Hedging Bets: The Effect of Field Boundary Variables on Farmland Songbird Breeding Success in Scotland

Rachel Shepherd

2014

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science and the Diploma of Imperial College London
DECLARATION OF OWN WORK

I declare that this thesis, “Hedging Bets: The Effect of Field Boundary Variables on Songbird Breeding Success in Scotland” is entirely my own work, and that where material could be construed as the work of others, it is fully cited and referenced, and/or with appropriate acknowledgement given.

Signature

Name of Student  

Rachel Shepherd

Name of Supervisor(s)  

Dr Marcus Rowcliffe  

Dr Dave Parish
## Contents

List of Figures ........................................................................................................................................... i  
List of Tables ................................................................................................................................................ i  
List of Acronyms ......................................................................................................................................... iii  
Abstract ....................................................................................................................................................... 1  
Acknowledgements ...................................................................................................................................... 2  
1. Introduction ............................................................................................................................................... 3  
2. Background ............................................................................................................................................... 6  
   2.1. Drivers of Farmland Bird Decline ......................................................................................................... 6  
   2.2. Limitations to Population Growth ....................................................................................................... 6  
   2.3. Tackling Decline ................................................................................................................................... 7  
      2.3.1. Providing for Songbirds ................................................................................................................ 7  
      2.3.2. Policy and Action ......................................................................................................................... 9  
   2.4. Methodological Challenges and Opportunities ................................................................................... 10  
   2.5. Study Site and Study Overview .......................................................................................................... 12  
3. Methods ...................................................................................................................................................... 13  
   3.1. Study Site and Farm Management ..................................................................................................... 13  
   3.2. Methodological Overview .................................................................................................................. 13  
   3.3. Bird Surveys ......................................................................................................................................... 15  
   3.4. Territory mapping ............................................................................................................................... 16  
   3.5. Statistical Analysis ............................................................................................................................. 17  
      3.5.1. Modelling Effects of Boundary Features on Breeding Success .................................................... 17  
      3.5.2. Number of Juveniles ................................................................................................................... 21  
   3.6. Detectability ......................................................................................................................................... 21  
4. Results ........................................................................................................................................................ 22  
   4.1. Nest Success ......................................................................................................................................... 22  
   4.2. Territory Models ................................................................................................................................ 23  
   4.3. Boundary Models ............................................................................................................................... 25  
   4.4. Productivity of Species ....................................................................................................................... 29  
   4.5. Detectability ......................................................................................................................................... 30  
5. Discussion .................................................................................................................................................. 32  
   5.1. Field Boundary Habitat Associations ................................................................................................. 32  
   5.2. Number of Juveniles Fledged ............................................................................................................. 35
5.3. Conservation Suggestions................................................................. 36
5.4. Further Research Areas and Conclusion........................................... 39
References ............................................................................................. 41

Appendix I - Feature composition of and breeding success on the 39 hedgerows surveyed 46
Appendix II – Study Site and Species Territory Maps..................................... 48
List of Figures

Figure 3.1. Flowchart showing data collected, processing and analyses. ........................................14
Figure 4.1. Proportion of successful and unsuccessful territories for each species. Width is proportional to number of samples. .........................................................................................23
Figure 4.2. The effect of hedge volume on breeding success for farmland bird species. ..........24
Figure 4.3. The effect of number of overlapping territories on nest success in woodland bird species ........................................................................................................................................25
Figure 4.4. The Effect of territory density on proportion of territories successful in all species........................................................................................................................................26
Figure 4.6. The effect of number of trees on breeding success in woodland birds ............27
Figure 4.5. The effect of territory density (number of territories /100m) on breeding success in woodland species ..................................................................................................................................27
Figure 4.7. The effect of proportion of territories held by woodland species on breeding success in farmland birds ...................................................................................................................................28
Figure 4.8. The effect of density of hedgerow vegetation on breeding success ....................28
Figure 4.9. Maximum number of juveniles for each species with over 10 territories. ...........29

List of Tables

Table 3.1 Species recorded in the study and classification according to ‘Bird Species by Habitat Indices’ (DEFRA, 2012). Species in brackets were recorded using hedgerows on boundaries with offspring but not as having territories on boundaries. ........................................17
Table 3.2. Variables used in territory level analysis and how they were calculated, including any measurements made in the field and how these were carried out. .................................18
Table 3.3. Variables used in boundary level analysis and how they were calculated, including any measurements made in the field and how these were carried out. .................................19
Table 4.1. Numbers of territories for each species found occupying the study site and frequency of successful and unsuccessful breeding outcomes ........................................................................22
Table 4.2. Sum of Akaike weights of evidence (wi) for each predictor variable in the territory information theoric models. Values >0.5 are in bold ........................................................................24
Table 4.3. Sum of weights of evidence (w_i) for each predictor variable in the boundary information theoretic models.

Table 4.4 Mean values for each species of maximum number of juveniles and average number of juveniles per nesting attempt from the BTO’s Nest Record Scheme (http://www.bto.org/volunteer-surveys/nrs).

