Barn Owls can breed two or three times per year where food availability is high, habitat enrichment actions should be implemented at every opportunity (Taylor, 1994; The Barn Owl Trust, 2012).

Enriched habitats resulted from good management of rough grassland can support a wealth of biodiversity, increasing numbers of wide array of other species, including wild flowers, grasses, butterflies, birds and mammals (The Barn Owl Trust, 2012). Farmlands with its combination of open fields, hedgerows, grassland and coppices, can support a diversified avifauna with species of conservation interest. The maintenance of diversity throughout countryside is as essential as conservation of isolated areas of natural habitats such as woodlands and moors (Fuller, 1987; Batten et al, 1990).

Furthermore, services provided by ecosystems are highly valuable to humanity, being easily compared to the total gross national product. It means that people don't earn money enough to rehabilitate the damage done to nature. Thinking about new sustainable policies that consider to integrate different economic sectors with nature conservation to reverse biodiversity loss trends is the starting point to reach a solution for the overuse of natural resources (Bibby, 2002). Nature conservation generates between 10.000 and 20.000 full-time jobs directly in the UK, and there is an estimative that four to six times more jobs can be supported by ecotourism to rural areas (Rayment, 1995). These numbers together with scientific knowledge needs to be applied effectively, so any opportunity can become a potential work placement and consciousness about conservation will be spread around.

Thereby bolstering Barn Owls populations by addressing scientific information about where to place new nest boxes and informing what type of habitat better supports Barn Owl prey, increasing their breeding success. In this way, attracting more tourists to the South Down National Park and developing nature related jobs opportunities, environmental education and enhancement of ecosystems services in a long term.

METHODOLOGY

Location of data collection

Data were collected between April and September, 2016, at 5 sites in the western section of South Downs National Park (SDNP) in Winchester, Hampshire, Southern England (Figure 2). This is a multi-functional landscape, supporting grassland, heathland, remnants of ancient woodland, it is economically active with large-scale farmland, pastoral and arable fields, also supporting local villages and touristic areas (South Downs National Park, 2016). All five-field sites had a minimum distance of 4 km among themselves, and data on breeding success, small mammal abundance and vegetation were collected across all sites.

Figure 2. South Down National Park extent map. Extracted from South Downs National Park website, 2016.

Barn Owl breeding success

The breeding success of 14 nest boxes located in five different regions in the South Down National Park (Figure 3), selected based on the criteria of breeding success for the initial phase of this long-term study, namely that there was some historical breeding activity, habitat features and representative sample of the population (Whyle, 2015).

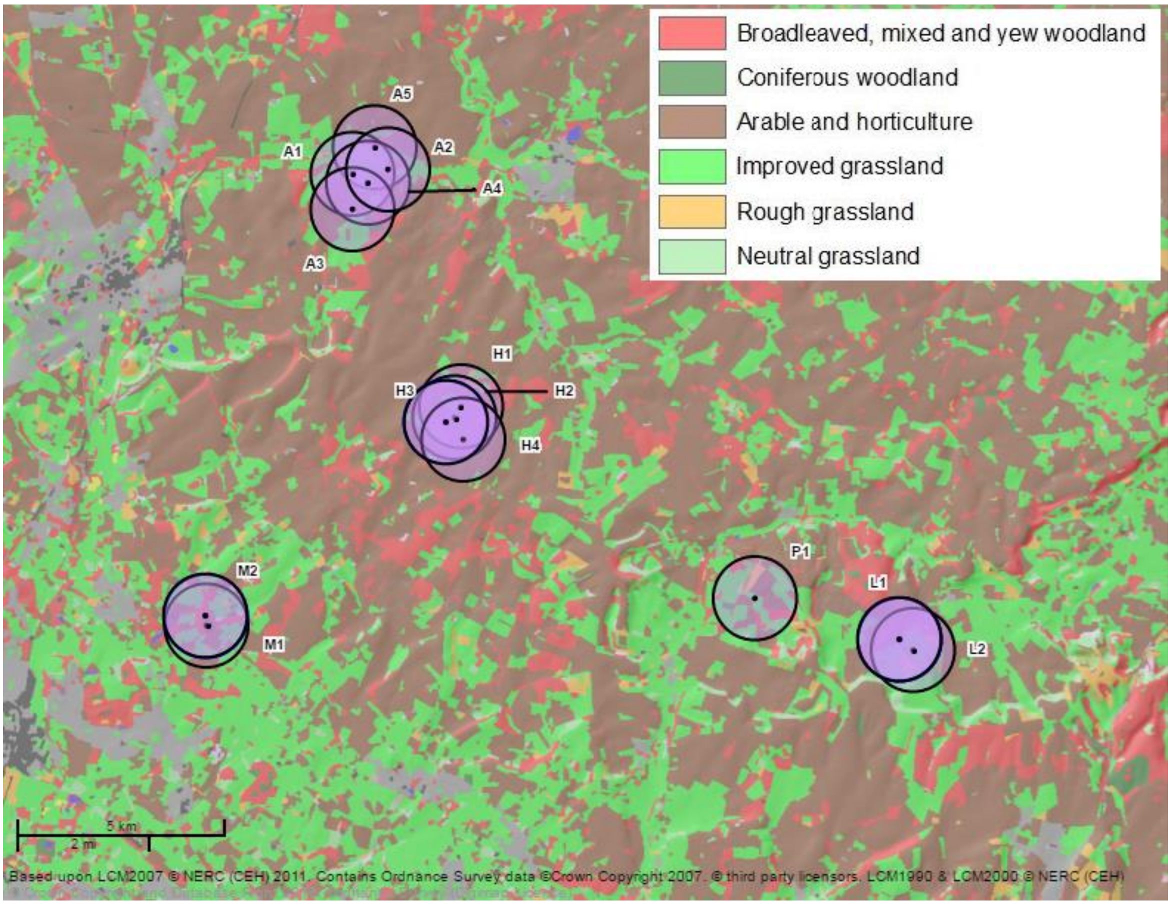

Figure 3. Nest boxes locations (black dots) and 1 km range (black circles)(n=14).

To measure breeding success, a combination of methods to assess whether or not a nest box is occupied, whether or not it is being used for breeding and whether or not it contains chicks were implemented, such as nest box checks, camera trapping and looking for fresh pellets and debris on the ground under nest boxes. During small mammal trapping survey, the ground under nest boxes within the survey range was checked for fresh barn owl pellets and debris, this methodology has been used in several previous studies (Dadam et al. 2010; Milchev & Gruychev 2014; Hindmarch et al. 2012; Santhanakrishnan et al. 2012).

The location of each of these 14 nest boxes were marked using a GPS and a range of 1 km radius were delimited, as this distance was considered the breeding range of Barn Owls (The Barn Owl Trust, 2012). The distance among nest boxes and numbers of nest boxes within the 1 km range were registered (Figure 3).

Once during the research, together with a specialist and Barn Owl license holder from South Downs National Park, the inside of nest boxes were checked to confirm breeding or presence of chicks. Presence and absence of barn owls, barn owls eggs and barn owls chicks were registered. Presence and absence of adults occupying the nest were registered using indicators, such as fresh pellets, droppings, feathers, young calling for food. The occupied nest boxes were observed and classified as breeding or roosting site, and presence or absence of chicks. To minimize disturbance, occupied nests were observed from the ground.

