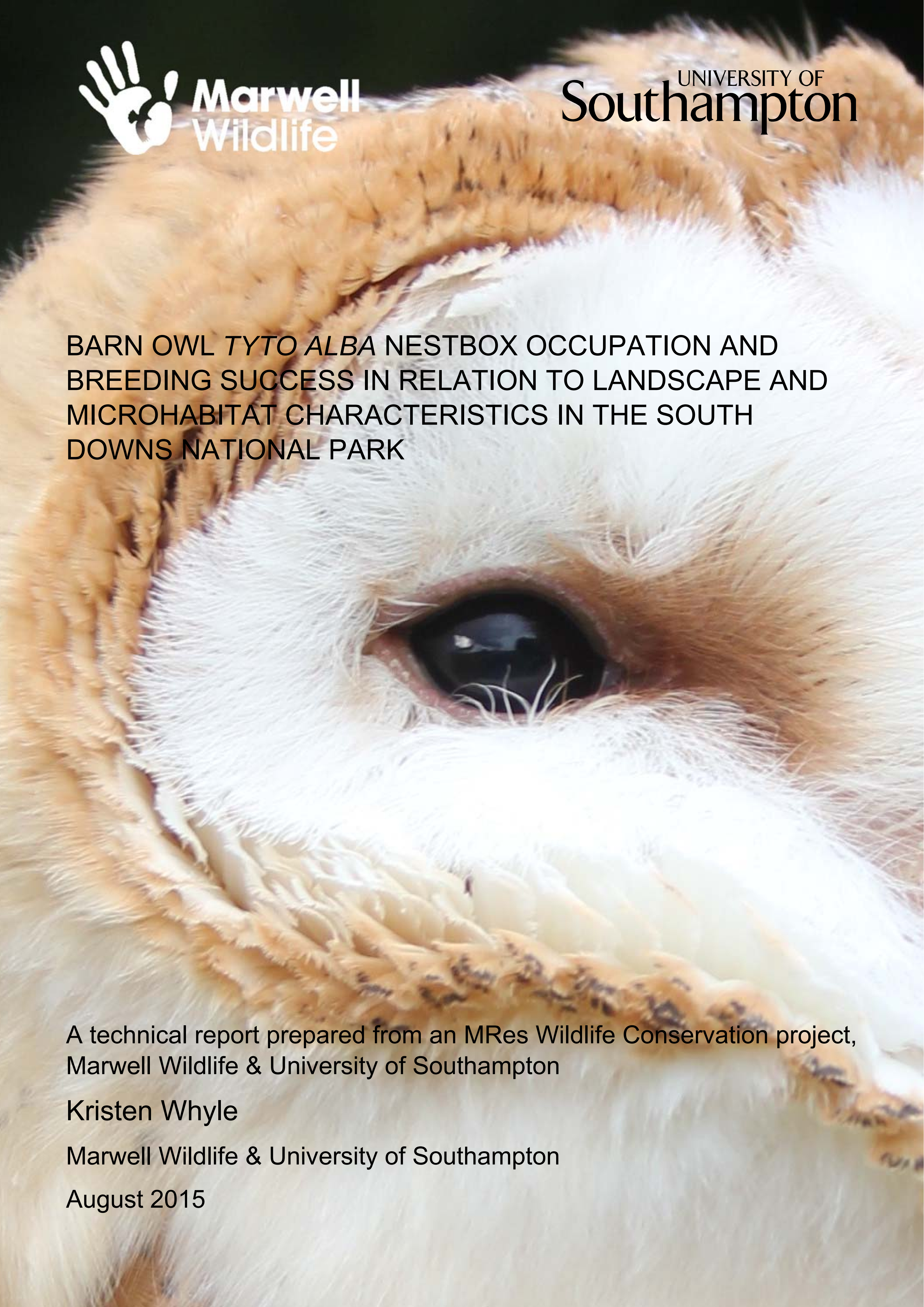

BARN OWL *TYTO ALBA* NESTBOX OCCUPATION AND BREEDING SUCCESS IN RELATION TO LANDSCAPE AND MICROHABITAT CHARACTERISTICS IN THE SOUTH DOWNS NATIONAL PARK

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

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August 2015

ABSTRACT

1. The barn owl *Tyto alba* population in the UK has declined drastically over the past decades, coinciding with loss of rough grassland habitat associated with agricultural intensification. They rely upon small mammal prey, such as the field vole *Microtus agrestis*, whose abundance is affected by the microhabitat vegetation structure and composition. Such microhabitat characteristics should be important determinants of barn owl success, however most studies have examined habitat only at a landscape scale. These studies have had mixed results, and lack the precision to make fine-tuned vegetation management recommendations to support barn owls.

2. This study investigated whether landscape-level habitat composition and microhabitat vegetation characteristics around barn owl nestboxes in the South Downs National Park had an effect on the success of nestboxes in terms of barn owl occupation and breeding success. It was hypothesized that there would be a difference in habitat characteristics between successful and unsuccessful boxes; with more successful boxes being in areas with vegetation structures more suitable for supporting prey. In addition, the microhabitat assessment was expected to better explain differences in success than the landscape assessment. Landscape data was collected from digitized habitat maps and microhabitat data from point quadrat vegetation assessments in potential hunting habitat around boxes. In addition nestbox configuration was examined to determine whether it effects success.

3. There was no effect of landscape-level characteristics, microhabitat characteristics, or nestbox configuration on nestbox success.

4. The results suggest that barn owls are more adaptable in their habitat requirements and less dependent on field voles than has been suggested in past studies.

5. Synthesis and applications: It is recommended that future microhabitat vegetation analysis be conducted across a larger sample of nestboxes than in the current study and in conjunction with data collection on the owl's specific hunting locations within their range, their diet, and small mammal abundance.

Target Journal: Journal of Applied Ecology

Contents

INTRODUCTION

The availability of habitat that allows an organism to meet its evolutionary needs is an important factor influencing its occurrence and breeding success in an area (Gillings et al. 2005; Pulliam & Danielson 1991). For a habitat to best meet the needs of an organism it should ideally be suitable both at a broad landscape scale and at a microhabitat scale, providing not only the direct needs, but also the complex interactions with other organisms in the ecosystem (Mayor et al. 2009). For example, the structure and composition of vegetation affects many key ecological processes including the availability of niches within the sward for invertebrates (Schwab et al. 2002), birds, and small mammals; which in turn determine distribution and abundance of species at higher trophic levels (Stewart et al. 2001). Therefore changes in the quantity and quality of such habitat can have major impacts on the success of a particular species at both the individual and population level (Hodgson et al. 2011).

Habitat destruction and degradation in the UK and globally, resulting from agricultural intensification over the past few decades, have been linked to population declines in many native species (Butet & Leroux 2001; Stoate et al. 2009). Farmland birds, in particular, seem to be sensitive to these changes (Donald et al. 2001; Benton et al. 2002; Gregory et al. 2004; Newton 2004; Vickery et al. 2004; Britschgi et al. 2006; Rodríguez et al. 2006; Arlettaz et al. 2010; Charter et al. 2012; Hindmarch et al. 2012). Population declines have been connected to the fragmentation and loss of grassland habitats, and in Britain 86% of farmland birds have experienced range contractions since the 1950's (Hindmarch et al. 2012).

The barn owl *Tyto alba* is a popular species, valued by farmers for providing rodent control, and recently voted favourite farmland bird in Britain (Ball et al. 2014). Although globally widespread, this flagship species has not been immune to the negative population trends (Taylor 1994). The British population suffered declines of approximately 69% between the 1950's and 2000's (Bond et al. 2005), with the number of breeding pairs falling from about 12,000 in 1932 to about 4,000 at the last national census in 1997 (Toms et al. 2001). Numbers are believed to have risen to over 6,000 pairs in 2009, with most substantial increases occurring in areas where extensive conservation action has been taken (Shawyer 2011). However, in 2013 nesting was estimated at 70% below the all-years average (Ball, et al., 2014), and the overall trend has been a declining one. A number of factors have been suggested for this, including weather extremes, rodenticide use, and increased road traffic (Green & Ramsden 2001), but the main is the loss of suitable grassland habitat for hunting their small mammal prey (Toms et al. 2001; Bond et al. 2005; Taylor 1994; Arlettaz et al. 2010; Askew et al. 2007b).

Barn owls are specialist predators of small mammals, with the field vole *Microtus agrestis*, common shrew *Sorex araneus*, and wood mouse *Apodemus sylvaticus* together comprising 80.90% of their diet in Britain (Love, et al., 2000; Keene & Keene, 2009; Barn Owl Trust, 2012). Their main prey, *M.agrestis*, alone comprises about 50-65% of the diet by weight (Taylor 1994; Love et al. 2000), and requires areas of rough grassland with a characteristically tall, tussocky structure (Tattersall, et al., 2000) and thick litter layer composed of dead grass (Hannson, 1971, cited in Askew et al. 2007). Shrews also attain their highest densities in grasslands, and long grassland and tussocky pasture will also be utilized by the more generalist wood mouse, which occurs in a variety of other habitats including woodland, hedgerows and crops (Taylor 1994).

Barn Owl population size is determined mainly by prey availability (Barn Owl Trust, 2012), with both survival and nesting success very closely linked to food supply (Bunn et al. 1982; Taylor 1994), which is itself determined by habitat type and quality (Bond et al. 2005). Therefore, prey habitat is one of the main factors dictating Barn Owl population size and breeding success, with rough grassland consequently cited as the best habitat for barn owls (Ausden, 2004; Keene & Keene, 2009; Shawyer, 2011; Barn Owl Trust, 2012). It is this specific habitat that has declined in the UK, due to the factors outlined previously (Askew et al. 2007b).