Table 4.5. Probability of detecting a successful nest for each species and predicted number of undetected nests on the sample site based on these probabilities. Probabilities taken from estimates made in Sage & Powell (in press).
List of Acronyms

AES  Agri-Environment Scheme
BAP  Biodiversity Action Plan
BBS  Breeding Bird Survey
BTO  British Trust for Ornithology
CAP  Common Agricultural Policy
CBC  Common Birds Census
DEFRA Department for Environment, Food and Rural Affairs
EFA  Ecological Focus Area
ELS  Entry Level Stewardship
EU   European Union
GWCT  Game and Wildlife Conservation Trust
HLS  Higher Level Stewardship
OELS  Organic Entry Level Stewardship
NRS  Nest Record Scheme
NGO  Non-Governmental Organisation
PSA  Public Service Agreement
RSPB  Royal Society for the Protection of Birds
SRDP  Scottish Rural Development Programme
Abstract

Farmland birds have suffered dramatic declines in population size and range over the last 30 years. Breeding success is a limiting factor on population growth for many species, but is rarely directly measured, especially for whole bird communities. This study aimed to evaluate the impact of hedgerow and field margin variables on breeding success of field boundary occupying songbirds. Regular surveys of field boundaries were carried out to map territories of occupying birds, with juveniles assigned to adult territories. Information theoretic modelling revealed ‘woodland’ and ‘farmland’ typical birds’ breeding success are affected by different factors. Density was positively correlated with nest success in woodland but not farmland birds, showing it is a poor proxy for quality of breeding habitat for all species. Increasing numbers of trees had a positive impact on nest success of bird species listed on the woodland habitat index. Increasing volume of hedge in a territory and greater density of vegetation in a hedgerow were associated with increasing nest success of bird species on the farmland habitat index. Increasing proportions of territories belonging to woodland typical birds reduced nest success of farmland birds. Management of hedgerows to encourage a reasonable size and minimise gappiness is advised to increase breeding in farmland birds.

Word Count: 12,834
Acknowledgements

My first thanks go to my field partner, Sophie, with whom I shared many early mornings and the joy of counting baby birds. My gratitude also goes to my two supervisors, Dave Parish (GWCT) and Marcus Rowcliffe (ZSL) for their advice, feedback and support in the statistics and write-up of the project. Thank you the Game and Wildlife Conservation Trust (GWCT), for the opportunity to carry out this research, and to the farmers and landowner of the study area for being friendly and taking an interest during data collection. Thanks to Imperial College and the Conservation Science MSc course directors for running the course. And finally to all those who have supported me in other ways – Lucy for the tea and work space, Sim for the baking and company when tending to the chickens, and Robert for general de-stressing.
1. Introduction

Extensive monitoring of birds in the UK since the 1960’s has revealed widespread and long-term declines in range and population size of many bird groups. Of particular concern are farmland birds, which went through the greatest decline of any habitat group (DEFRA & JNCC, 2012). Since 1970 there has been an average population decline of 48% in farmland species, and populations of individual species have declined as much as 97% (Tree Sparrow, Baillie et al., 2007). Although a few select species, such as the jackdaw and woodpigeon, have experienced increases in population, the majority of species show declining national trends. For many declining species, the rate of decline has slowed recently, and although none have recovered to pre-decline levels a few have shown moderate increases (Baillie et al., 2007). Some species such as tree sparrows, yellowhammers and linnets are experiencing continuing declines and are still on the national ‘red list’ (Eaton et al., 2009).

A suite of changes in agricultural practices that occurred in the 1960s-1990s resulting in intensification on currently farmed land is thought to be the primary causal factor of farmland bird decline (Chamberlain et al., 2000; Newton, 2004; Fuller et al., 2005). Increased use of pesticides, reduced insect abundance, loss of semi-natural habitat coverage used for foraging, and decrease in size of hedgerows since mechanisation of hedgerow management have all been linked to decline in songbirds and gamebirds on farms (Chamberlain et al., 2000; Benton et al., 2002; Newton, 2004).

A similar pattern of agricultural intensification and farmland bird decline has occurred across much of Europe (Donald, Green & Heath, 2001). Concerns over biodiversity loss and pollution in farmland systems fuelled the development of Agri-Environment Schemes (AES) within the European Union (EU). The aims of AES are to “reduce environmental risks associated with modern farming” and “preserve nature and cultivated landscapes” (European Commission, 2005). In 1985 reform of the EU’s agricultural policy introduced an optional regulation for AES to be set up in Member States. This became a requirement in 1992. Now at least half of the cost of AES are co-funded by the EU (European Commission, 2005). In the UK, voluntary schemes focus on providing benefits to biodiversity, including plants, invertebrates and birds. Farmers and landowners are compensated for the cost of implementing management practices to benefit biodiversity and loss of income associated
with these practices (Kleijn & Sutherland, 2003; Natural England, 2009). In 2000, the UK government created a Public Service Agreement (PSA) objective ‘to care for our living heritage and preserve natural diversity by reversing the long-term decline in the number of farmland birds in England by 2020, as measured annually against underlying trends’. In addition, ‘The Wild Bird Indicator’ was adopted as one of the headline indicators of quality of life (Chamberlain, 2004). AES are the main mechanism through which it is hoped these goals will be achieved, therefore having the most effective scheme possible is paramount to bringing about the greatest change and fastest recovery of bird populations.