Small Mammals abundance

Each site were censured in a three night capture-recapture sampling effort, in two different seasons: Spring (April) and Summer (August) Two transects of live traps were established within each study region. Each transect consisted of 10 points with 10 m spacing. One Longworth live trap was placed at each trap point. Traps contained bedding and bait. A mix of oats, peanut and peanut butter, tinned tuna, and a piece of carrot were used as bait. Traps were set at 18:00 on day one, and inspected at 6:00 and 18:00 on day two to four, following methodology described in Gurnell and Flowerdew (2006). All traps were removed after the second inspection on the fourth day. Each trapping point on the grid were marked using red wool and a way point in the GPS (Gamin 62).

Individuals were temporarily marked (fur clipping), so if the same individual is caught again, it won't be counted as a second different individual Weight (g) was taken with a spring balance (Pesola 100g), tail and body length were measure with a calliper rule (Mitutoyo 180mm). Breeding status and species were also registered.

Vegetation quality

Canopy height (the highest plant within the 1m^2) and litter depth were measured to the nearest 0.5 cm within the small trapping grid to evaluate if there are correlation between abundance of species trapped to these habitat characteristics. In each site, within three 20m^2 areas, were carried out the measurement of these two vegetation parameters (canopy height, and litter depth). Ten 1m^2 sample points were randomly selected in each transect with GIS software, and 10 measurements points were taken within each 1m^2 sample points as repetitions.

Indirect observations

Indirect observations of the nest-boxes were conducted while the researcher was in the field carrying on small mammals trappings and vegetation surveys, from April to August 2016.

- ***Pellets***

During the first period of trappings, all old visible pellets were removed from under the nest-boxes, to ensure that pellets found afterwards indicated the use of the nest. At every visit to the nests, presence of pellets were registered.

- ***Feathers***

The presence of feathers under nest boxes was used as a confirmation of the presence of a Barn Owl at that nest. However, the absence of feathers were not consider as proof of absence, as it is not unusual for there to be no visible feathers at an occupied site (The Barn Owl Trust, 2012). The presence of nestling fluff, which differs from small fluffy feathers, indicates a breeding site as owlets can be covered of it until 8 weeks old (The Barn Owl Trust, 2012). Presence of feathers and nestling fluff were registered.

- ***Droppings***

Droppings alone were not consider an evidence of Barn Owl presence, but together with the other signs (e.g. pellets) it was used to confirm species and use of the site.

Weather Conditions

Weather parameters as rainfall, temperature and sunlight were taken from the Met Office website. Each mean value per day, during the months of small Mammals capture-recapture and vegetation surveys, of rainfall, temperature and sunlight were registered and a mean value per site per trapping season (Spring and Summer) were used in the data analysis.

Data analysis

Breeding success was defined by presence of hatchlings in the nest-box (nest-site), as no eggs were found, this parameter was not included in the definition of breeding success. Nest box occupation was defined by the presence of a barn owl individual or couple in the nest-box either for roosting purposes (roost-site) or breeding purpose (nest-site).

Generalized linear models (GLM) were used to analyse barn owl nest box success, assessing factors of small mammals population and vegetation characteristics. The response variable for analysis was always in the form of count data (number of individuals), which follows a Poisson distribution; therefore GLM's with Poisson error structures and log link function were used to examine the explanatory variables of small mammals abundance, richness and diversity, litter layer depth and vegetation height on the nest-box occupancy by barn owls.

The use of this model has been widely applied (Senzaki, 2016; Freeman et al 2007; Tubelis, 2007; Pierce, 2003; Link , 2002; Link, 1998) to optimize data analysis and improve the understanding of ecological processes in bird and small mammals communities (Bourne at al, 2007). As censuses of whole populations are usually logistically impossible, monitoring has to rely on counts of subsets of a population and the GLM model with an appropriate error structure takes into consideration that count data can be variable and overdispersed. The use of GLM based on assumptions of overdispersed Poisson distributions are widely acknowledge as appropriate for analyses of count data (McCullagh and Nelder, 1989; Diggle et al 1994).

The Shannon's diversity index was use to indicate the different small mammal species present in each site where the trappings were conducted. The index takes in account how evenly the individuals are dispersed among the species. A high value of the Shannon's index (H) represent a high level of evenness, that means all species present in the sample are equivalently abundant (Shannon, 1948; Hill, 1973; Tuomisto, 2010). The Shannon's index was one of the explanatory variables in the GLM Poisson model.

To examine the occupancy of nest-boxes, the numbers of owls occupying the nest were the response variable in the first GLM Poisson model with nine explanatory variables: small mammal abundance, small mammal richness, small mammal diversity, temperature, rainfall, sunlight, litter layer depth and vegetation height:

Presence of Owls = α + $\beta 1$ Abundance + $\beta 2$ Richness + $\beta 3$ Litter Depth + $\beta 4$ Vegetation Height + $\beta 5$ Trapping Seasons + $\beta 6$ Shannon's diversity index + $\beta 7$ Temperature + $\beta 8$ rainfall + $\beta 9$ Sunlight + $\mathcal{E}$ [1]

Thus, the second model, testing the breeding success, had the presence of chicks in the nest as response variable and used the same seven explanatory variables:

Presence of Chicks = α + $\beta 1$ Abundance + $\beta 2$ Richness + $\beta 3$ Litter Depth + $\beta 4$ Vegetation Height + $\beta 5$ Trapping Seasons + + $\beta 6$ Shannon's diversity index + $\beta 7$ Temperature + $\beta 8$ rainfall + $\beta 9$ Sunlight + $\mathcal{E}$

[1]: Where α is the intercept, β are the treatment coefficients and $\mathcal{E}$ is the model error.

Other simplifications from the first model were run, as for each explanatory variable alone, and combination of variables, which is widely used in statistical analysis to determine how the explanatory and response variables interact and which one of them actually matters in the proposed model (Kydes et al, 1981; Dallal, 2012).

A third model was testing the explanatory variables for the abundance of small mammals:

Small Mammals Abundance = α + $\beta 1$ Temperature + $\beta 2$ Litter Depth + $\beta 3$ Vegetation Height + $\beta 4$ Trapping Seasons + $\beta 5$ rainfall + $\beta 6$ Sunlight + $\mathcal{E}$ [1]

[1]: Where α is the intercept, β are the treatment coefficients and $\mathcal{E}$ is the model error.

Statistical simplifications for the Small Mammal Abundance model were also performed for each explanatory variable and a combination of explanatory variables.

Although the best model fit was used to analyse the data, the sample size is small, which highly increases the risk of overfitting data, particularly on the model for the presence of chicks in the nest-boxes. A discussion of problems associated with the small sample size effects is reserved for the *Discussion* section.

A post hoc analysis of Bonferrroni (Dunn, 1961) was taken to analyse the differences between each season for each of the explanatory variables: small mammals abundance, small mammals richness, small mammals diversity (Shannon's index), temperature, rainfall, sunlight, litter layer depth and vegetation height.

RESULTS

Nest-box success

Of the 14 nest-boxes monitored in this study, four (28.6 %) were occupied by barn owls for the study timeframe. However, only three (21.4%) were determined as "confirmed occupation" in the data analysis, , as one of them was used for less than two weeks which was not considered long enough to be included as a roosting site. One of the nest-boxes (7,1 % of total) were confirmed to support breeding, while the other two (21,4% of total) had evidence of use for roosting only. Each of the three boxes with confirmed occupation belonged to a different site (Figure 4), and the one with confirmed breeding contained 2 chicks (Table 1).