In addition to loss of hunting habitat, loss of suitable habitats for breeding and roosting are also major factors implicated in barn owl decline (Bunn et al. 1982; Taylor 1994; Toms et al. 2001; Bond et al. 2005; Askew et al. 2007; Arlettaz et al. 2010). Barn Owls are cavity-nesters that generally roost and breed in dry, elevated places in buildings or tree cavities, with most owls using one nest site and several roosting sites within their range (Taylor 1994). Agricultural changes have resulted in the loss of many traditional farm buildings, many of which contained potential nest and roost site; they are often replaced with modern buildings unsuitable for use by barn owls (Taylor, 1994; Barn Owl Trust, 2012; Hindmarch et al., 2012). Agricultural intensification has also led to field enlargement which, along with hedgerow destruction and Dutch Elm disease, has resulted in the loss of many hollow trees with cavities suitable for nesting and roosting (Taylor, 1994; Barn Owl Trust, 2012; Hindmarch et al. 2012). As a result of these substantial losses of old farm buildings and hollow trees, the British barn owl population has become increasingly dependent on the availability of man-made nestboxes, which in 2006 were estimated to represent 70% of all known breeding sites in the UK (Shawyer, 2011; Barn Owl Trust, 2012).

Nestbox provision has become an important tool used for barn owl conservation in the UK, as well as other countries, and has proven successful in boosting local population numbers (Johnson 1994; Taylor 1994; Santhanakrishnan et al. 2012). However, providing nestboxes alone is not enough for successful barn owl conservation, and where erected in suboptimal habitat nestboxes could potentially be harmful to owl populations by attracting owls to areas where breeding performance will be below that at other locations (Eadie et al. 1998; Martínez & Zuberogoitia 2004; Klein et al. 2007). To aid population growth the habitat around nestboxes must be able to support barn owl survival and breeding success, and it has been suggested that providing prey-rich foraging areas around suitable nest-sites should be the foundation of all conservation projects (Taylor 1994).

Vegetation structure and composition is an important factor which determines the suitability of the habitat to support barn owl prey species (Askew et al. 2007b). For example, the litter layer is an important component of field vole habitat (Tattersall 2000; Askew et al., 2007), and will also be utilized by common shrews and other small mammals (Taylor 1994). Its presence and depth determine the suitability of an area for field voles, which use it for tunnelling and nesting, with a layer 7 cm or greater stated as optimal for field voles (Barn Owl Trust, 2012). Tattersall et al. (2000) examined vegetation structure and composition through the use of 0.5 x 0.5 m quadrats and found a significant positive relationship between field vole abundance and the percentage of dry litter and percentage of grass within quadrats. Small mammal numbers have also been positively associated with vegetation cover (Yletyinen & Norrdahl 2008) and sward height (Askew et al. 2007b). Thus, assessment of the microhabitat vegetation characteristics in the hunting habitat around nestboxes should be an essential component of barn owl conservation research. However, the topic is surprisingly neglected in the literature.

Habitat has been the focus of many barn owl studies, but these have mostly been done on a landscape scale, focusing on broad habitat characteristics (Andries et al. 1994; Bond et al. 2005; Meek et al. 2009; Hindmarch et al. 2012). Such studies cannot provide a complete picture of the quality of barn owl hunting habitat. To do this a study must take into account the vegetation characteristics of the microhabitat, which affect small mammal abundance and should therefore be the underlying determinants of barn owl success in an area (Tattersall et al. 2000; MacDonald et al. 2007).

The ability of landscape scale studies to determine the suitability of an area for barn owls has been criticized (Barn Owl Trust, 2012), and many have had mixed or inconclusive results. For example, both Hindmarch et al. (2012) and Meek et al. (2009) found little evidence that habitat variables at the landscape scale accounted for the difference in breeding success between sites. Even the amount of rough grassland around sites has not been a consistent predictor of barn owl use; with some studies finding considerable variation between sites and no correlation with occupancy (Taylor 2000 in Barn Owl Trust, 2012); some finding a weak positive correlation between the presence of rough grassland and breeding success (Meek et al. 2009); and others finding occupancy rates highest in rough grassland areas (Dadam et al. 2010). Detailed information on microhabitat vegetation composition and structure could help to clarify the mixed results from landscape scale studies and better explain barn owl occurrence and breeding success in an area (Charter et al. 2012). Indeed, broad scale studies miss out on the finer features of the microhabitat that support small mammal prey, and broad habitat types can differ in their quality and suitability to support foraging (Askew et al. 2007a). Some broad-scale studies have incorporated finer habitat characteristics, by accounting for the presence of relatively small landscape features such as ditch banks, which can be important hunting areas for barn owls (Dadam et al. 2010), or by examining the length of margin features which owls will utilise to hunt in, such as those along woodland edges (Taylor 1994). While this provides a more accurate picture of barn owl habitat it's still incomplete, as it doesn't quantify the vegetation structure and composition within features.

This study aimed to fill the gap in knowledge connecting the fine-scale vegetation characteristics of potential hunting habitat around barn owl nestboxes to occupation and breeding success. It examined habitat both on a landscape scale as in previous studies, and on a microhabitat scale through vegetation assessments examining structural and compositional characteristics.

The study focused specifically on the western region of the South Downs National Park (SDNP), an area with an active barn owl nestbox monitoring programme. The SDNP is a multi-functional landscape, with the study region supporting an array of habitats and land-uses. These include grassland, heathland, remnants of ancient woodland, large-scale open farmland, arable and pastoral fields, villages, and recreational areas (South Downs National Park, n.d.). Agriculture is a major economic and socio-cultural factor within the region, with farming and land management having shaped the area for hundreds of years (South Downs National Park, 2015a).

Many land managers within the National Park work with the South Downs National Park Authority to help conserve wildlife and improve important habitats across the landscape through conservation and environmental stewardship programmes (South Downs National Park, 2015a). The barn owl nestbox monitoring programme is one such scheme, which involves the set-up and monitoring of numerous boxes across the SDNP, with over 100 erected to date.

This project aimed to inform the management of vegetation which supports barn owl occupation and breeding in the area. It also sought to inform placement of new nestboxes when assessing the suitability of a location. It hypothesized that measures of barn owl success in nestboxes, namely occupation, confirmed breeding, and confirmed chicks, would be determined by the quality of the microscale forging habitat, namely the structure and composition of the sward. Additionally, it was hypothesized that a microhabitat vegetation assessment would give a better indication of the suitability of an area to support barn owls than a landscape scale assessment. It also tested whether nestbox design, location and configuration have an effect on nestbox success.

METHODS

Data was collected between 20th May and 15th July, 2015, at 6 sites within the western region of the South Downs National Park (SDNP) in Hampshire, UK (Figure 1). Field sites were all part of the South Downs barn owl nestbox monitoring programme, each containing at least one monitored nestbox, with the total per site ranging from one to five. Sites were separated by a minimum distance of 2 km between nestboxes, and data was collected on a total of 16 nestboxes across all sites (Figure 2).

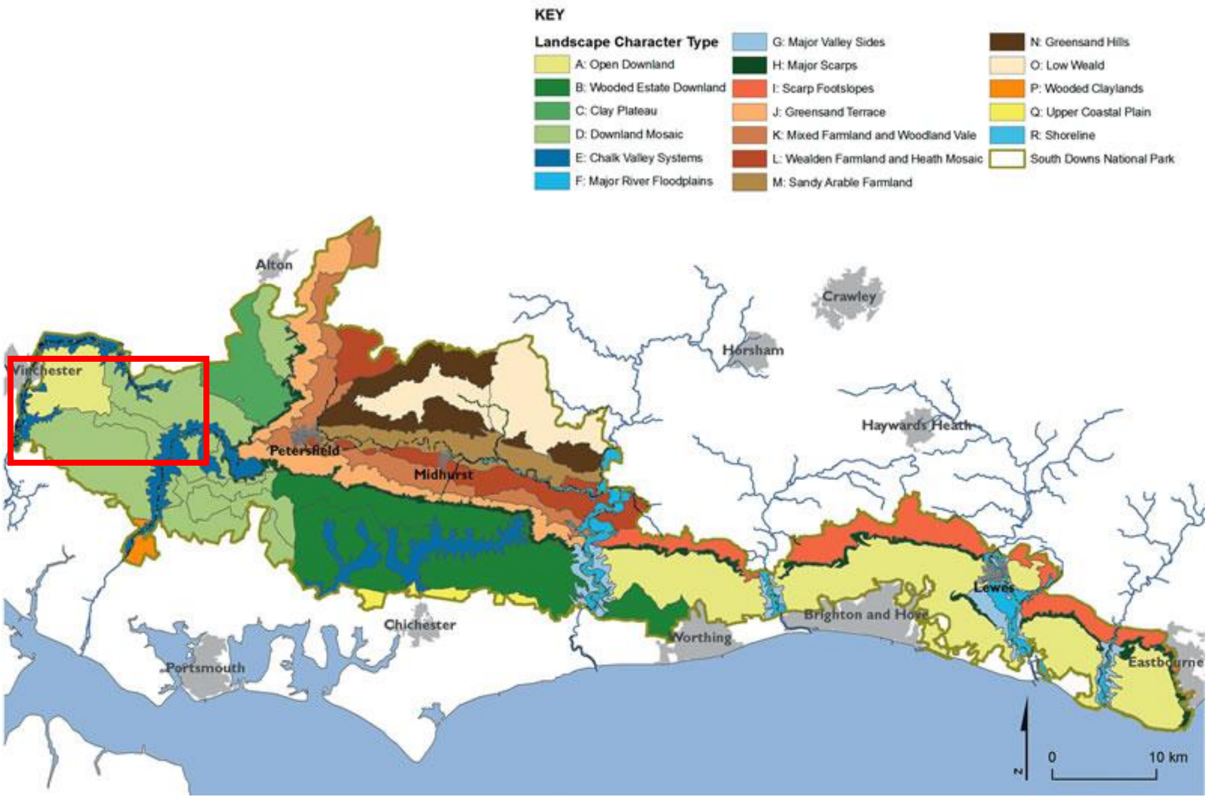

Figure 1: Location of study area (red box) in the western region of the South Downs National Park, Hampshire, UK. Study area indicated by red rectangle (Source: South Downs National Park, 2015b).