Monitoring and research are recognised as vital in contributing towards the ongoing development and future reforms to the schemes. Natural England underline one of the key drivers for monitoring being ‘to understand the effectiveness of management and to feed this back into scheme development and design’ (Natural England, 2009). The majority of research into habitat requirements of farmland birds to date has been investigated through quantifying density or carrying out habitat association and territory selection modelling. However, as pointed out in Van Horne (1983) and Vickery et al. (1992), density or occurrence do not always correlate with fitness of the individuals present. Ideally fitness should be evaluated directly through measurements of survival and reproduction. For large scale studies, productivity can be evaluated through mist-netting and comparing adult to juvenile ratios, giving an idea of landscape level suitability for breeding. This is done in the Constant Effort Survey Scheme carried out by the British Trust for Ornithology (BTO) which monitors passerines in scrubland and wetland (eg Peach, Buckland and Baillie, 1996), however it is not currently carried out in farmland. Broad trends through time looking at where populations increase and decrease could give an idea of landscape level habitat suitability, but due to the high mobility of birds, including migration in some species, this will reflect population increase through immigration as well as by reproduction. Currently lacking is finer scale detail, especially for whole bird community assemblages, of local environmental and habitat influences on individual fitness. The majority of studies on farmland birds are relatively small scale in both time and spatial coverage, and in these types of studies habitat quality evaluation for farmland birds can advance knowledge of bird needs by quantifying fitness components.
This study aims to provide new insight into fine scale habitat requirements of farmland songbirds during the breeding season by quantifying breeding success of individuals. The impact of habitat and management variables was evaluated by linking breeding success to local features. Reviews have shown features on field margins and boundaries between fields to be important in determining the presence and density of field boundary occupying species, for example properties of hedgerows, number of trees and presence of field margins (Hinsley & Bellamy, 2000; Vickery et al., 2004). It was therefore considered that characteristics of boundaries between fields, including field margins, would provide a good investigation focus for evaluating impact on breeding success of boundary occupying songbirds.

Quantifying breeding success also gives the opportunity to assess the potential for local populations to recover and increase in size. Species have shown different levels of increase or decline, and it is possible that nest success, number of juveniles produced, or both could be contributing to these trends. Breeding success may differ locally, giving a good indication of where conservation measures may be best applied to give results for particular species, especially those on the UK birds of conservation concern red or amber list (Eaton et al., 2009).

The objectives of this study were:

1) To determine which habitat variables show evidence of effect on breeding success of boundary occupying songbirds.
2) Assess whether density is a good predictor of breeding success of ‘farmland’ and ‘non-farmland’ species groups occupying field boundaries.
3) For each species, calculate fledgling productivity of nests on the study site to give an idea of relative potential for population recovery.

Information gained from this study can feed back into guiding which management practices should be a priority for inclusion and promotion in agri-environment schemes. Encouraging uptake of practices which show higher breeding success will help address the government’s goal to ensure the reversal of declines in widespread farmland birds.
2. Background

2.1. Drivers of Farmland Bird Decline

Farmland birds have suffered from massive and widespread declines in population size and range across Europe. Declines were first noticed in the 1970s, and have been documenting as continuing since, with very few species showing changes in direction of trajectory (Donald, Green & Heath, 2001; Donald et al., 2006). 116 farmland bird species in Europe have become of conservation concern, and in Britain alone an estimated 10 million individuals were lost from the ten most affected species, in the period from 1980-2000 (Krebs et al., 1999). Farmland habitat specialists have declined the most, and for the longest (Chamberlain et al., 2000).

Recent biodiversity loss has occasionally been called ‘the second Silent Spring’, and in Europe can largely be attributed to intensification of agriculture (Krebs et al., 1999). Food production went through a revolution in the latter half of the 20th century, resulting in a huge increase in the quantities of food able to be grown per hectare of land. A wealth of studies on the association of agricultural intensification with biodiversity loss on farms are available, and it is now recognised that a suite of interacting factors are responsible for farmland bird decline (Fuller et al., 1995; Chamberlain et al., 2000; Donald, Green & Heath, 2001; Newton, 2004; Donald et al., 2006). Changes in planting of cereal crops from spring to autumn, increased use of herbicides and pesticides and increased densities of livestock on grassland have reduced the availability of seed and invertebrate food for both granivorous and insectivorous species (Fuller et al., 1995; Wilson et al., 1999). Removal of trees, hedgerows and rough patches have also reduced nesting habitat for many species. In most cases declines have been associated with reduced survival, and in some cases reduced production (Newton, 2004).