Table 1: Barn owl nest-box occupation (n=3) and breeding success within nestboxes (n=1) at each site (n_{total}= 14).

Nestbox ID	Confirmed occupation	Confirmed breeding	Number of chicks
Marwell 1	No	No	0
Marwell 2	Yes	Yes	2
Holden 1	No	No	0
Holden 2	No	No	0
Holden 3	Yes	No	0
Holden 4	No	No	0
Avington 1	No	No	0
Avington 2	No	No	0
Avington 3	No	No	0
Avington 4	No	No	0
Avington 5	No	No	0
Peake 1	No	No	0
Lower 1	Yes	No	0
Lower 2	No	No	0
Total	3 (21.4%)	1 (7.1%)	2

Table 2: Data collected on indirect observations around barn owl nest-boxes (n=14) and nest-boxes locations.

Nestbox ID	Confirmed occupation	Location of nest-box	Feathers	Droppings	Pellets
Marwell 1	No	Tree	No	No	2
Marwell 2	Yes	Tree	Yes	Yes	13
Holden 1	Yes	Building	Yes	Yes	32
Holden 2	No	Tree	No	Yes	4
Holden 3	No	Building	Yes	Yes	11
Holden 4	No	Tree	No	No	3
Avington 1	No	Tree	No	No	2
Avington 2	No	Tree	No	No	4
Avington 3	No	Tree	No	Yes	4
Avington 4	No	Tree	No	No	1
Avington 5	No	Building	No	No	2
Peake 1	No	Building	Yes	Yes	15
Lower 1	Yes	Building	Yes	Yes	24
Lower 2	No	Building	No	No	0
Total	3 (21.4%)				

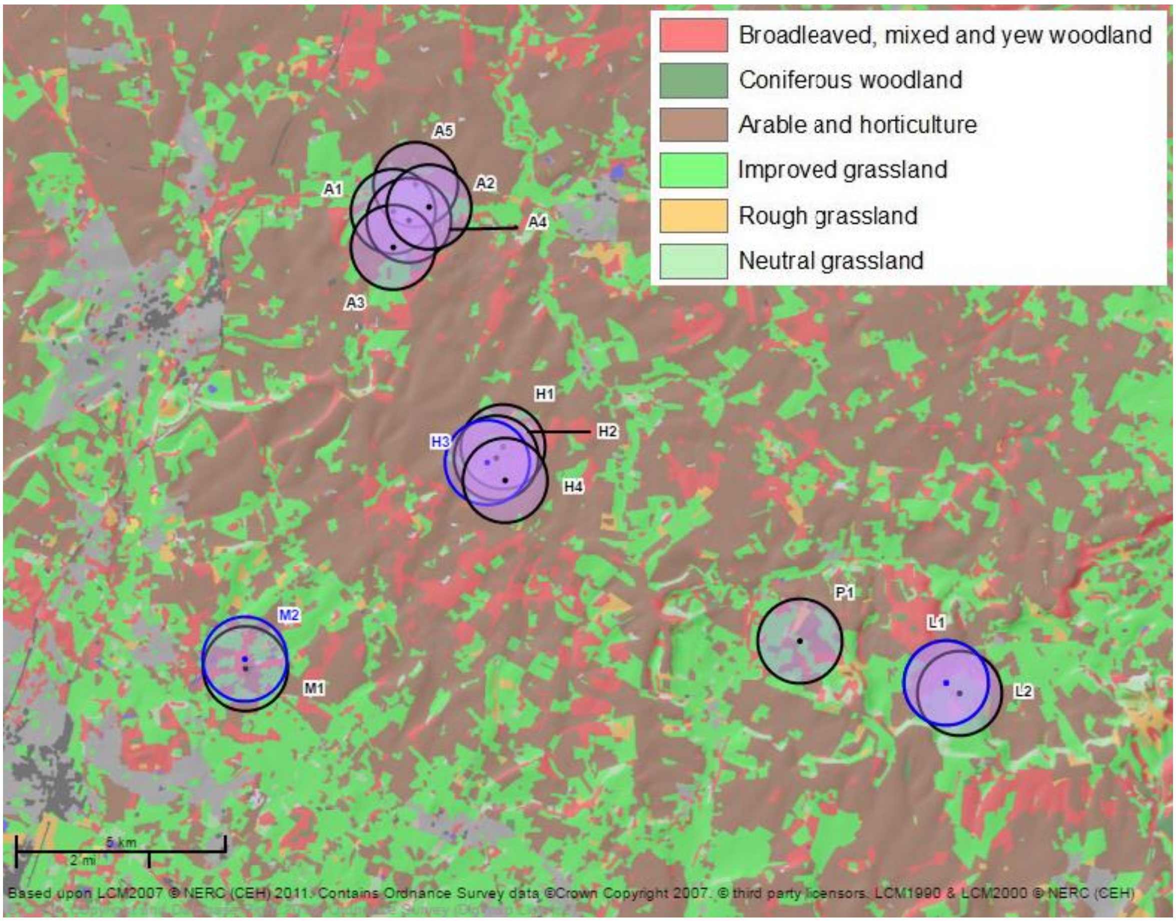

Figure 3: Location and occupancy and breeding success of each nest-box (n=14) in the study. Blue circles indicate confirmed occupancy (n=3), being M2 the only one containing chicks. Black circles indicate unoccupied boxes. Each circle indicates 1km radius around boxes, backdrop shows landscape habitat composition (LCM 2007).

The GLM Poisson model for chicks presence in the nest-box returned t values of zero, and p values of 1, demonstrating no informative value for breeding success in nest-boxes by barn owls, thus the results for this model will not be displayed in the next sections, but it will be discussed in the *Discussion.*

Small Mammals Abundance and Richness

Over the two trapping seasons (spring and summer), a total of 217 individuals of small mammals were captured across all 5 sites, totalling 6 different species: Wood Mouse (47.5%), Field Vole (31.8%), Bank Vole (14.3%), Common Shrew (3.7%), Yellow Necked Mouse (1.8 %), Pygmy Shrew (0.9%).

Overall abundance for the summer trapping (127 individuals) was higher than the overall abundance for the spring trapping season (90 individuals).

Shannon’s diversity index shows that Marwell has the greatest evenness across all sites for small mammal community structure (H=1.37) in the spring trapping season, while Avington holds the greatest evenness for the summer trapping season (H=1.37) (Table 3 and 4).

Table 3: Data on species of small mammal capture and recapture trapping on the spring season (April 2016).

	Marwell	Holden	Avington	Peake	Lower
Field Vole *(Microtus agrestis)*	6	5	0	2	2
Bank Vole (*Myodes glareolus)*	7	4	0	1	2
Wood Mouse *(Apodemus sylvaticus)*	5	14	10	11	16
Yellow Necked *(Apodemus flavicolis)* Mouse	0	1	0	0	0
Common Shrew *(Sorex araneus)*	4	0	0	0	0
Pygmy Shrew *(Sorex minutus)*	0	0	0	0	0
Total Abundance	22	24	10	14	20
Total Richness	4	4	1	3	3
Shannon’s diversity index	1.37	1.07	0	0.66	0.64

Holden Farm (24 individuals), Marwell (22 individuals) and Lower Farm (20 individuals), in this order, hold the highest numbers of small mammals for the spring trapping season (Tabley). Lower Farm (37 individuals) and Marwell (36 individuals), detain the highest numbers of small mammals for the summer season (Figure 5 and 6). Holden Farm was the only site that had a lower rate of capture – recapture for the summer season than the spring season (Table 3 and 4).