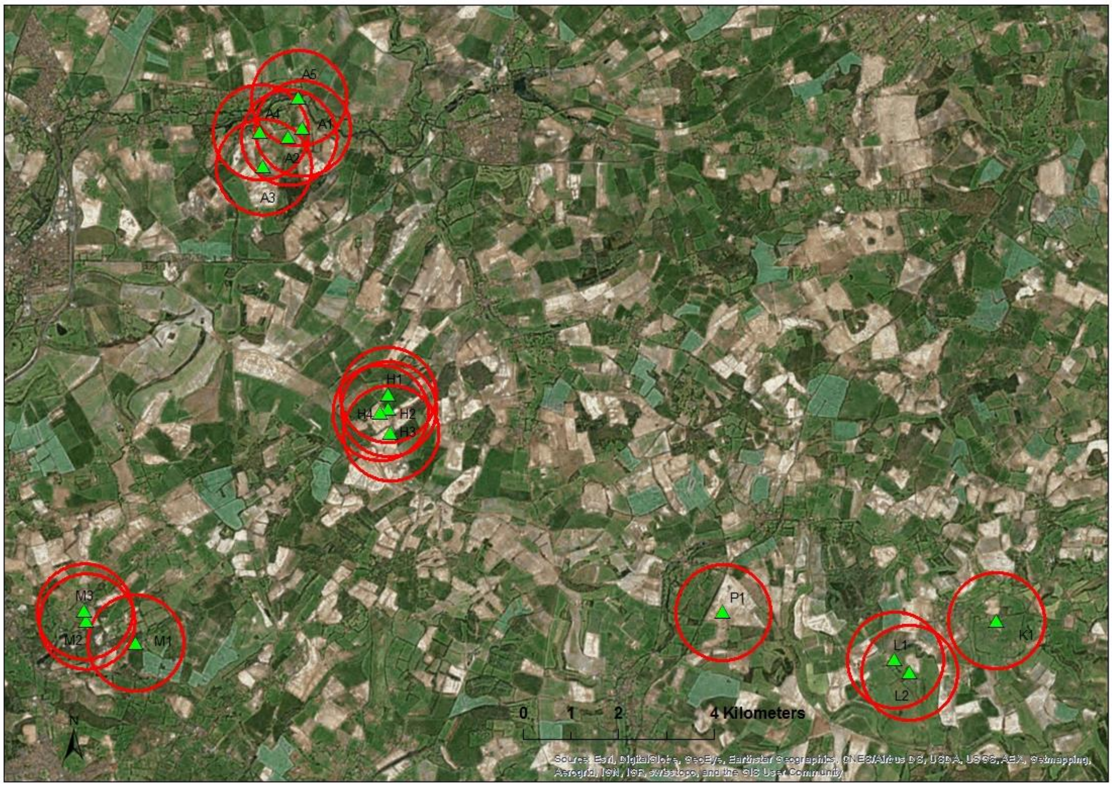

Figure 2: Satellite imagery showing the configuration of nestboxes (green triangles) within the habitat mosaic of the agricultural-dominated study area. Red circles indicate the 1 km radius area around each nestbox, taken to approximate the barn owl breeding range. Nestbox ID is labelled (Source: ArcGIS Esri basemap)

Nestbox configuration

The location of each nestbox was marked using a GPS (Garmin GPS map 62s), and Geographic Information System (GIS) software (ArcMap 10.2.2) was used to distinguish the 1 km radius area around each nestbox. This is an area which approximates the breeding range of barn owls (Taylor, 1994; Barn Owl Trust, 2012) and has been used to assess barn owl habitat in a number of previous studies (Andries et al. 1994; Love et al. 2000; Toms et al. 2001; French et al. 2004; Martínez & Zuberogoitia 2004; Bond et al. 2005; Meek et al. 2009; Hindmarch et al. 2012). GIS was also employed to determine the distance of each nestbox to the nearest neighbouring box, and the number of nestboxes located within a 1 km radius of each box. In addition, nestbox design and whether it was located in a building or tree was recorded (Table 1).

Table 1: Design, location, and configuration of each nestbox (n=16) within the landscape; site indicated by first letter of nestbox ID

Nestbox ID	Design of nestbox	Location of nestbox	Number of boxes within 1 km	Distance to nearest nestbox (m)
A1	A	tree	3	340
A2	A	tree	4	340
A3	A	tree	2	729
A4	E	tree	3	604
A5	A	building	2	640
H1	D	building	3	300
H2	D	building	3	182
H3	A	tree	3	478
H4	C	tree	3	182
L1	C	building	1	402
L2	A	tree	1	402
L4	B	building	1	495
M1	A	building	0	1118
M2	B	tree	1	215
M3	A	tree	1	215
P1	C	building	0	unknown

Landscape Assessment

To examine the effect of habitat at a landscape scale on nestbox success, raster based GIS techniques were used to quantify habitat composition around nest-sites, a method utilised in previous studies (Bond et al. 2005; Meek et al. 2009; Andries et al. 1994). Specifically, the LCM2007 Ordinance Survey habitat classification map (LCM2007) was used to classify habitat types, and ArcMap 10.2.2 was used to determine the percent composition of each habitat type falling within the 1 km radius range of each nestbox.

Vegetation Assessment

To examine the effect of habitat at a microscale on nestbox success, vegetation assessments were carried out within a 1 km radius of nestboxes at each site. A point quadrat method, which has been used extensively to study grasslands (Goodall 1952), was employed to quantify specific aspects of the vegetation structure and composition; in particular those which should give an indication of the suitability of the habitat to support field voles and other small mammals.

A stratified sampling procedure was employed to determine locations for point quadrat data collection, with each site divided into different features based on habitat type. Sampling was carried out in features classified as: open grassland, young tree plantation, agricultural set-aside, and margin habitat. Margin habitat was further divided by type; including field, hedge, woodland, stream, fence, and road margin. Feature types were chosen based upon studies of barn owl foraging behaviour indicating these are areas they use for hunting (Taylor, 1994; Barn Owl Trust, 2012). Barn owls will sometimes hunt in hayfields and crops, but for logistical reasons, and because research indicates these areas are less profitable to owls than most of the features described above (Taylor 1994), they were not sampled in.

In order to represent the diversity of habitat around nestboxes as many feature types as possible were sampled in for each box. Features were identified during on-the-ground site surveys and their borders traced out using a GPS (Garmin GPSMAP 62s). Locations for quadrats within each feature were generated randomly using a random point generator tool in ArcGIS (ArcMap 10.2.2), with a specified minimum separation distance of 20 m between quadrats. Data from a minimum of 20 quadrats was collected around nestboxes at each site, with a total of 150 quadrats analysed from across the 6 sites.

Point quadrat data collection was facilitated by the use of a point frame through which vertical metal point quadrat rods (approximately 2 mm diameter) were passed (as described in Floyd & Anderson 1982). Quadrats consisted of 16 individual rods spaced evenly (16.5 cm apart) within a 0.5 m x 0.5 m square area, a quadrat size which has been used previously to assess field vole habitat preferences (Tattersall et al. 2000).

Cover repetition, which reflects the number of layers of vegetation above a specific point on the ground, was recorded for each rod by counting the number of plant contact points along its length (Goodall 1952)(Appendix note 1). This was subdivided into the number of contacts with grass and non-grass species, and the number of contacts with live and dead grass. The most dominant species, in terms of contact points, was also recorded for each rod. Contact with moss or non-rooted plant material was included in a separate category of ground cover, rather than in the cover repetition total.

Ground cover was additionally examined in terms of litter layer quality. The presence or absence of a litter layer, defined as a layer (consisting of multiple strands) of vegetation composed mainly of dead horizontal grass, and whether or not it was greater than 5 cm in depth was recorded for each rod. Additionally, to obtain more exact figures on litter layer depth, it was recorded to the nearest 0.5 cm at four pre-selected rods within each quadrat. Canopy height, or highest point of contact between a plant and the rod, was also recorded to the nearest half cm at these 4 points.

Additional vegetation data was also collected within each 0.5 m^2 quadrat separately from point quadrat data. The height of the tallest plant was recorded, to the nearest half cm, as was an estimate of the average height of the live vegetation canopy within the quadrat. The three most dominant plant species were recorded from visual estimation, as were percent cover estimates of each vegetation/ground cover functional group (including grass, herb/forb, sedge, woody vegetation, and bare ground). Similar measurements and methods to those outlined above have been used successfully to collect vegetation data in relation to other grassland bird species (University of Montana 1997; Smith et al. 2007).

Additionally, the photosynthetic active radiation (PAR) of the vegetation was measured with a Lux light meter (HANNA HI 97500 Luxmeter; range 0.001 to 199.9 Klux). This method provides an easily quantifiable measure of the light absorption of the vegetation canopy (Schwab, et al, 2002). Readings were taken to the nearest .01 Klux at 10, 20, 30, 40, 50, and 60 cm above the ground within each quadrat.

Nestbox Success

Whether or not a nestbox was occupied by barn owls during the sampling period, whether it was used for breeding, and whether it contained chicks was determined through a combination of methods, including examining the ground below boxes for fresh barn owl pellets, nestbox checks, and camera trapping.

At least once a month, the ground below each nestbox was visually inspected for the presence of fresh barn owl pellets (Appendix note 2). Surveys of this kind have been carried out in numerous previous studies examining barn owl site occupation (Dadam et al. 2010; Milchev & Gruychev 2014; Hindmarch et al. 2012; Santhanakrishnan et al. 2012). As in these studies, fresh pellets found below a box were taken as evidence that a box was occupied.

To supplement this, and to determine whether boxes were being used for breeding or contained chicks, nestbox checks were carried out at each box at least once during the study timeframe. The inside of boxes were checked for the presence of barn owls, barn owl eggs, barn owl chicks, and other evidence of occupation including fresh pellets.