2.2. Limitations to Population Growth

Farmland birds can be limited by mortality at a number of stages, which fall into 2 main categories: survival and reproduction (Newton, 2004; Vickery et al., 2004). Survival is most threatened in the winter, when food supply is limited, but post-fledging survival, defined as the survival of young from when they fledge to independence from parents, can also have
large effects on populations. For several declining farmland songbirds, including yellowhammers, tree sparrows and corn buntings, over-winter survival is predicted to be the primary limiting factor to population growth. Breeding success is also predicted to be a prominent factor limiting population growth or exacerbating decline in some farmland species, for example whitethroats, linnets and skylarks (Vickery et al., 2004). Breeding success has 2 elements (Murray, 2000): nest success, which is whether or not a nest produces fledglings, and productivity, which is the number of young produced from successful nests.

The RSPB and Natural England promote provision of ‘The Big Three’ requirements of farmland birds: nesting habitat, summer food and winter food. Currently it is predicted that 4-7% of land needs to be under sympathetic management in order to halt the decline of farmland birds (Phillips, Willmott & Grice, 2013).

2.3. Tackling Decline

2.3.1. Providing for Songbirds

Farmland songbird communities contain a mix of birds dependent on different kinds of habitat (Atkinson et al., 2002). Some species, which reside almost wholly in hedgerows and trees, are birds typically also found in scrub or woodland. There are numerous birds of this type: chaffinches, dunnocks and blackbirds for example are typical woodland generalists also commonly found on farmland. In addition there are species for which populations are primarily found on farmland, and depend on open habitat to nest, forage or both (Hinsley & Bellamy, 2000). Many of these birds nest in or under shrubby vegetation, for example yellowhammers, linnets and whitethroats, and may also forage in hedges. Tree sparrows need mature or dead trees in which to nest, but are also reliant on open farmland or grassland for foraging weed seeds and grains (Snow & Mayer-Gross, 1967; Hart et al., 2006). The single open field nesting songbird in the UK, the skylark, prefers entirely open fields, and avoids tall or dense vegetation (Chamberlain & Gregory, 1999). Diets of species also vary, from those reliant on invertebrates alone to species which eat mostly seeds and grains (Cowie & Hinsley, 1988; Wilson et al., 1999; Holland et al., 2006). With a diversity of farmland birds, groups and individual species have different feature and habitat preferences, which can occasionally conflict (Vickery et al., 2004). Skylarks prefer large fields.
with short vegetation, whereas partridges and most hedge-associated species prefer many field boundaries and tall vegetation for foraging (Chamberlain & Gregory 1999; Aebischer, 2009; Whittingham et al., 2009). Furthermore, different seed types and insect groups are preferentially exploited by different species, therefore the availability of plants which provide seeds and support different insect communities needs to be considered (Holland et al., 2006). There is no silver bullet prescription of optimally beneficial management for all species. Thus there needs to be a balance between providing features and landscapes that will host the greatest diversity or abundance of birds, and optimising habitat for birds most in need of conservation action.

There has been extensive research into which habitat features and management practices are important to support farmland bird populations. Hedgerows in particular are a central habitat for many species. Hedgerows provide shelter from the environment, cover from predators, and a large proportion of farmland birds roost, nest and forage to some extent in hedgerows (Cracknell, 1986; Hinsley & Bellamy, 2000). Even many species of seed eating birds feed their young on insects foraged from hedgerows and surrounding habitats (Moreby & Stoate, 2001; Whittingham et al., 2001; Vickery Carter & Fuller, 2002). However skylarks avoid hedgerows, making nests in low vegetation in open field, so may be negatively impacted by hedgerow presence (Chamberlain & Gregory, 1999)

For birds that nest and forage in hedgerows, presence of a hedgerow, size of the hedgerow and presence and number of trees are the most important variables in determining species richness and abundance (Hinsley & Bellamy, 2000). Many studies have found additional aspects of hedgerows, including increased structural complexity, reduced gappiness and more diverse hedge species composition to positively affect songbird occurrence (Arnold, 1983; Parish, Lakhani & Sparks, 1994; 1995; Hinsley & Bellamy, 2000). Other boundary features in combination with hedgerows, such as field margin vegetation strips and ditches are often shown to have positive influences on songbird species richness and abundance (Arnold, 1983; Parish Lakhani & Sparks, 1994; 1995).

Territories located along hedgerows that have additional non-crop habitat nearby are likely to have a better food supply than territories that do not. Several studies have found that insect and plant species richness and abundance is greater in conservation headlands and other field margins than surrounding field crops. These are likely to provide seeds and
invertebrate food for birds (Morris et al., 2001; reviews by Vickery, Carter & Fuller, 2002; Vickery, Feber & Fuller, 2009). Increased abundance of invertebrates close to territories may improve breeding success as it will reduce the energy parents have to spend on foraging trips, and decrease time between feeds for chicks (Hinsley & Bellamy, 2000). Headlands and field margins have especially diverse and abundant plant and invertebrate communities when they are not sprayed with pesticides (Chiverton & Sotherton, 1991).

2.3.2. Policy and Action

The primary approach to tackling farmland bird decline is through development of agri-environment schemes (AES) in each EU country, partially funded by the state government and partially through the European Commission. AES aim to integrate care for the environment into the Common Agricultural Policy through paying farmers for the provision of environmental services, including biodiversity conservation (European Commission, 2005). Agreements are voluntary but can be legally binding, and last for at least 5 years.