Table 4: Data on species of small mammal capture and recapture trapping on the summer season (August 2016).

	Marwell	Holden	Avington	Peake	Lower

Field Vole *(Microtus agrestis)*	27	8	4	9	6
Bank Vole (*Myodes glareolus)*	5	5	5	0	2
Wood Mouse *(Apodemus sylvaticus)*	3	5	4	8	27
Yellow Necked *(Apodemus flavicolis)* Mouse	0	0	3	0	0
Common Shrew *(Sorex araneus)*	0	0	0	2	2
Pygmy Shrew *(Sorex minutus)*	1	1	0	0	0
Total Abundance	36	19	16	19	37
Total Richness	4	4	4	3	4
Shannon's diversity index	0.8	1.22	1.37	0.96	0.84

Small mammal abundance did not show any significant effect on occupation of nest-boxes by barn owls (z value =1.062; p value = 0.288), neither small mammals richness (z value = -0.397; p value =0.763), nor Shannon's diversity index (z value = 0.930; p value = 0.352) for both seasons. However, when the GLM Poisson model was run only with the abundance explanatory variable, it returned significant at a 10% level (z value = 1.806; p value = 0.0709). Nevertheless, the effects remained non-significant for richness and diversity, when these two explanatory variables were performed in the model separately.

When the GLM Poisson model was performed with abundance as the response variable and temperature, vegetation height, litter layer depth as explanatory variables, litter layer depth returned significant (z value = 3.890; p value =0.0001), while vegetation height (z value =1.075; p value =0.2826) and temperature (z value = -1.355; p value = 0.1754) did not.

The outcome from the Post Hoc Bonferroni method showed no significant difference between both seasons for small mammals abundance (p value = 0.25), small mammals richness (p value = 0.36) and Shannon's diversity index (p value = 0.29).

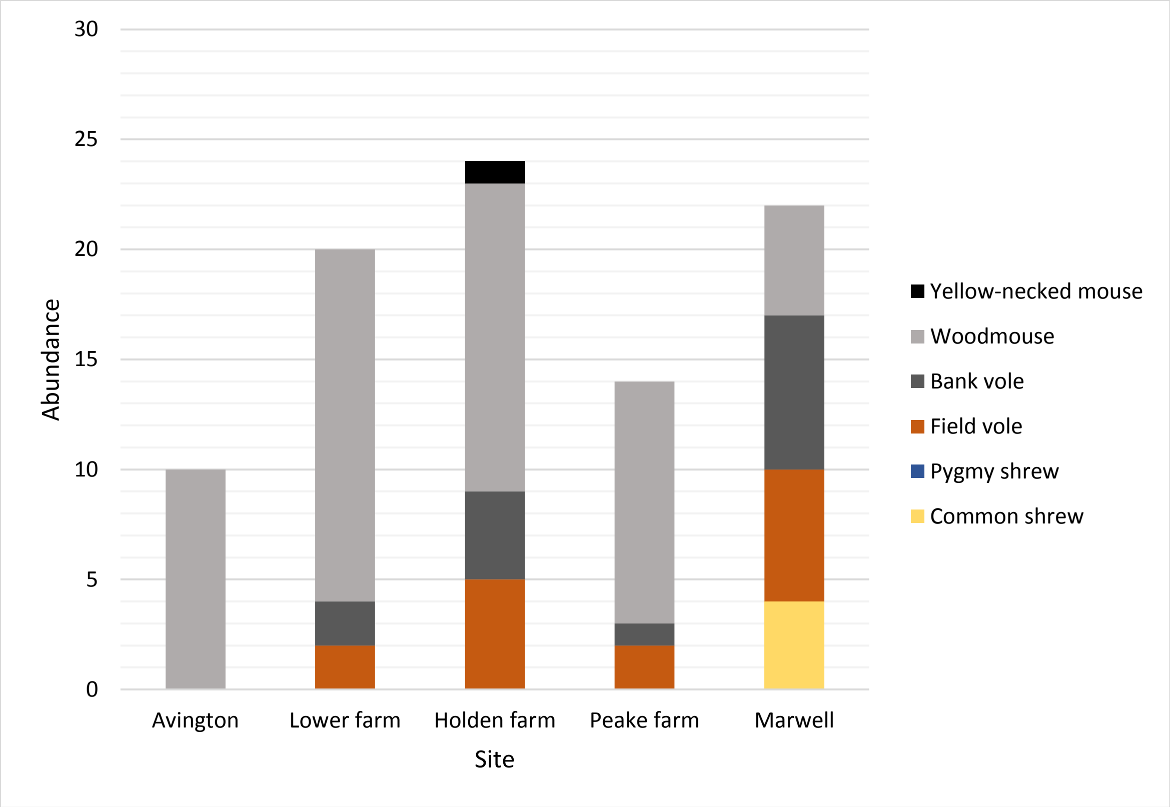

Figure 4: Abundance of species of small mammals per site on spring trapping season (April 2016).

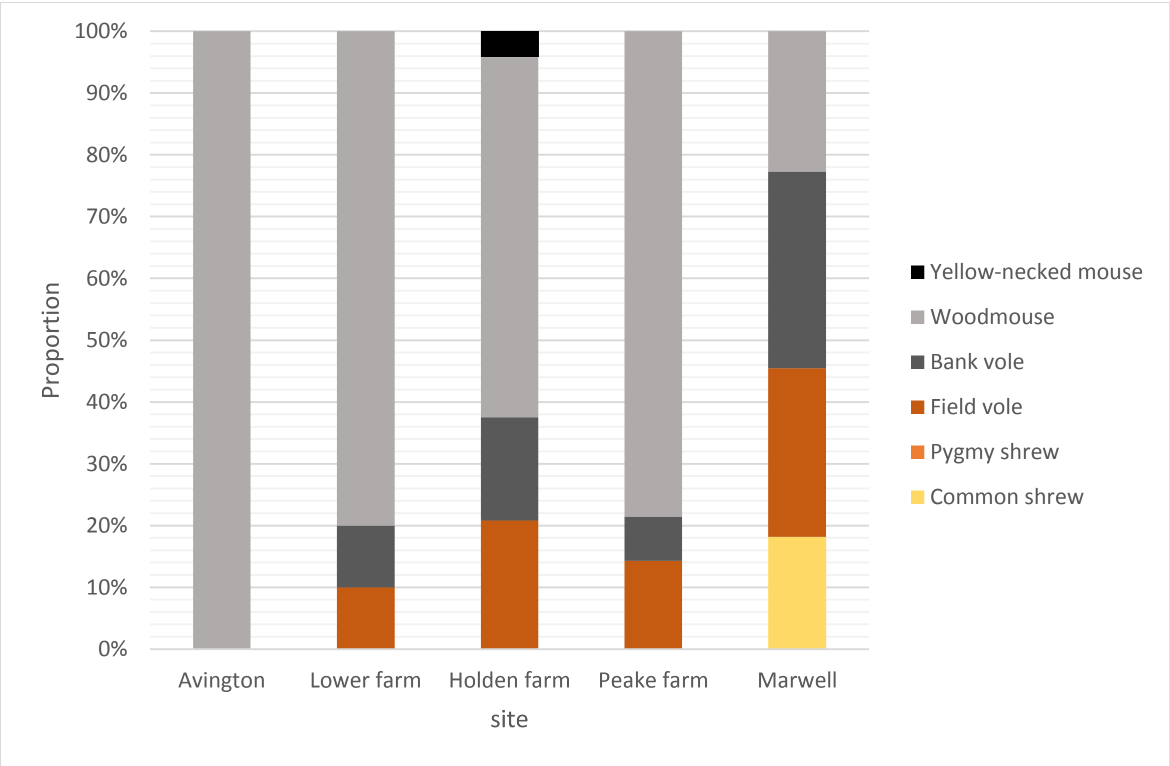

Figure 5: Proportion of species of small mammals per site on spring trapping season (April 2016).