In addition, camera traps (Bushnell Trophy Cam model 119636) were set up opposite four nestboxes to provide further evidence to confirm or deny utilization of the boxes by barn owls and to examine their ability to provide information on nestbox use for future studies. Images obtained from one trap during the study timeframe were examined, and those containing a barn owl/barn owls inside and in the vicinity of a box were used as evidence to classify the nestbox as occupied by barn owls.

Using more than one method allowed better assurance that nestbox occupation was not underestimated, especially as pellets often aren't found below active breeding sites (Dadam et al. 2010). Information from all three methods combined was used to categorize nestbox success for statistical purposes. First, nestboxes were categorised by whether or not they supported occupation by barn owls, with occupation indicated by owls, eggs, or chicks inside a nestbox, fresh pellets inside or below a nestbox, or camera traps photos of owls using a nestbox. Second, nestboxes were categorised by whether or not they supported breeding, with breeding indicated by the presence of barn owl eggs and/or chicks inside a box. Finally, boxes were categorised by whether or not they supported chicks, indicated by the presence of hatched chicks inside a box during nestbox checks (Appendix note 3).

The timeframe of fieldwork coincided with the normal breeding season of barn owls, which is between March and August (Taylor, 1994); with most eggs laid in April or May (Barn Owl Trust, 2012), and most young fledging between July and September (Shawyer 2011). Therefore, data on whether a nestbox in this study has supported breeding and chicks should be relatively accurate, although it is possible for breeding to occur outside of this timeframe (Barn Owl Trust, 2012). However, even if data collection missed out on including later breeding success and hatched chicks, research has shown that earlier laying females are generally those with the best food supply available (Taylor 1994); therefore land around boxes categorized as supporting breeding and chicks should theoretically still reflect habitat that better supports barn owls than land around boxes where no chicks or breeding were recorded.

Ethical considerations

Evidence suggests that barn owls can be sensitive to disturbance, particularly during the early stages of the breeding season (Barn Owl Trust, 2012), and the species is legally protected from reckless disturbance under Schedule 1 of the Wildlife and Countryside Act (1981) (Barn Owl Trust, 2012). When working around nestboxes special care was taken to minimise any potential disturbance to birds that might be present.

Nestbox checks were carried out by an experienced professional from the SDNP under proper licensing and followed a set of precautions put in place to minimise disturbance to birds. Camera traps were set up and collected quickly and quietly, and nestboxes were not touched or immediately approached during the process. As a precaution time spent in the immediate vicinity of nestboxes was restricted to five minutes when searching quietly below boxes for pellets and droppings, and this activity has been deemed non-disruptive and acceptable to carry out without a licence (Barn Owl Trust, 2012).

Data Analysis

Generalized linear models (GLMs) were used to analyse barn owl nestbox success, assessing factors of nestbox configuration and habitat characteristics for both the landscape and microhabitat datasets. The response variable for analysis was always in the form of presence/absence data, which follows a binomial distribution; therefore GLMs with binomial error structures and logit link functions were used (Martínez & Zuberogoitia 2004).

The three ways of categorizing nestbox success; occupation, confirmed breeding, and confirmed hatchlings, were not mutually exclusive (i.e. all nestboxes supporting hatchlings were also categorized as supporting breeding, and all boxes categorized as supporting breeding were also categorized as supporting occupation in general). Therefore they were analysed through separate models under each of the logically grouped explanatory variable sets; nestbox configuration, landscape characteristics, and microhabitat vegetation characteristics. This helped to minimise pseudoreplication and answer slightly different questions about the degree to which the 1) nestbox configuration, 2) landscape habitat characteristics, and 3) microhabitat characteristics of an area 1) support occupation by barn owls, 2) support breeding, and 3) support successfully hatched chicks. Conducting analysis separately to examine the effects of landscape habitat characteristics, obtained from LCM data, and microhabitat characteristics, obtained from vegetation assessments, allowed comparison between the methods in terms of their ability to explain the variation in barn owl success between nestboxes.

To identify which characteristics best explained the occurrence and breeding success of barn owls in nestboxes, an information theoretic approach to data analysis was used (Burnham & Anderson 1998). The small sample size in this study necessitated relatively simple models (Burnham & Anderson 2002 in Smith, Kelly, & Finch, 2007).

Therefore, model complexity was reduced by removing the less biologically meaningful potential explanatory variables and interactions prior to model testing. In cases where explanatory variables were correlated or explained similar characteristics only one was retained. Which variables were retained was based upon biological relevance, previous studies and ability of management to influence the variable. All data was analysed using R version 3.1.2 (R Core Team, 2014).

Nestbox configuration

Before running analysis on habitat data, analysis was performed comparing the three categories of nestbox success against nestbox design, location and configuration, to determine whether these variables have an effect on nestbox success and should therefore be retained in models assessing habitat characteristics. The final model examining occupation contained explanatory variables (i) nestbox location, (ii) number of boxes within 1 km, and (iii) nestbox design. The final models examining breeding and hatchlings each contained explanatory variables for (i) nestbox location and (ii) number of nestboxes within 1 km.

Landscape composition

Landscape habitat types occurring in the ranges around barn owl nestboxes were excluded from the models for analysis if they only occurred marginally and are not known to be biologically meaningful to barn owls. The final model examining occupation contained (i) rough grassland, (ii) neutral grassland (iii) improved grassland, (iv) arable and horticulture, as well as the interaction between rough grassland and each of the other variables. Models examining breeding and hatchlings could not be fit to all of these explanatory variables, and therefore contained only rough grassland as an explanatory variable, based upon its biological relevance.

Vegetation characteristics

As vegetation characteristics naturally change over time, and the sampling period of this study ranged across two months, before analysing vegetation data ANOVAs and homogeneity of variance tests were run comparing the mean date of sampling between presence and absence of the three nestbox success measures. This was done in order to take into account any affect that sampling date may have had on vegetation parameters, which could have resulted in spurious results. Mean sampling date did not differ between response categories and data met the assumption of homogeneity of variances (occupation: $F_{1,14}$=0.444 p=0.516, df=14, Bartlett's K-squared$_1$=0.1058, p=0.7449; breeding: $F_{1,13}$=0.1, p=0.923, Bartlett's K-squared$_1$= 0.0934, p=.7599; chicks: $F_{1,13}$=0.693, p=0.42, Bartlett's K-squared$_1$=0, p=.9947).

For the analysis of vegetation characteristics, data collected at each nestbox was split into two groups containing the average values from margin features and non-margin features (i.e. open fields, pastures, areas of planted saplings, non-margin set-aside). Both the margin and non-margin value, plus the interaction between the two, were input as explanatory variables in models. This is because prior knowledge expects the two habitat types to differ in their vegetation characteristics and the quality of both were expected to make a difference in terms of the suitability of an area for barn owls. An average value of the two habitat types combined was not used in the analysis because access to the 1 km range around nestboxes differed at each site; therefore the results might have reflected a difference in feature type access, rather than a difference in the habitat as a whole.

Only the most biologically meaningful explanatory variables and interactions were tested, based upon previous studies (Tattersall et al. 2000) and knowledge of barn owl and small mammal (particularly field vole) biology. As the both margin, non-margin, and the interaction between them had to be tested for each vegetation characteristic examined, point quadrat vegetation data was split into the following models:

Models 1), 2), and 3) examined each success measure against margin canopy height, non-margin canopy height, and their interaction. Models 4), 5) and 6) examined each success measure against margin litter layer, non-margin litter layer, and their interaction. Models 7), 8) and 9) examined each success measure against margin percentage grass, non-margin percentage grass, and their interaction; with percentage grass calculated as the total number of contacts between quadrat rods and grass, divided by the total number of contacts between quadrat rods and any vegetation (Goodall 1952). Models 10), 11) and 12) examined each success measure against margin cover repetition, non-margin cover repetition, and the interaction between the two.

RESULTS

Nestbox success

Of the 16 nestboxes monitored in this study, 11 (68.75 %) were determined to be used by barn owls during the study timeframe, including at least one box at each site. Five of these boxes (31.25 % of total) were confirmed to support breeding, while another five had evidence of use for roosting only (Appendix note 3). Each of the five boxes with confirmed breeding belonged to a different site, and four of these boxes contained chicks (25.00 % of total)(Figure 4). Three of these boxes contained two chicks, and one contained a single chick (Table 3).

Table 3: Data on barn owl nestbox occupation (n=16) and breeding success within nestboxes (n=15) at each site (site indicated by first letter of nestbox ID)

Nestbox ID	Confirmed occupation	Confirmed breeding/evidence	Number of chicks
M2	No	No	0
H3	No	No	0
H4	No	No	0
A4	No	No	0
A5	No	No	0
M1	Yes	No	0
M3	Yes	No	0
H2	Yes	No	0
A1	Yes	No	0
A2	Yes	No	0
A3	Yes	Yes/Eggs	0
H1	Yes	Yes/Eggs, chicks	2
L2	Yes	Yes/Eggs, chick	1
K1	Yes	Yes/Eggs, chicks	2
P1	Yes	Yes/Eggs, chicks	2
L1	Yes	Not checked	Not checked