Within the UK, each country has developed AES with options for management. Schemes exist for different types of farmland and rural habitats, with different management options tailored to the biodiversity and habitat usually present. The current Scottish scheme is the Scottish Rural Development Programme (SRDP). Currently options within the SRDP focus mainly on field margins. New ‘Greening’ funding to be introduced in 2015 stipulates that 5% of land should be designated as Ecological Focus Areas (EFAs), including having hedgerow and vegetation field margins of between 1 and 20m (The Scottish Government, 2014). England’s Entry Level Stewardship (ELS) scheme similarly supports management of hedgerow and options for field margins. Field margins fit into the following broad categories:

- Cultivated low-input margins - unsprayed cereal margins allowing broad-leaved weeds and annual arable plants to regenerate, plus their associated insects,
- Bird seed margins – margins sown with plants left to set seed to provide winter food for birds,
- Permanent grass or grass and wildflower strips,
- Wildflower margins – sown to provide floral resources for invertebrates.
Margin types that have high numbers of seeding plants are expected to provide good winter food supplies, and structurally and floristically diverse margins are expected to provide a high abundance of seed and insect food in the summer (Vickery, Feber & Fuller, 2009). Field margin packages have been investigated through association with farmland bird abundance and diversity, and sampling for seed and invertebrate provision (Vickery, Carter & Fuller, 2002; Marshall, West & Kleijn, 2006; Vickery, Feber & Fuller, 2009), but have not yet quantified effects on survival rates or breeding success. Width of field margin is not often looked at, yet wider margins may support larger insect and seed abundances, increasing bird food supplies.

Widespread schemes such as the SRDP and ELS have been developed to reverse the overall decline in common farmland birds. Priority species, being either rare or having experienced particularly devastating declines, have been given additional support in England through implementation of the Higher Level Stewardship scheme. HLS aims to improve farmland habitat specifically for the ‘Arable Six’ - tree sparrow, lapwing, grey partridge, turtle dove, corn bunting and yellow wagtail (Phillips, Willmott & Grice, 2013). ELS and further management options are available in HLS schemes and a larger proportion of land is required to be under management.

Several farmland bird species, including the arable six but also other species, have biodiversity action plans (BAPs, jncc.gov.uk). These are often operated on a county level, with monitoring of trends and setting of targets occurring at this level. Several Wildlife Trusts in England have farmland managed as nature reserves for plant, invertebrate, bird and mammal biodiversity (eg see Worcestershire Biodiversity Partnership, 2008). Although farmland nature reserves are likely to deliver the highest quality practices, for most bird species the majority of populations will always reside outside of protected areas, so it is important to implement conservation actions across the wider farmland landscape.

2.4. Methodological Challenges and Opportunities

Studies investigating associations of features, management or conservation practices to farmland bird populations usually take one of two forms: a broad study of habitat associations, territory selection or density of many bird species in relation to their surroundings, or an in depth study into factors involved in habitat selection, winter survival
or breeding success for a single species. Information gained from both study types are useful in providing insights into the needs of birds. In depth studies can provide detail about individual species, with fairly intensive fieldwork required by a full time professional researcher. Recording breeding success often involves searching for nests and following particular pairs through the breeding season (eg in Bradbury et al., 2000; Brickle et al. 2000, Hart et al., 2006). Broad association or density studies can be carried out at lower intensity, with fewer samples on each site. When repeated every year, these can illicit trends over time. For example the Common Birds Census (CBC), now Breeding Bird Survey (BBS), is carried out by citizen science volunteers with at least 4 visits per breeding season. This allows high volumes of information to be taken across a large geographical range. Whilst habitat association modelling, territory selection and density mapping information can tell us where birds are, and on a local level where they choose to set up territories, it should not assume to tell us about fitness of birds in relation to their environment.

In fact, according to different theories, density could be related to breeding success in a number of ways (Begon, Mortimer & Thompson, 2009): positive correlation with breeding success if birds are found at higher density on higher quality habitat, negative correlation with breeding success if higher densities of birds increases local competition for breeding resources, or no correlation with breeding success if birds are found in an ‘ideal-free’ distribution, with competition and habitat quality interacting (Cody, 1981). Density has not yet been linked to breeding success in farmland songbirds, but in American grassland systems, the relationship has been shown to differ between species (Vickery, Hunter & Wells, 1992).

A novel method described by Sage & Powell (in press) provides a practical midpoint between broad habitat association modelling for many species and in-depth breeding success studies. It allows a measure of fitness to be quantified by recording breeding success for many field boundary occupying birds, which can then be linked to the environment, management and features present in their immediate surroundings. This method is non-invasive, as it does not require finding nests to count eggs or nestlings. Instead fledglings are recorded after leaving the nest, and linked to adult pairs based on location of sighting. It requires full time researchers to collect the data, but it can provide information about several species on the same survey and is relatively easy to conduct. It is
therefore able to provide details on features that significantly boost the fitness of whole communities of birds, or certain subsets of birds in the community. Sage & Powell’s method can also adjust for detectability if quantifying productivity over a large area, though this is not possible when associating individual successes and failures with the surrounding environment. Understanding what factors will boost breeding success can help guide conservation actions, and will be especially useful in designing action plans for species still suffering from declines.