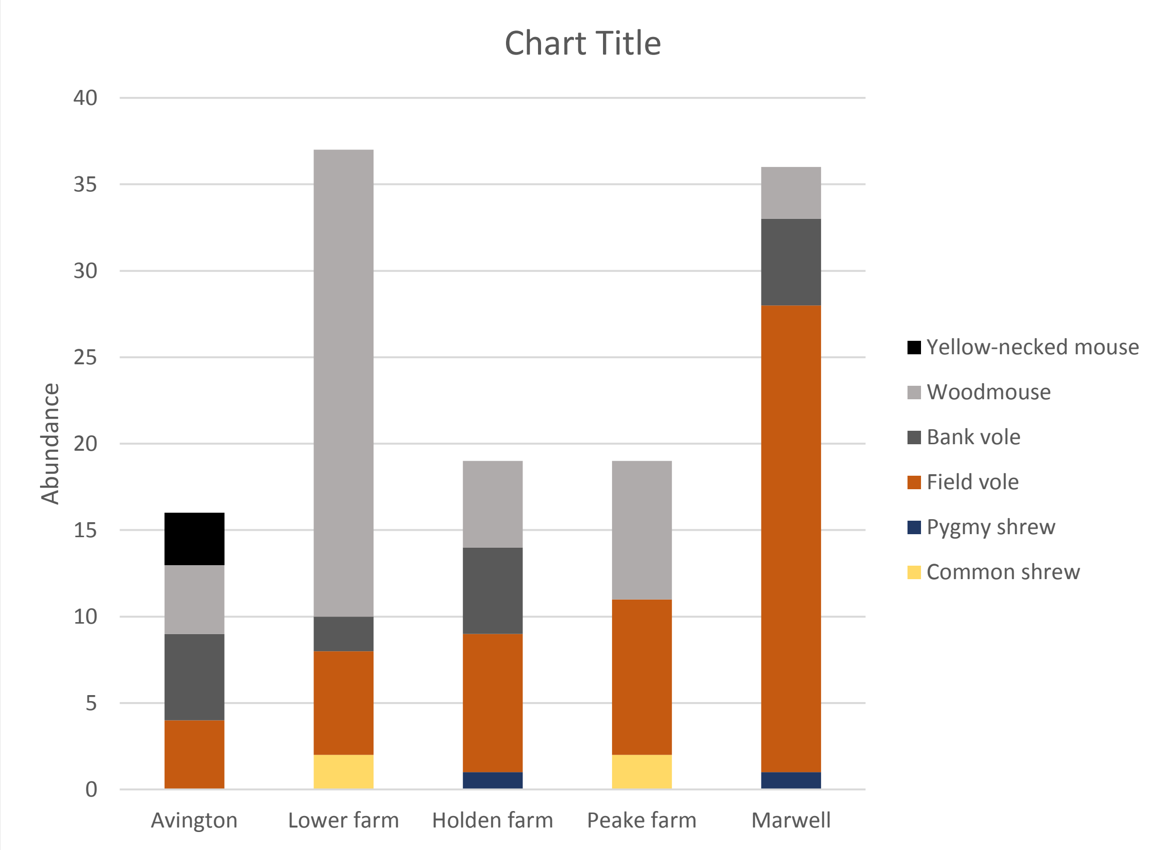

Figure 6: Abundance of species of small mammals per site on summer trapping season (August 2016).

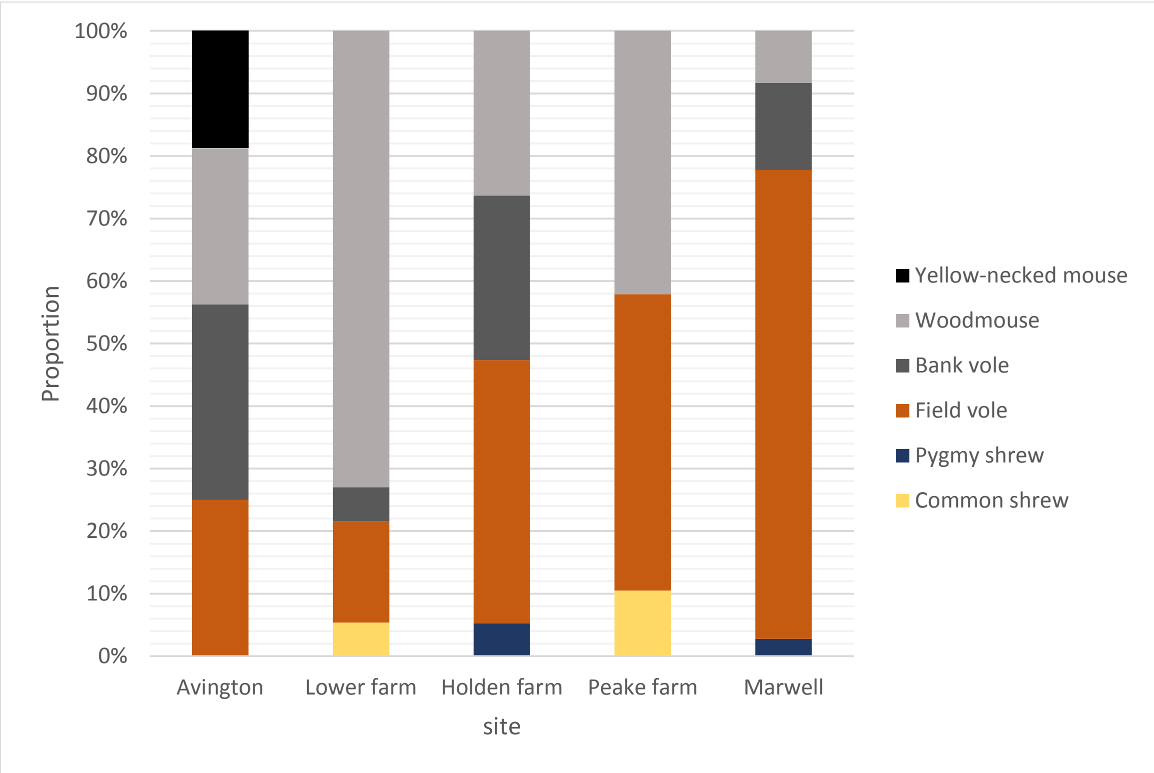

Figure 7: Proportion of species of small mammals per site on summer trapping season (August 2016).

Across all 5 sites, the species captured the most during the spring trapping season was the Wood mouse *(Apodemus sylvaticus)* (Figure 5), while for the summer season it was the Field vole (*Microtus agrestis)*(Figure 7).