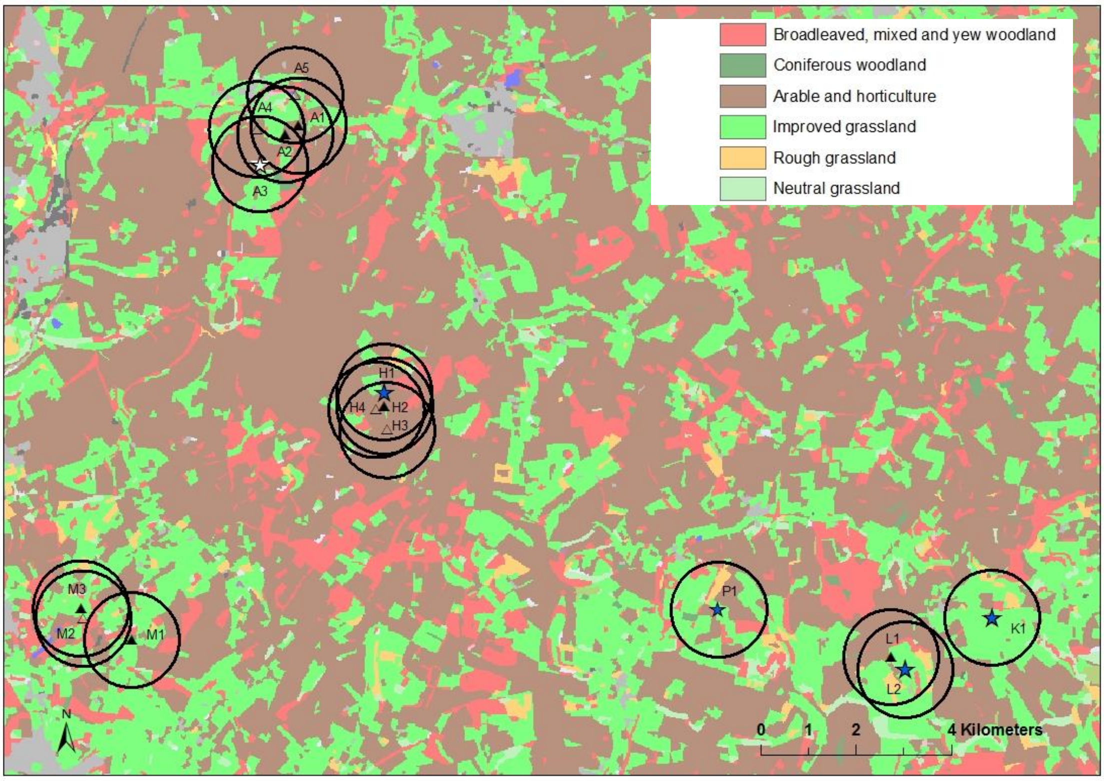

Figure 4: Location and degree of barn owl success at each nestbox (n=16) in the study. Stars indicate confirmed breeding (blue=hatchlings, white=eggs only), black triangles indicate occupied boxes with no confirmed breeding, open triangles indicate unoccupied boxes. Black circles indicate 1 km radius around boxes, backdrop shows landscape habitat composition (LCM 2007).

Nestbox configuration

There was no effect of nestbox design on occupation (design B: $z_{15,9}$=-1.168, p=0.243; design C: $z_{15,9}$=-0.644, p=0.519; design D: $z_{15,9}$=0.004, p=0.997; design E: $z_{15,9}$=-0.003, p=0.998).

Nor was there an effect of nestbox location on any measure of success, although there was a higher proportion of nestboxes in buildings than in trees under the presence response for each category (occupation: $z_{15,9}$=-0.122, p=0.903; breeding: $z_{14,12}$=-0.723, p=0.470; chicks: $z_{14,12}$=-1.243, p=0.214) (Fig 5). There was no effect of number of nestboxes within a 1 km range on nestbox success, however nestboxes under the absence category for each level of success had a higher number of boxes within their 1 km range than nestboxes with the presence of success (occupation: $z_{15,9}$=-1.110, p=0.267, breeding: $z_{14,12}$=-1.042, p=0.297, chicks: $z_{15,13}$=-0.970, p=0.332) (Fig 6).

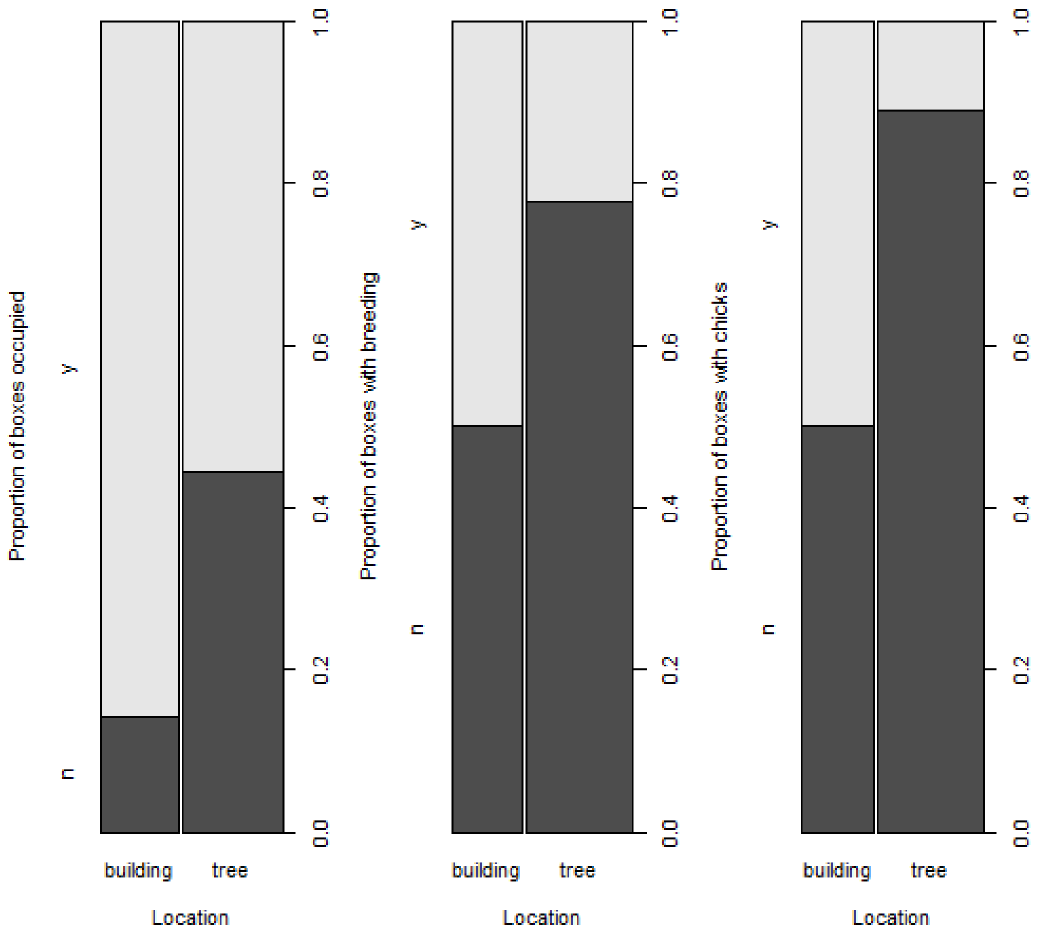

Figure 5: Proportion of boxes with the presence (y) and absence (n) of occupation ($z_{15,9}$=-0.122, p=0.903), breeding (breeding: $z_{14,12}$=-0.723, p=0.470), and chicks ($z_{14,12}$=-1.243, p=0.214) in buildings (n=7 for occupied, n=6 for breeding and chicks) and trees (n=9).

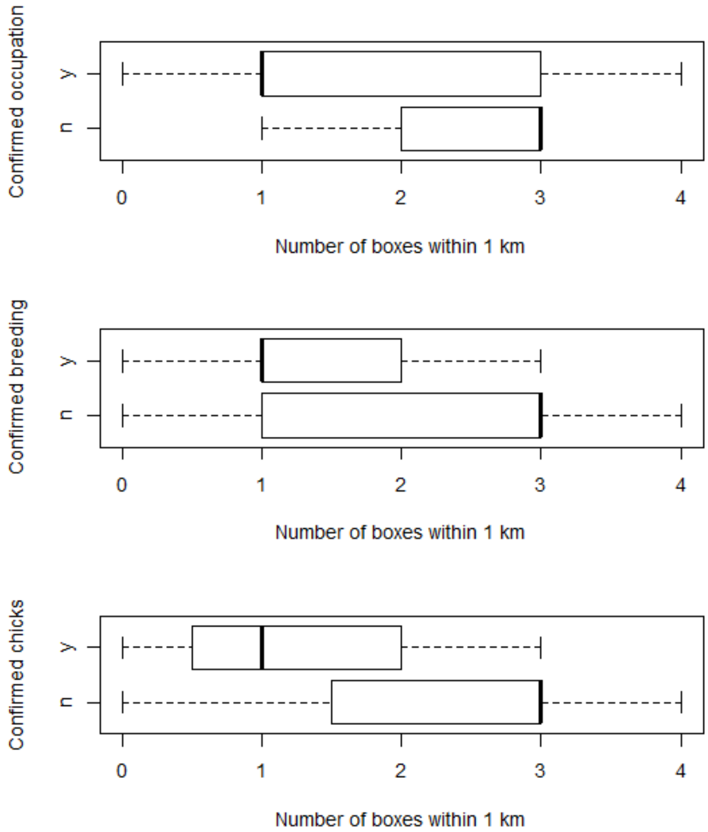

Figure 6: Nestbox success in relation to number of additional nestboxes within 1 km; bold line indicates median, box indicates interquartile range, dashed lines indicate 10th and 90th percentiles (occupation: n=16, $z_{15,9}$=-1.110, p=0.267, breeding: n=15, $z_{14,12}$=-1.042, p=0.297, chicks :n=15, $z_{15,13}$=-0.970, p=0.332).

Landscape composition

Across sites there were thirteen habitat categories represented in the range around barn owl nestboxes (Table 4), with improved grassland and arable and horticulture being the two most dominant categories around all boxes (Figure 7).

There was no effect of percentage of improved grassland ($z_{15,8}$=-1.013, p=0.311), neutral grassland ($z_{15,8}$=0.846, p=0.398), arable and horticultural land ($z_{15,8}$=-1.067, p=0.286), nor an interaction between rough grassland and improved grassland ($z_{15,8}$=0.550, p=0.582), rough grassland and neutral grassland ($z_{15,8}$=-0.520, p=0.603), or rough grassland and arable and horticultural land ($z_{15,8}$=0.657, p=0.511) on nestbox occupation.