2.5. Study Site and Study Overview

The study site is a set of Scottish lowland farms practicing mixed arable and livestock farming (see Appendix II for study area map). The majority of studies on farmland birds take place in England, particularly in the south-east, therefore this study will provide a slightly different context. Most of the common farmland birds are present in the region, including good sized populations of several UK red- or amber-listed songbird species – tree sparrow, yellowhammer, linnet and skylark. The farms follow high-quality conservation practices, with a variety of management practices carried out on field boundaries and small patches of woodland present across the landscape. Consequently, this area was expected to provide large sample sizes of birds with enough variation in field boundary variables to observe effects they might have on breeding success. Furthermore, control of predators such as foxes and carrion crows is applied on site, which will remove some of the effect of predation on breeding success and thus may allow a clearer picture of other habitat effects on breeding to be detected.

In this study the new fledgling count method will be used to investigate hedgerow and field margin variables on nest success in 3 groups of songbirds: the whole community, birds categorised as having woodland or scrub as their primary habitat, and birds that are categorised as having farmland as their primary habitat. It is predicted that each specified group will show different responses to environmental variables, or will have different variables showing greatest effect on breeding success. The accuracy of using density of birds as a proxy for breeding success is assessed and numbers of juveniles per successful brood is calculated for each species to assess potential for population expansion.
3. Methods

3.1. Study Site and Farm Management

Data collection took place in summer 2014 on 4 adjacent farms covering a total of approximately 10 km$^2$ in the Midlothian and East Lothian regions of Scotland. The farms were managed as a single unit and were consistent in both farming and conservation practices. The farms had mixed farming systems with primarily wheat, barley and oilseed rape crops, and pasture for sheep and cattle (see Appendix II for study site layout). Pesticide, herbicide and inorganic and organic fertilisers were used on crop fields. Farm management included involvement in the Game and Wildlife Conservation Trust (GWCT) Grey Partridge Recovery Programme, as described in Aebischer (2009). Predator control, supplementary feeding via grain hoppers and field margin habitat management were practiced across many but not all field boundaries, giving a heterogeneous landscape. Where habitat management on field margins was practiced, a mix of headland types were present. Almost all margins had a permanent grass strip of around 3m wide, with some having an additional strip next to the grass of either sown wild flowers or a conservation headland of sown brassica crop and broad leaved plants. Field margins varied in overall width, and though most boundaries had a strip of vegetation on either side of the hedgerow, those next to roads had only one. Once crops had established, pesticides were not applied to field margins.

3.2. Methodological Overview

This study combined an established method of mapping territories by compiling locational and behavioural observations from repeat surveys (Marchant et al. 1983), with the novel addition of counting and assigning fledged broods to parental territories (Sage et al., 2011; Sage & Powell, in press). From this, nest success and productivity estimates could be produced. Nest success was linked to local field boundary characteristics through modelling, and productivity was calculated for each species. Figure 3.1 shows a flowchart summarising the methodology. Specific details of data collection and analysis are described in the following sections.
Figure 3.1. Flowchart showing data collected, processing and analyses.
3.3. Bird Surveys

Initial mapping and bird surveys of all boundaries within the 4 farms was carried out from mid-April to mid-May to profile field boundary features. Hereafter, a boundary describes the section of land between where two fields meet or between a field and a road. Often boundaries are marked with a hedge, wall, fence or non-crop vegetation. Boundaries with no songbirds present were eliminated from the selection of survey sites. The focus of this study rests on quantifying breeding success, therefore although excluding boundaries without birds may be criticised in habitat selection modelling, for this study it was deemed necessary for boundaries to contain songbird territories.

39 boundaries were selected to survey, using a semi-experimental design. Important field margin and hedgerow features identified from the literature were used to choose a set of boundaries with a range of values for these features. It was decided that all boundaries should include a hedgerow because the birds of focus in this study are reported to nest in hedgerows, and many also forage in hedgerows. (Hinsley & Bellamy, 2000; Vickery et al., 2004). However hedgerow size, density of hedgerow vegetation, width of field margins, number of brassica headlands, number of trees, and presence of feeders and a nearby woodland edge varied (see Appendix I for hedgerow features composition). Specifics of features considered and how these were measured can be seen under ‘Statistical Analysis’. Number or species of birds present on the initial survey did not influence selection of the boundaries included in the study, except for the exclusion of boundaries with no recorded birds.

Bird surveys along the boundaries were carried out using the Common Birds Census (CBC) method (Marchant et al. 1983), recording the majority of songbird species occurring on or near field boundaries, both when stationary and in flight. Juveniles were recorded using separate notation from adults, as juvenile location was key to determining territory nest success (see section 3.4). Bird groups not recorded in surveys were Hirundinidae (swallows and martins), Apodidae (swifts), Columbidae (pigeons and doves) and Corvidae (jackdaws and crows). Skylarks were also excluded, as they are considered open field occupying rather than boundary occupying. Songbird surveys took place from 18th May-3rd July. Surveys on each hedgerow were repeated 2-3 times per week and no more than 4 days apart to ensure
high probability of detecting juveniles over the fledging period (Sage & Powell, in press). Each boundary took between 10 and 30 minutes to survey, depending on the number of birds present and length of hedgerow. Days with poor weather conditions such as rain, fast wind or thick fog were considered unsuitable for surveying. Surveys in May were carried out in the 3-4 hours after dawn during the dawn chorus singing period and in June surveys were moved to later in the morning (07:00 – 12:00) to record feeding activity in the day.