Table 5: Data collected on diagnostic features from small mammal capture and recapture trapping, spring season and summer season showed respectively.

	Weights (g)	HBL* (mm)	Percentage of adults	Breeding (%)	Sex (% Females)
Field Vole (*Microtus agrestis)*	29 - 26	101 – 100	93% - 92%	26% - 82%	53% - 13%
Bank Vole (*Myodes glareolus)*	24 - 23	98 - 96	93% - 88%	21% - 76%	49% - 15%
Wood Mouse *(Apodemus sylvaticus)*	19 - 17	103 - 101	98% - 89%	34% - 77%	56% - 21%
Yellow Necked Mouse *(Apodemus flavicolis)*	25 - 20	115 - 109	100% - 33%	0% - 33%	100% - 33%
Common Shrew *(Sorex araneus)*	7 - 6	73 - 74	100%-100%	0% - 0%	75% - 25%
Pygmy Shrew *(Sorex minutus)*	NA - 5	NA - 58	NA - 100%	NA - 0%	NA - 50%

*HBL: Head-body length.

The percentage of small mammals breeding on summer season was higher than in the spring season. Small mammals rate of adults over young was extremely higher for both seasons, while females were caught more frequently in spring then summer. Smaller and lighter individuals were caught in the summer season (Table 5).

Vegetation quality

Vegetation parameters, litter layer depth and vegetation height were registered on spring and summer of 2016 (Table x). Litter layer depth did not show any significant effect on occupation of nest-boxes by barn owls (z value = 0.313; p = 0.754), neither vegetation height (z value =0.017; p = 0.987).

Table 6: Average of litter depth and vegetation height in centimetres per site in each of the trapping seasons (spring and summer in 2016).

Sites	Season	Litter Depth (cm)	Vegetation height (cm)
Marwell	Spring	4.5	37.5
Marwell	Summer	6.5	47.5
Holden	Spring	4.0	40.5
Holden	Summer	5.5	55.5
Avington	Spring	2.0	36.5
Avington	Summer	3.5	75.5
Peake	Spring	5.0	41.5
Peake	Summer	5.5	47.5
Lower	Spring	4.0	48.5
Lower	Summer	6.5	79.0

When the response variable abundance of small mammals and the explanatory variables litter layer depth and vegetation height were applied to the GLM Poisson model, litter layer depth showed a significant relationship with small mammal abundance (z value = 3.890; p value = 0.0001).

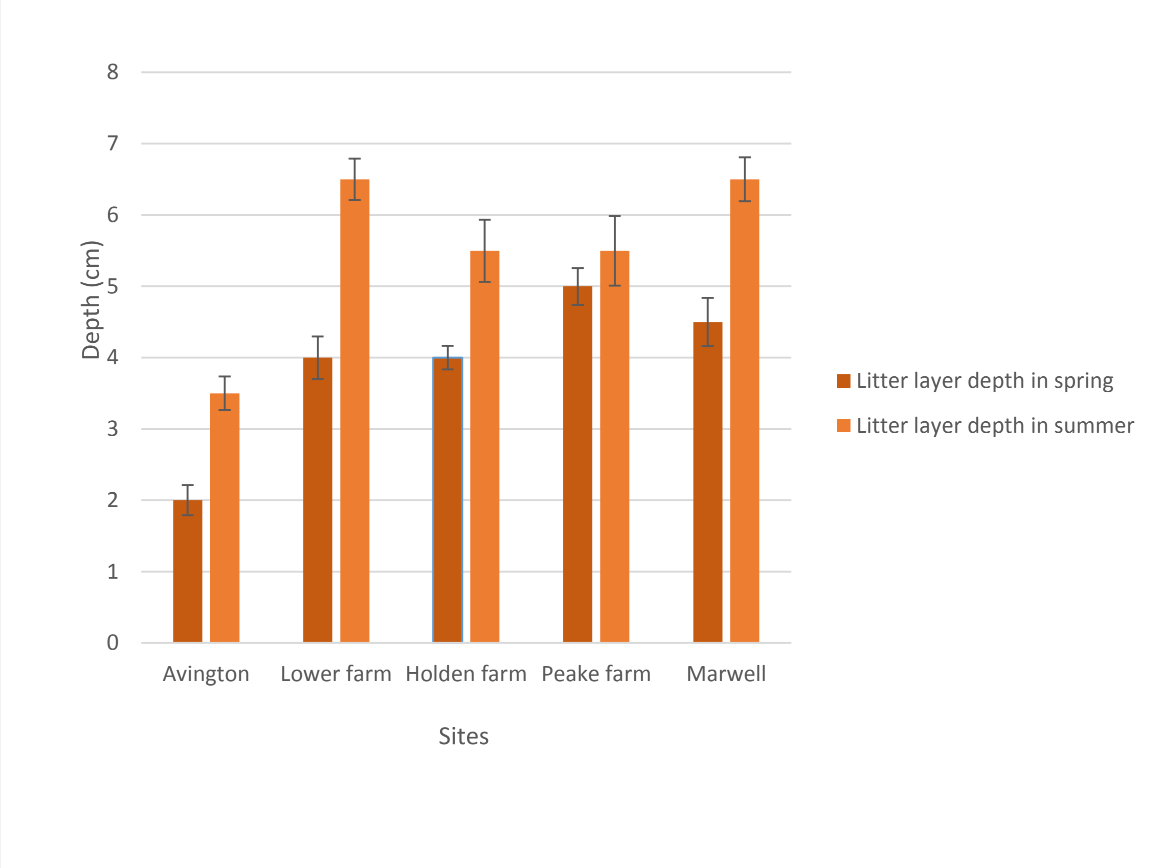

Figure 8: Differences of litter layer depth in spring and summer season with standard error.