Nor was there an effect of the percent of rough grassland on occupation ($z_{15,8}$=-0.575, p=0.565), breeding ($z_{14,13}$=1.402, p=0.161), or chicks ($z_{14,13}$=-1.618, p=0.106). However, the average percentage of rough grassland was always higher under the presence group of each success category. There was a higher average percentage of rough grassland in the areas around nestboxes containing chicks 5.79% (+/-2.84 SD) than any other category measured; the next highest was for boxes with confirmed breeding 4.82% (+/- 3.38 SD); then occupied boxes in general 3.20% (+/-2.98 SD). The percentage around unoccupied boxes was 0.52% (+/-0.46 SD)(Fig 8).

Table 4: Summary of average percent habitat composition within a 1 km radius of nestboxes occupied and not occupied by barn owls, nestboxes used for breeding and not used for breeding, and nestboxes with chicks and without chicks.

Habitat type	occupied (n=11)	Unoccupied (n=5)	Breeding (n=5)	No breeding (n=10)	Chicks (n=4)	No chicks (n=11)
Broadleaved, mixed and yew woodland (%)	10.37	9.72	8.24	11.33	7.44	11.41
Coniferous woodland (%)	0.63	0.00	0.94	0.14	0.37	0.47
Arable and horticulture (%)	45.80	58.53	43.63	53.47	41.16	53.69
Improved grassland (%)	37.76	27.12	41.18	30.38	44.01	30.08
Neutral grassland (%)	1.13	1.42	0.75	1.50	0.75	1.43
Rough grassland (%)	3.20	0.52	4.82	0.88	5.79	0.80
Calcareous grassland (%)	0.14	0.00	0.15	0.06	0.17	0.06
Heather grassland (%)	0.26	0.51	0.00	0.54	0.00	0.49
Fen, marsh and swamp (%)	0.00	0.07	0.00	0.04	0.00	0.03
Inland rock (%)	0.14	0.17	0.00	0.23	0.00	0.21
Freshwater (%)	0.11	0.24	0.00	0.24	0.00	0.22
Suburban (%)	0.30	1.41	0.29	0.86	0.30	0.81
Urban (%)	0.16	0.19	0.00	0.26	0.00	0.24

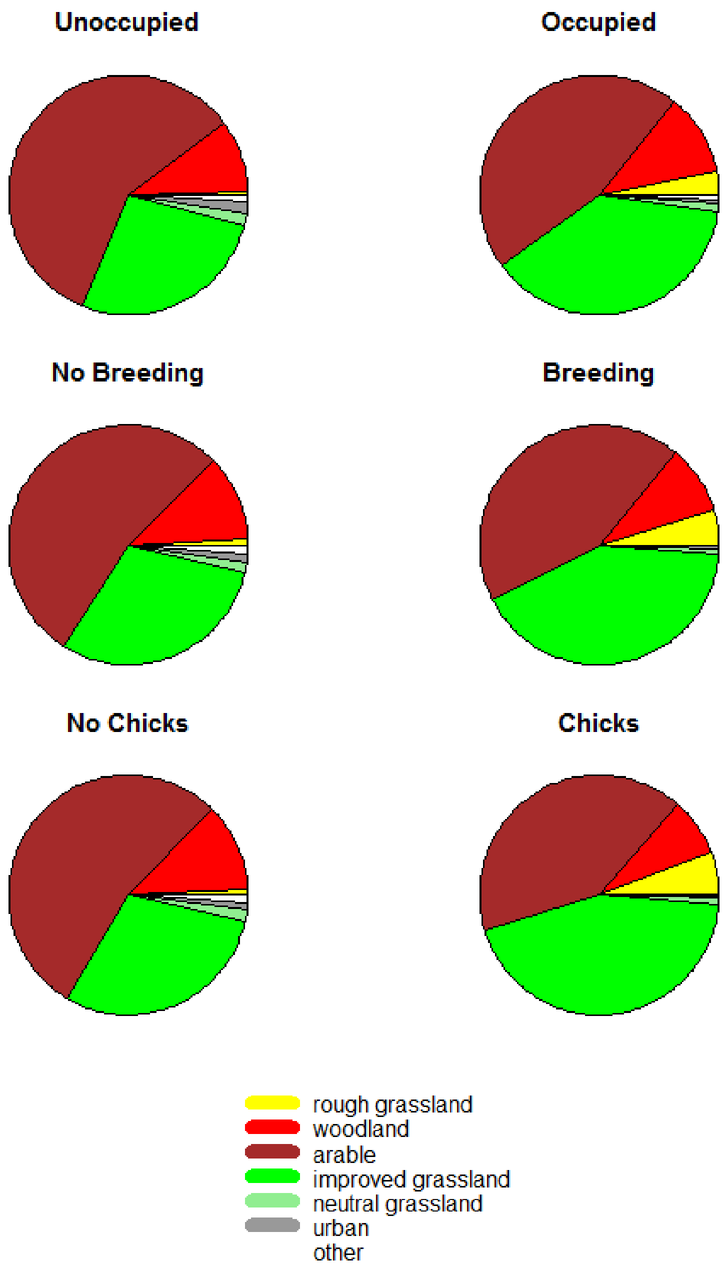

Figure 7: Average percentage habitat composition in 1 km radius range around nestboxes with the presence or absence of barn owl occupation (n=16), breeding (n=15) and chicks (n=15).

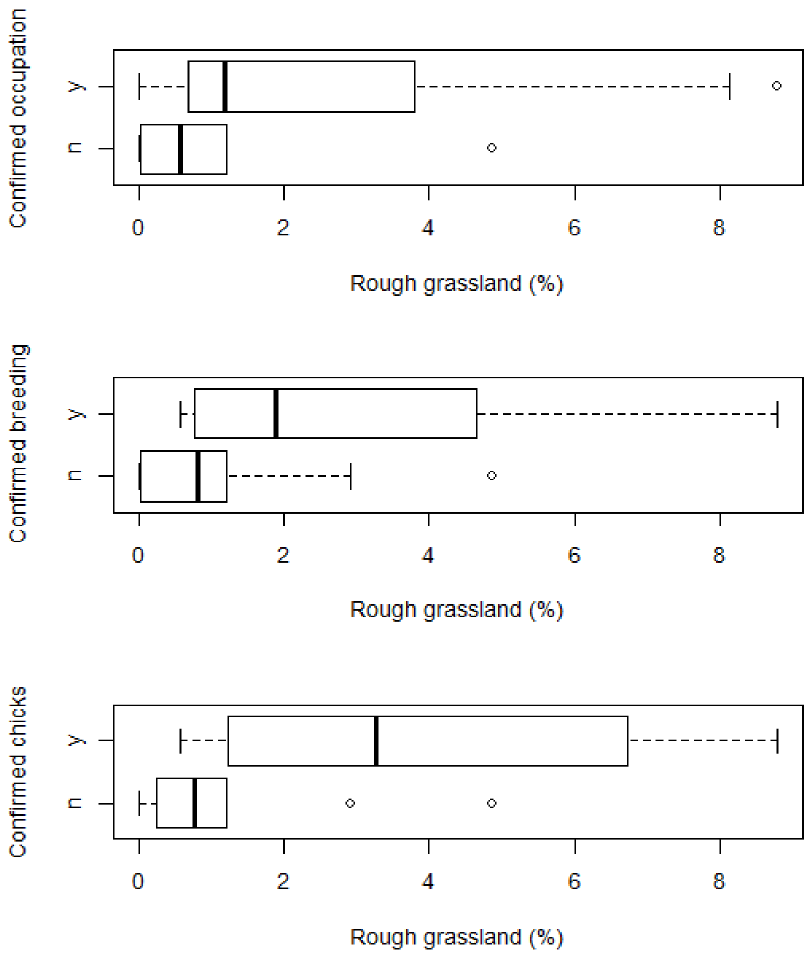

Figure 8: Percentage rough grassland in 1 km range around boxes with the presence (y) and absence (n) of occupation ($z_{15,8}$=-0.575, p=0.565), breeding ($z_{14,13}$=1.402, p=0.161), and chicks ($z_{14,13}$=-1.618, p=0.106). Bold line represents median, box represents interquartile range, dashed line represents 10th and 90th percentiles. Circles represent outliers.

Microhabitat vegetation assessment

None of the vegetation characteristics assessed were shown to have an effect on nestbox success. Litter layer depth did not have an effect on occupation (margin: $z_{13, 10}$= 0.325, p=0.745; non-margin: $z_{13, 10}$=-0.236, p=0.813; interaction: $z_{13, 10}$= -0.207, p=0.836), breeding (margin: $z_{12, 9}$= -0.905, p=0.365; non-margin: $z_{12, 9}$=-0.528, p=0.597; interaction: $z_{12, 9}$= 0.759, p=0.448), or chicks (margin: $z_{12, 9}$= -0.294, p=0.769; non-margin: $z_{12, 9}$=0.211, p=0.833; interaction: $z_{12, 9}$= -0.117, p=0.907), but was on average higher under the absence of each success variable (Figure 9).

Percentage of grass in the sward did not affect occupation (margin: $z_{13, 10}$= -0.138, p=0.890; non-margin: $z_{13, 10}$=-0.116, p=0.908; interaction: $z_{13, 10}$= -0.038, p=0.969), breeding (margin: $z_{12, 9}$= -0.868, p=0.386; non-margin: $z_{12, 9}$=-0.888, p=0.375; interaction: $z_{12, 9}$= 0.892, p=0.373), or chicks (margin: $z_{12, 9}$=-1.34, p=0.180; non-margin: $z_{12, 9}$=-1.30, p=0.193; interaction: $z_{12, 9}$= 1.32, p=0.188).

Nor did canopy height affect occupation (margin: $z_{13, 10}$= -0.734, p=0.463; non-margin: $z_{13, 10}$=-0.866, p=0.386; interaction: $z_{13, 10}$= 0.744, p=0.439), breeding (margin: $z_{12, 9}$= -0.817, p=0.414; non-margin: $z_{12, 9}$=-0.539, p=0.590; interaction: $z_{12, 9}$= 0.580, p=0.562), or chicks (margin: $z_{12, 9}$= -0.205, p=0.838; non-margin: $z_{12, 9}$=-0.295, p=0.768; interaction: $z_{12, 9}$= 0.110, p=0.912).