3.4. Territory mapping

Location data for each survey were inputted into ArcGIS 10.2 in a map covering the extent of the farms. A unique layer was assigned for each species on each date, with an individual represented by a data point in the location it was recorded. These layers were overlaid and used to identify and map individual territories from spatio-temporal clusters of occurrence, as described in Marchant et al. (1990) (see Appendix II for species territory maps). Birds were considered to have part of their territory on a boundary if recorded there at least once per 2 weeks, although the majority were recorded more frequently. It became clear that linnets could not accurately have full territories mapped due to very high mobility, therefore were excluded from the mapping and subsequent analysis. Tree sparrow territories were mapped for either breeding pairs or small breeding groups, and both were considered as equal samples for when modelling breeding success.

Once territory maps had been produced, juveniles recorded were assigned to territories, on the assumption that juveniles will be recorded in their parental territories (Sage & Powell, in press). When juveniles were seen on a boundary for which a territory had not been mapped for the adult of that species, the brood was assumed to have moved onto the boundary from the surrounding landscape. These records were used in comparisons of brood size between species, but not in modelling associations between nest success and boundary features. Juveniles moving onto boundaries from surrounding hedgerows was particularly common in tit species but rarely seen from other species. The maximum number of juveniles recorded on the same day for a territory was extracted, to provide a measure of productivity.

Territory density on hedgerows and overlap of territories into a pair’s territory (see section 3.5 for calculation) were calculated at this point. Based on observations in the field, the
composition of birds on the boundary appeared to be having an effect on breeding success of certain species. Thus it was decided that in addition a social variable describing the proportion of woodland birds or proportion of farmland birds would be calculated to test for effect in the analysis.

3.5. Statistical Analysis

3.5.1. Modelling Effects of Boundary Features on Breeding Success

Analysis of data was carried out at 2 levels: territories and boundaries, in a method similar to Whittingham *et al.* (2005; 2009). The territory level analysis used defended territories as replicates (n=204) with the response variable being nest successful (1) or nest unsuccessful (0). For the boundary level analysis, each field boundary is a replicate (n=39) with proportion of successful territories for each species as the response variable. The predictor variables used in the territory and boundary models are listed in Tables 3.2 and 3.3 (respectively), including how they were calculated and any measurements made in the field.

For both the territory and boundary level, species were grouped into the categories ‘woodland’, ‘farmland’ and ‘all’, with birds being classified according to the ‘Bird Species by Habitat Indices’ used by DEFRA, the BTO and the RSPB. (see Table 3.1; DEFRA, 2012).

*Table 3.1 Species recorded in the study and classification according to ‘Bird Species by Habitat Indices’ (DEFRA, 2012). Species in brackets were recorded using hedgerows on boundaries with offspring but not as having territories on boundaries.*