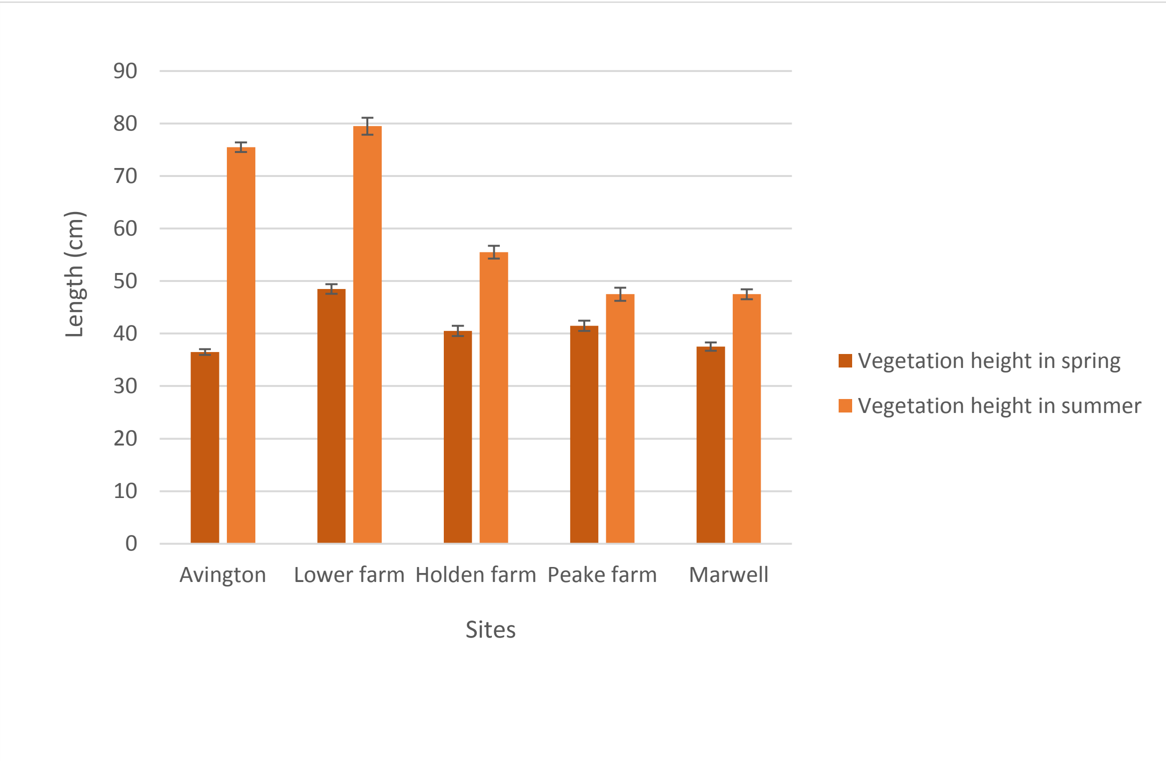

Figure 9: Differences of vegetation height in spring and summer season with standard error.

The outcome from the Post hoc Bonferroni method showed significant differences between seasons for vegetation height (p value = 0.02) and litter layer depth (p value = 0.06) at 10% level of significance.

Weather conditions

The GLM Poisson model run with occupancy of nest-boxes by owls as response variable and weather conditions as explanatory variables showed significant effects at a 10% significance level for rain (z value = -1.649; p value = 0.0998) and sun light (z value = -1.647; p value = 0.0995) and no effect for temperature, as the values did not calibrate in the model, returning as non-applicable (NA).

However, a GLM Poisson model run with small mammals abundance as response variable and weather conditions as explanatory variables showed significant effects for temperature (z value = -2.498; p value = 0.0124) and rain (z value = - 2.576; p value = 0.0099).

The outcome from the Post-hoc Bonferroni method showed significant differences between seasons for temperature (p value = 1.1e-10), rain (p value = 9.2e-13) and sun light (p value < 2e-16).

DISCUSSION

This study is part of a long term research evaluating habitat quality, vegetation characteristics and prey availability to assess breeding success through small mammal communities' population dynamics. Past planning decisions has had an adverse impact on Barn Owls, due to lack of information about relevant planning policies and guidance. The decrease of suitable sites for nesting and roosting results in population decline and can limit population recover (The Barn Owl Trust, 2012; Mainwaring, 2015). Supplementation with nest boxes has become an essential device for barn owl conservation in the UK, proven to be successful in promoting increases on local populations numbers (Johnson, 1994; Taylor, 1994).

The purpose of this study was to find positive relationships among habitat features that under good management could increase barn owl population by providing high quality hunting and nesting sites, supporting their needs in a long term horizon. The improvement of habitat would bring benefits not only for Barn Owls, but for all the others species existing within rough grassland landscapes.

Although all explanatory variables together in the model did not show significant effects on occupancy of nest-boxes by barn owls, the effect of small mammals abundance alone on occupancy revealed a significant response at 10% level (p value = 0.07). This make sense as prey availability has been documented as the most important factor on supporting barn owl populations (Taylor, 1994; Love et al, 2000; Barn Owl Trust, 2012) when their preferred prey type is absent, they will leave the location searching for a better hunting site able to support the energetic needs during breeding season (Yalden, 2009).

The proportion of wood mouse in the samples alone is almost 50% of all small mammals caught in this study and together with field voles, they account for 79.3%. Marwell, Lower Farm and Holden Farm were the sites with the greatest number of these two species, and also the greatest numbers of small mammals in general, which coincidently were the sites with occupied nest-boxes. Field voles are considered the most important prey item for barn owls in the UK (Love et al 2000), as they were found to be more profitable and easy to catch than other small mammals species – common shrews follow as the second preferred prey on barn owl diet in Europe (Morris, 1979; Taylor, 1994). However, in occasions where voles and shrews populations are scarce, wood mice become the most important prey item found in Barn Owl pellets (Glue, 1974; Taylor, 1994; Love, 2000; Aulagnier et al, 2008).

Although litter layer depth and vegetation height did not show any significant result towards nest-box occupancy directly, litter layer depth revealed a very significant effect on small mammals abundance, which matches with findings from previous studies related to small mammals and habitat preference (Tattersall et al, 2002; Barn Owl Trust, 2012; Sullivan et al, 2016).

Intuitively, if abundance of small mammals have a significant effect over occupancy of nest-boxes by barn owls and litter layer depth has a significant effect over abundance of small mammals, indirectly higher litter layer depth is an important asset to be consider in conservation efforts for improvement of barn owl habitat quality. Perhaps a bigger sample effort in this study could have showed this effect of litter layer depth over occupancy of owl in the nest-box directly.

Rain and temperature had a significant negative effect on small mammal's abundance, which corroborates with their behaviour of avoidance of rainfall and cold temperatures to save energy, preventing heat loss under natural conditions (Vinne et al, 2015; Wróbel and Bogdziewicz, 2015; Sullivan and Sullivan, 2016).

The Post Hoc Bonferroni correction illustrates significant differences between both season of data collection for the weather parameters, perhaps indicating that temperature, rainfall and sunlight might have had influence in the low occupancy of nest-boxes. That probably is because barn owls loose heat during flight very quickly, as their body is incapable to store too much body fat, when the temperature is low, this loss of heat happens quicker, decreasing periods of foraging behaviour (Barn Owl Trust, 2012).

As the average of the temperature around spring this year was lower than last year's (Met office, 2016), it could indicate a late breeding season for barn owls as those would not be in good body conditions to breed. The rainfall average this year was higher than last year's during the same season (Met Office, 2016), which could have contributed to the late breeding season as well, as barn owls become unable to fly properly when they are wet, that happens because their feathers are not water repellent, therefore barn owl weight can increase by 27% disabling them to hunt or look for nesting sites.

The percentage of small mammals breeding on summer season was higher than in the spring season, which followed the expected regarding life cycle of these animals (Gurnell and Flowerdew, 2006). Small mammal rate of adults over young was extremely higher, while females were caught more frequently in spring then summer, as during the peak of breeding season they are probably lactating and spend more time in their borrows than looking for food (Macdonald et al, 1999). Smaller and lighter individuals were caught in the summer season, as young individuals are already sexually mature after one month alive, that way those ones born in the beginning of the breeding season are ready to mate for the first time and old enough to forage for food. Those results corroborate with other capture-recapture studies (Macdonald et al, 1999; Flowerdew et al, 2004; Gurnell and

Flowerdew, 2006; Barros et al, 2015; Eva et al, 2016) which possibly indicate a health and stable population of small mammals.