Additionally, cover repetition was not found to have an effect on occupation (margin: $z_{13, 10}$= 0.432, p=0.666; non-margin: $z_{13, 10}$=0.521, p=0.603; interaction: $z_{13, 10}$= -0.451, p=0.652), breeding (margin: $z_{12, 9}$= 0.401, p=0.688; non-margin: $z_{12, 9}$=0.421, p=0.673; interaction: $z_{13, 10}$= -0.387, p=0.699), or chicks (margin: $z_{12, 9}$= 0.029, p=0.977; non-margin: $z_{12, 9}$=-0.029, p=0.977; interaction: $z_{12, 9}$= -0.029, p=0.977).

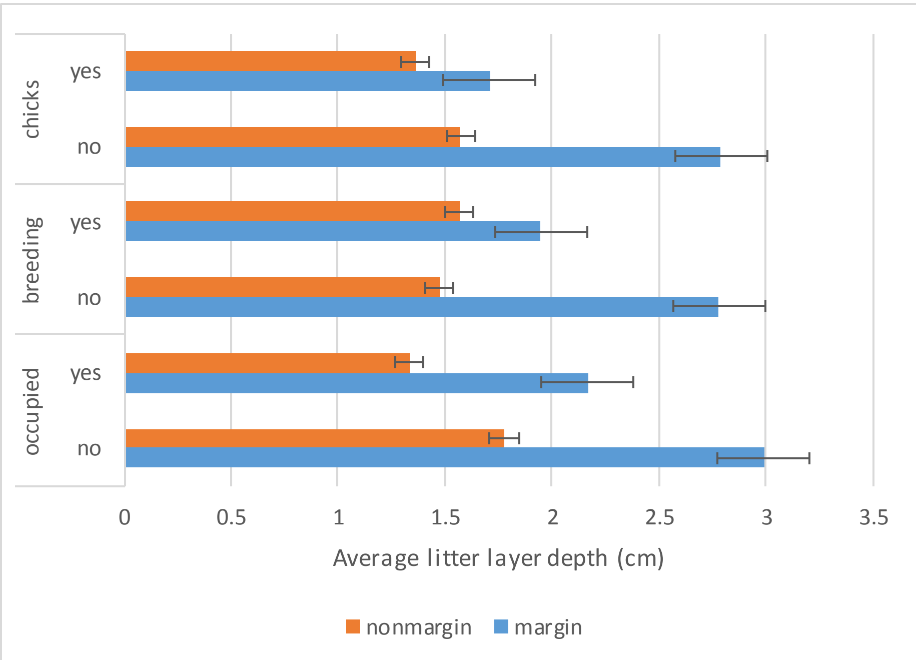

Figure 9: Nestbox success in relation to average depth of the litter layer (cm) within margin and non-margin features (n=15 margin, n=14 non-margin), all p<0.05.

DISCUSSION

Nestbox configuration

Although nestbox configuration was not found to effect success, there was a higher proportion of successful boxes in each category located within buildings compared to trees, which coincides with findings of previous studies (Santhanakrishnan et al. 2012). This makes sense as boxes within buildings are more sheltered from the elements, and weather extremes are known to have negative effects on barn owl survival (Altwegg et al. 2009).

Interestingly, there was trend towards an effect of a lower number of other nestboxes within a 1 km range being associated with the presence of each success measure, and a higher number of boxes around those with an absence of the three success measures. This seems counterintuitive considering the importance of the availability of suitable nesting and roosting sites to barn owls, but the potential for an effect is something nestbox erection programmes should consider. It could be that too many nestboxes in an area may attract more barn owls than the area can sustain successfully, with a specific amount of prey and therefore the right quality habitat needed to support higher levels of success for multiple owls. In fact, too high a density of nestboxes has been linked to population declines in other species (Eadie et al 1998). A higher number of nestboxes does not however mean a higher number of owls; a study taking into account the individual ID of owls using boxes, and comparing the density of individual owls and breeding output in an area to the amount and quality of habitat in the area could help to shed light on this.

Habitat effects

Surprisingly, neither the landscape scale analysis nor microhabitat vegetation analysis were able to provide evidence of how different habitat characteristics may affect barn owl success.

Landscape effects

The fact that the percentage of rough grassland was always higher under the presence group of each category of nestbox success, and was highest around nestboxes containing chicks, followed by breeding, then occupied boxes, is as expected. This is because in order to survive in an area, produce eggs, and sustain young an increasing food supply quality is needed, which has been linked to rough grassland habitat (Taylor 1994; Askew 2007b; Barn Owl Trust 2012). However, these trends were not significant, similar to the findings of other studies (Taylor 2000 in Barn Owl Trust 2012). It's possible that with a larger sample size a trend between success and rough grassland habitat would become clear, as was the case in other studies (Meek et al. 2009; Dadam et al. 2010).

Past landscape research has indicated that there is an interaction between the overall habitat type of a landscape, and the proportion of rough grassland needed to support a sustainable breeding population of barn owls, estimating 2.5 to 3.7 % rough grassland is needed in pastoral landscapes, 1.4 to 2 % needed in mixed landscapes, and 1.1 to 1.7 % needed in arable landscapes (Barn Owl Trust, 2012). No interactions were found in this study between percent rough grassland and arable land nor neutral or improved grassland, however this study was done at the level of individual nestboxes, rather than the barn owl population as a whole.

Neither was any negative relationship found between the amount of improved grassland and the success of a nest-site, as was found by Bond et al. (2005), although both studies used LCM data and were conducted in neighbouring regions. In fact, on average successful sites in this study had more improved grassland than unsuccessful sites.

The discrepancies between the present study and other studies could be due to a lower sample size, differing methods and source data for categorizing and analysing habitat composition, or it could indicate that habitat composition at the landscape scale is not as important to barn owl success in relation to other factors, such as microhabitat features and prey availability.

Microhabitat effects

The need for more specific evaluation of microhabitats has been specified for overcoming the limitations of landscape analysis (Charter et al. 2012), but surprisingly none of the microhabitat vegetation characteristics examined showed any effect on nestbox success. This was unexpected as previous studies have found small mammal abundance to be related to vegetation characteristics including composition, cover, sward height, and litter layer (Tattersall et al. 2000; Keene 2009). Particularly unexpected was the fact that average litter layer depth was not greater in areas with more success, but rather displayed a trend in the opposite direction.

Possible reasons for a lack of effect of habitat characteristics

It's possible that the lack of effect found in this study stems from the degree to which barn owls in the study area rely on field voles. Field voles are widely considered the most important prey species for British barn owls; they make up the largest portion of their diet (Love et al. 2000), studies have indicated they are more profitable than other species in terms of net energy gain (Taylor 1994), and have concluded that barn owls selectively prey upon them (Glue 1967) and in areas where they are more abundant (Askew et al. 2007a). Therefore, the vegetation analysis in this study focused particularly on specific habitat features related to the field vole's lifestyle which one would expect to affect their abundance, including the percentage of grass within the sward, the depth of the horizontal litter layer, and vegetation cover, which have been positively associated with field vole numbers (Tattersall et al. 2002; Barn Owl Trust 2012).

Although these factors can also influence the suitability of a habitat to support other prey species such as common shrews and wood mice, these species are not dependent upon a rough grassland habitat and litter layer as the field vole is; in particular the wood mouse is more generalist, found in a wide variety of habitats including hedges, woodland, and crops, and generally nests underground rather than in the litter layer (Glue 1974; Taylor 1994; Barn Owl Trust, 2012). Common shrews can also be found in hedgerows, scrub and woodland in addition to rough grassland (Barn Owl Trust, 2012). Therefore, a lack of the expected relationship between vegetation characteristics, like litter layer depth, and nestbox success might be the result of barn owls in the study area not being as highly dependent on field voles, and thus field vole habitat, as is often assumed (e.g. Askew et al. 2007b). Their diet may include enough other species that their success in an area is not linked to field vole habitat needs.

Studies have found barn owl diets to differ within the same region (Charter et al. 2009), and Cayford 1992 (cited in Barn Owl Trust, 2012) found individual birds to favour hunting in specific locations; for example some were found to favour hunting rodents around farm buildings, while others prefered hunting along ditches, locations likely to support different prey species. There were open farm buildings offering access to barn owls at study sites, often containing hay and other resources small mammals might utilise; if prey originating from these buildings comprised a significant portion of their diet it could help explain the lack of a relationship found between vegetation characteristics and nestbox success.

Meek et al. (2009) suggested that barn owls might actually be more adaptable in their habitat requirements and less dependent upon large areas of field vole habitat than is suggested by other studies. This was based upon a landscape analysis comparing breeding success at 86 different nest-sites over a period of 14 years which, despite the large dataset, found few correlations. Although the study didn't take microhabitat into account, it did examine diet, and found annual fluctuations in the main prey species taken at the same sites. This indicates that prey availability was changing over time and that barn owls may be more opportunistic predators than thought.

This makes sense as small mammal populations are known to fluctuate over time (Corbet & Harris, 1991), and the diet of the barn owl has also been shown to change over time (Love et al. 2000), and there has been a documented decline in field vole populations over time, linked to the loss of rough grassland habitat in arable regions (Love et al 2000; Shore et al. 2005). It's possible that barn owls are starting to show an adaptation to the changes in the agricultural landscape and resulting changes in prey abundance and availability. It's also possible that field voles themselves may be adapting to these changes, and utilizing habitat traditionally thought of as non-ideal. For example Renwick & Lambin (2011) found field voles to be utilizing crop fields prior to harvest, which contrasts with previous studies (Tattersall et al. 2002).

The lack of an effect of the vegetation variables measured in the present study on barn owl nestbox utilization lends support to these ideas. However, to obtain actual evidence vegetation sampling would need to be conducted in conjunction with small mammal trapping and/or barn owl pellet analysis to examine what the diet of owls in the area is, what prey species are present within the habitat, and in what proportions.

It's also possible that none of the expected trends were found because there might be a subtle balance of different vegetation characteristics needed throughout the habitat in order to support the appropriate population dynamics between barn owls and their small mammal prey. The most ideal vegetation characteristics to support small mammals might hinder successful barn owl foraging, in which case a balance must be met within the habitat, between the need for vegetation characteristics which support small mammal populations and those which support successful barn owl hunting. For example, Arlettaz et al. (2010) found small mammal density to be highest in wildflower areas, which barn owls avoided in preference for hunting in grassland habitat. They suggested prey availability plays a more important role than abundance for barn owl foraging, and that the density of vegetation in wildflower areas may impede successful hunting.

Considering all of these intricacies, a comprehensive study collecting microhabitat vegetation data through the methods employed in this study, along with small mammal trapping and data collection on barn owl hunting locations and diet would be extremely informative in terms of understanding these complex relationships. Collecting point quadrat data in the specific areas individual owls are known to hunt in would be particularly useful for future studies which aim to inform management of vegetation which supports barn owls. Specific hunting locations can be obtained through direct visual observations of birds at dawn or dusk as they emerge from nest/roost sites (Askew et al. 2007a) and can be facilitated by utilising radio tracking (Taylor 1994; Arlettaz et al. 2010). The advantage to this method is that it collects data in those locations where barn owls have been observed to hunt, rather than in areas where it is only speculated, which was a limitation of the current study. This could be especially important if the quality of the entire landscape is not as important as the quality of select features within it. If so, it might help explain the lack of a trend found between vegetation data and nestbox success data, as this study used a restricted random sampling approach, with no direct link between owls and the vegetation sampled in.

Study Limitations

There were also several limitations to this study which may help to explain the lack of effects found. The study assumed the breeding range to be a 1 km radius circular area around nestboxes, however in reality owls are not restricted to this range, and might hunt outside of it (Andries et al. 1994). Additionally, although this study aimed to be as representative of the entire 1 km radius range around each nestbox as possible, access was restricted to a different degree at each site. The vegetation survey was therefore a restricted sample of the potential breeding range around nestboxes rather than a truly representative sample, which would have taken into account all features which fell within the box's range, as well as their areas.

The sample size of the study (maximum n=16) was low, which limited the ability of all analyses to detect trends and to test multiple explanatory variables and their interactions together. Additionally, nestboxes were not independent nor true replicates; many had overlapping breeding ranges (and thus vegetation quadrat data), and the same owls could have provided success measures for multiple nestboxes.

Sites were chosen on the basis of having at least one nestbox in the SDNP's monitoring programme, which erects boxes in locations subjectively assessed to contain suitable barn owl foraging habitat. This selection bias may have meant sites lacked the variation in habitat characteristics needed to detect potential effects of habitat on nestbox success.

In addition there are other unmeasured factors which can influence whether or not owls use a box. For example management actions, such as mowing and grazing fields and spraying margins with herbicides, have an impact on the structure of the vegetation and the ecological communities it supports (Wheeler 2008; Keene 2009); such actions occurred at field sites, but were not quantified. Also, barn owls usually exhibit strong site fidelity, repeatedly using the same nest and roost sites (Barn Owl Trust, 2012), so it's possible that nestboxes which have been up for longer are more likely to be occupied than those erected more recently. In addition, nestbox checks themselves can act to influence whether or not owls continue to occupy and successfully breed in a box; in some cases they can cause nest site abandonment (Shawyer 2011).

Landscape analysis vs microhabitat analysis

It is not surprising that the landscape scale analysis failed to yield any significant effects, as such an approach has proven to yield few, weak or mixed results in the past (Hindmarch et al. 2012; Meek et al. 2009), and it has many inherent limitations. First off, its level of clarity is crude, with the LCM data used in this study only accurate to the level of 25 m^2 blocks. Thus it misses out on numerous features of the landscape that are too small to be detected at such a scales, including field margins and areas of agricultural set aside nestled within arable land; features that can be extremely valuable hunting habitat for barn owls, particularly in more intensively-managed areas (Bond et al. 2005).

In addition, although the landscape assessment accounts for differences in habitat type, it misses out on differences in habitat quality indicated by the differences in vegetation characteristics within and between habitat types. Also, raster-based information on habitat type might be out of date; the fact that the habitat data used in this study was based on information from 2007 meant that some potentially significant habitat changes since then were not accounted for.

These factors, plus the lack of effects found in this study, as well as the lack of consistency and clear trends in studies with larger sample sizes (i.e. Meek et al. 2009), suggests that a landscape scale method might not be the best way forward in terms of evaluating the suitability of a location to support barn owls.

Considering the microhabitat vegetation analysis did not have these limitations associated with landscape scale analyses, the fact that it too failed to yield any significant results is more surprising, and may be explained by the factors outlined above. In comparison with the raster-based landscape methodology the point quadrat based vegetation assessment requires a much greater time commitment, and is likely to face more logistical constraints and be more costly as it requires a substantial amount of fieldwork. However, if conducted on a wider scale than in the current study, and in conjunction with other methods, could prove informative.

Camera Traps

Camera traps were successfully used in this study to confirm that barn owls occupied a nestbox during the study timeframe. Images examined from camera traps can also provide information on the number of barn owls using a box, whether other species use a box, barn owl behaviour (Roulin & Bersier 2007), and potentially individual identification (O'Brien & Kinnaird 2008), all of which may be applicable to future research.

In particular, camera traps allow for nestbox use to be measured in a continuous fashion over time, which is more accurate and informative response variable than the categorical presence/absence classification this study was limited to. Additionally, a camera trap methodology could potentially be used to replace or reduce the number of nestbox checks needed in future studies in an attempt to minimize disturbance to birds, and reduce the potential for nest site desertion.

Management and Conservation Recommendations

Study Area

Brood size in all boxes in this study were lower than the all-years average, which is 2.76 (Barn Owl Trust 2015). Perhaps this is an indication of rather poor quality habitat all around the study area, or maybe it reflects a more widespread trend of decline in small mammal populations. However, both small mammal populations and barn owl brood size are known to fluctuate between years (Barn Owl Trust 2012). As the present study was the first of its kind there is no historic data to compare it with, but future studies conducted in the same manner in the same area could be beneficial in determining trends, such as how changes in vegetation characteristics over time might influence barn owl nestbox use, and could also take other variables such as weather into account.

Average litter layer depth around all nestboxes, including those containing chicks, was less than the 7 cm depth recommended for field voles (Barn Owl Trust 2012). Since breeding output from owls in this study was below average, and many nestboxes in the study area that could have been utilized by barn owls were not, it is recommended that where barn owl population increase is the required outcome, land managers take actions to increase the depth of the litter layer in the grassy fields and margins around nestboxes in an attempt to make them more suitable to support field voles and other small mammals, which should theoretically improve the quality of the habitat to support barn owls.

In terms deciding where to erect future nestboxes to maximise success, no clear conclusions can be drawn from the present study. However, as there was a higher proportion of success in boxes located in buildings as opposed to trees, supporting trends found by others, it suggests erecting boxes in buildings could be more beneficial than erecting them in trees, as has been suggested by others (Barn Owl Trust, 2012).

There was also a trend towards an effect of the amount of rough grassland in a box's range on each level of nestbox success. Considering this habitat is directly linked to field voles and recommended as the most suitable habitat for barn owl foraging in numerous studies it would be sensible to erect nestboxes in areas with a greater amount of rough grassland habitat when all else is equal. However the results of this study may indicate that the habitat requirements of barn owls are less restricted to specific field vole habitat than is widely believed.

Conclusions

The ability of the microhabitat vegetation assessment methodology used in this study to elucidate trends in nestbox use compared to the landscape approach has yet to be proven, and plans for future studies need to consider the resources they have available, and the questions they want to answer, when choosing whether to carry out a landscape scale or microhabitat scale assessment. The main drawback of the microhabitat point quadrat vegetation assessment method, in comparison to raster-based landscape assessments, is that it is more time consuming. However, where the desired result is to make direct vegetation management recommendations, the use of a microhabitat vegetation assessment methodology such as outlined in this paper is recommended, as it provides much more detailed and easily quantifiable data and measures parameters of the vegetation over which local management has some control. Based on the results of this study it's recommended that such an assessment be carried out on a broader scale than the current study, and in conjunction with data collection on small mammal abundance, barn owl hunting locations, and barn owl diet, utilizing camera traps to obtain detailed information on nestbox occupation over time. With such modifications the vegetation sampling methodology outlined in this study could prove to be a powerful tool for barn owl conservation, and could also be applied more broadly to other grassland-dependent species.

Acknowledgements

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, for which I'm extremely grateful.

I’d like to thank my fellow MRes students and all of the staff at Marwell Wildlife and the University of Southampton who helped me with this project. I’d especially like to thank Laura Pratt for her important assistance with this project. Finally, I’d like to thank my supervisors, Dr Martin Wilkie and Dr Judith Lock.

Appendix

Appendix notes:

1. In some instances the vegetation layers were taller than the point quadrat frame height (which was adjustable up to about 45 cm); in these instances, to maintain an accurate representation of the vegetation structure, the quadrat rod was extended upwards through the point frame and any plant contact points (or would-be contact points) extending upwards above the frame over that specific point on the ground were also recorded and included in total measurements.
2. Pellets were classified as fresh if they were black and glossy in appearance, soft and easily pulled apart, and old if they were a lighter grey colour and dry (Barn Owl Trust, 2012).
3. All but one nestbox containing evidence of use by owls were checked twice during the study period. This box was included in analysis of data comparing occupied and non-occupied boxes, but for consistency was not included in analysis of data on breeding and the presence of hatchlings in the box. Four other boxes were also only checked once, but contained no evidence of owls and were classified as not supporting chicks and not supporting breeding during the study timeframe.

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