The fact that small mammals abundance was always higher at the sites where barn owl couples were occupying nest-boxes, and was the highest for field voles in the one containing chicks on both seasons, is as expected from the literature. That is because in order to survive in any location, laying and brooding eggs, and sustaining nestlings, a large amount of food supply and quality is needed, which has been linked to rough grassland habitat for field voles, ideally with 7cm of litter layer depth (Taylor 1994; Askew 2007b; Barn Owl Trust 2012). However, in this study these trends were not statistically significant. It is possible that with a larger sample size a trend between breeding success and rough grassland habitat would become clearer, as was the case in other studies (Meek et al. 2009; Dadam et al. 2010).

Limitations of the study

It is surprising that only three nest-boxes were being used by barn owls and a single nest supported breeding this year, as the first phase of this long-term study conducted last year (Whyle, 2016) documented the occupancy of 11 nest-boxes (out of 16), five supported breeding and four had chicks.

However, this year has been irregular regarding barn owl breeding season, it started later than usually is expected according to the Barn Owl Trust and barn owl monitoring groups around the UK, which reported a delay in this annual breeding cycle (Barn Owl Trust, 2016). In spite of the usual variation, annual nesting cycles of barn owls often starts around mid-February with the courtship leading to laying eggs by March and April, and nestlings hatching around May and June (Barn Owl Trust, 2012).

The expectations from other studies results (Taylor 2000 in Barn Owl Trust, 2012; Dadam et al. 2010; Meek et al. 2009) that the explanatory variables would explain the occupation and breeding success of nest-boxes were not met statistically, as none of them returned significantly for both of the models. Although from a statistical point of view, this was likely to happen due to the low sample size.

Mainly for the presence of chicks model, where only one observation was registered opposing to any attempt of statistical interpretation. It was considered to apply the quasi-poisson family on the GLM model, however, it would only overstate that single observation leading to a skewed interpretation of the data. For future studies, the use of a larger sample size, as in number of nest boxes, could possibly show some trend among success in breeding, habitat quality and prey availability. Unfortunately, due to the time and resources available for this research, that was not logistically possible to happen.

Although the trends in this study were not significant, it is possible to see that the sites with greatest overall abundance of small mammals, Marwell (58 individuals), Lower Farm (57 individuals) and Holden Farm (43 individuals) detained the nest-boxes that were occupied, in addition the abundance explanatory variable was the least insignificant among all explanatory variables.

Droppings, pellets and feathers were accessed only as an auxiliary parameter to corroborate to the occupation and use of the nest-boxes. Dense vegetation around the nest-boxes located on trees made it difficult to spot some of the pellets. Additionally, the barns where the nest-boxes were located, were filled by stacks of hay in between the first trapping season to the second, preventing the approximation to the nest-boxes and searching for new pellets, droppings and feathers. In addition, nest-boxes located on the trees are very exposed to the weather conditions, thus droppings, feathers and pellets could have been washed or carried away.

In this study, again for logistic reasons, it was not possible to set up a bigger number of Longworth traps per transect even though some of the sites (Marwell, Holden Farm and Lower Farm) had more than 50% of the traps occupied, and as advised by Gurnell and Flowerdew (2006), in this situation more traps should be placed at each point. Thus, the value of abundance might have been underestimated.

Taking in consideration that this is the second year of this long-term research and the high rate of capture per transect at Marwell and Lower Farm, which had barn owls occupying the nests last year and on the current year, it is likely that the small mammal population at Marwell and Lower Farm can support breeding.

The nest-box at Peake Farm was excluded from the analyses due to the time length of the couple of owls that was spotted in that nest-box, as revealed by the camera located inside the nest the couple was there for only two weeks on April. Perhaps this can be an indication of poor quality of habitat and prey availability, as Peake Farm was the second least site in numbers of small mammals and richness, behind only of Avington, that did not have any indication of barn owl presence in the nest-boxes. In addition, during the first trapping data collection in spring, the fields within that 1km range around nest-boxes were mowed, cutting the hedgerows invasively. A future study comparing nest-boxes occupation at sites following the set-aside scheme from sites not following the scheme could bring important information on how effective the scheme actually is towards wildlife conservation and if it has any impact on small mammal population.

The second GLM Poisson model considering number of chicks as response variable returned values for "t" equals zero and "p" equals one, this is because there was only one single nest containing chicks, which is not enough to calibrate the model with a poisson error. A GLM quasi-poisson was run with the chicks presence in the nest, returning significant values for all explanatory variables: small mammals abundance (t value = 6.672; p value = 0.006), small mammals richness (t value = 4.734; p value = 0.017), Shannon's diversity index (t value = -5.771; 0.01), litter layer depth (t value = - 4.327; p value = 0.022), vegetation height (t value = -17.613; p value = 0.0003), and temperature (t value = 7.531; p value = 0.004). However, those are skewed results as the rely on the information of a single observation, overstating the values related to that single nest-box.

Recommendations

Most of the questions that this study was trying to answered did not get an statistical confirmation due to the size of the sample effort. It is highly recommended that these numbers to be increased for future studies and better logistical resources are allocated to fulfil completely the methodology and even improve it.

A comparison between nest-boxes and natural nest situations related to breeding success, dispersal patterns and adult mortality would be very informative to improve conservation and management problems. The lack of information about road mortality of barn owls in the UK is concerning and should be the focus of future studies as well.

The outcome from this study, yet not statistically significant, indicate that management towards increasing of litter layer depth to augment small mammal population, perhaps through Agri-Environment grant schemes could benefit both the human and wildlife populations. The exploration of other wildlife economic benefits, such as use of barn owls as pest-control, could decrease human-wildlife conflicts (Kross et al, 2016)

CONCLUSIONS

The capacity of the small mammals communities parameters and vegetation characters in this study to assess the effects and to elucidate trends in nestbox use and breeding success has yet to be proven. Some trends in small mammals abundance, litter layer depth and weather conditions were able to be observed, however, future studies need to take in consideration the resources they have available to plan the best strategy to answer the questions they are interest in solving. When choosing whether to carry out a small mammal capture-recapture, pellets analysis or vegetation survey, a deep consideration of the timeframe of the study and logistics is necessary. However, where the desired result is to access vegetation quality and prey availability in order to address nest-boxes placement recommendations, the use of vegetation parameters measurements and capture-recapture methodology such as outlined in this paper added to pellets analysis is recommended.

Based on the results of this research, it’s endorsed that broader scale assessment is carried out, expanding the number of nest-boxes being assessed and including pellets analysis to compare them to small mammals abundance and richness from capture-recapture, testing if those species found in the field reflect what it is actually being consumed by barn owls, and to which extent field voles are still the preferred prey item for barn owls in the UK.

Habitat management to improve habitat quality to augment small mammal populations concerning barn owl populations could also be applied to other bird of prey species and a vast quantity of species existent within rough grassland habitat.

Acknowledgements

I would like to thank my fellow MRes students and all of the staff at Marwell Wildlife, especially Dani for that talk and the one-to-ones in the beginning of the course, also Kezia and Rachel for driving me around my trapping sites and the University of Southampton who helped me with this project. I'd especially like to thank Jane and Katie for all the taxi bookings and for solving my doubts regarding so many things during the course.

I would like to thank the South Downs National Park Authority, especially Rob Nicholls, for project assistance and the provision of data from nestbox checks. I would also like to thank site owners for granting me access to their land to carry out fieldwork, which I am extremely grateful.

I would like to thank Carla Broom for driving me and assisting me with the fieldwork in all those mornings and late afternoons. Finally, I'd like to thank my supervisors, Dr Martin Wilkie and Dr Judith Lock for the orientation and patience with my anxiety crisis.

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