<table>
<thead>
<tr>
<th>Farmland</th>
<th>Woodland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goldfinch</td>
<td>Blackbird</td>
</tr>
<tr>
<td>Greenfinch</td>
<td>Blue tit</td>
</tr>
<tr>
<td>Tree sparrow</td>
<td>Chaffinch</td>
</tr>
<tr>
<td>Whitethroat</td>
<td>(Coal tit)</td>
</tr>
<tr>
<td>Yellowhammer</td>
<td>Dunnock</td>
</tr>
<tr>
<td></td>
<td>Great tit</td>
</tr>
<tr>
<td></td>
<td>Robin</td>
</tr>
<tr>
<td></td>
<td>Song thrush</td>
</tr>
<tr>
<td></td>
<td>Willow warbler</td>
</tr>
<tr>
<td></td>
<td>Wren</td>
</tr>
</tbody>
</table>
Table 3.2. Variables used in territory level analysis and how they were calculated, including any measurements made in the field and how these were carried out.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Measurement method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hedge Volume</td>
<td>Length of each mapped territory was measured on ArcGIS. Multiplying hedge area (see Hedge Area, Table 3.3) by territory length.</td>
</tr>
<tr>
<td>Number of Overlapping</td>
<td>Counted number of territories which overlapped at least half of the area of the focal territory.</td>
</tr>
<tr>
<td>Territories</td>
<td></td>
</tr>
<tr>
<td>Vegetation Width</td>
<td>Measured vegetation on both sides of the boundary from the edge of the hedgerow to the start of the crop line. 2 measurements were taken per boundary and averaged. The value for each side was added to get total vegetation width. The vegetation width for the boundary which the occupants were recorded on most frequently was used for the territory.</td>
</tr>
<tr>
<td>Number of Brassica</td>
<td>0 = no brassica headlands, 1= brassica headland on one side of the boundary, 2= brassica headland on both sides of the boundary. Value for the boundary was used rather than checked for each territory.</td>
</tr>
<tr>
<td>Headlands</td>
<td></td>
</tr>
<tr>
<td>Feeder presence</td>
<td>Feeder positions were mapped on ArcMap. Territories mapped with at least one feeder inside were assigned a value of 1, territories with no feeders within mapped boundaries were assigned a value of 0.</td>
</tr>
<tr>
<td>Trees</td>
<td>Tree locations along hedgerows were mapped on ArcGIS. Categories were formed of no trees (0 trees), few trees (1-3 trees) and many trees (4+ trees).</td>
</tr>
<tr>
<td>Proximity of Woods</td>
<td>Small patches of woodland were mapped in ArcGIS. When a territory was on a section of hedgerow close to (approx. &lt;100m from) woodland, this was recorded as 1, when not close to woodland, 0.</td>
</tr>
</tbody>
</table>
Table 3.3. Variables used in boundary level analysis and how they were calculated, including any measurements made in the field and how these were carried out.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Measurement method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hedge Area</strong></td>
<td>2 measurements of height and 2 measurements of width were taken and averaged. Multiplying height x width.</td>
</tr>
<tr>
<td><strong>Density of Hedgerow Vegetation</strong></td>
<td>A judgement by eye on the scale of 1-4, where:</td>
</tr>
<tr>
<td></td>
<td>1= very open, frequent gaps</td>
</tr>
<tr>
<td></td>
<td>2= fairly open, some medium sized gaps</td>
</tr>
<tr>
<td></td>
<td>3= mostly solid, a few small gaps</td>
</tr>
<tr>
<td></td>
<td>4= totally compact, no gaps</td>
</tr>
<tr>
<td><strong>Territory Density (per 100m)</strong></td>
<td>Number of territories on the boundary divided by length of boundary, multiplied by 100.</td>
</tr>
<tr>
<td><strong>Proportion of territories held by woodland birds</strong></td>
<td>Number of territories held by woodland species and by farmland species was calculated. Number of woodland species divided by total number of territories (woodland + farmland species).</td>
</tr>
<tr>
<td><strong>Vegetation Width (m)</strong></td>
<td>Measured vegetation on both sides of the boundary from the edge of the hedgerow to the start of the crop line. 2 measurements were taken per boundary and averaged. The value for each side was added to get total vegetation width.</td>
</tr>
<tr>
<td><strong>Feeder presence</strong></td>
<td>Whether feeders were present on either side of the boundary (1) or not (0).</td>
</tr>
<tr>
<td><strong>Trees</strong></td>
<td>Number of trees on the boundary in the categories 0, 1-2, 3-4 and 5+.</td>
</tr>
<tr>
<td><strong>Proximity of Woods</strong></td>
<td>Whether any section of the boundary was close to (&lt;100m from) a woodland patch (1) or not (0).</td>
</tr>
</tbody>
</table>
Correlates of breeding success were modelled for woodland species, farmland species and all species using generalised linear models (GLMs, logistic regression with binomial error distribution).

Information theoretic modelling, described in Burnham & Anderson (2002) was used to select a set of ‘best fit’ models as ranked by Akaike information criterion (AIC) weightings using the *dredge* function in the R package ‘MuMIn’. Information theoretic modelling involves comparing all candidate models which might be expected to show effects on the response variable. All variables in this study had potential to show an impact on nest success, therefore dredging was used to construct and compare models using all possible combinations of the explanatory variables. For the boundary models there were seven variables, producing 64 models, and for the territory models there were eight variables, producing 128 models. AICc estimations were calculated to adjust for bias, as the sample size is small compared to the number of predictor parameters (Hurvich & Tsai, 1989). Akaike weights \( (w_i) \) are assigned to each model, giving the relative probability that a given model \( (i) \) is the actual best model to fit the data (Burnham & Anderson, 2002). Where there are a high number of potential best models (of low AIC values), the Akaike weights are lower for each model. In information theoretic modelling, poor predictors still have a small probability of being selected within models with low AIC values, therefore rather than using the model with the lowest AIC value to evaluate which variables have the greatest impact on breeding success, the sum of Akaike weights were calculated for each variable. This was calculated by, for each explanatory factor, summing the Akaike weight value of each model containing the factor. This gives a measure of ‘importance’ of this variable in explaining the response variable. Importance values are between 0 and 1, with values closer to 1 representing greater importance. In this study, importance values of greater than 0.5 were considered high evidence for contribution to explaining breeding success, and were plotted to evaluate the direction and strength of the relationship. Using the *predict* function, the effect of the variable alone was added as a trend line whilst keeping all other variables at their mean values. Information theoretic methods were considered the most suitable technique for model selection in this case, as the commonly used alternative, stepwise regression, has increased error for models with a large number of explanatory variables (Burnham & Anderson, 2002).
No adjustment was made for different detectability rates between species when modelling effects of boundary variables; instead simply the number of fledged broods counted were used in analysis. This is because the models use individual boundaries and territories as replicates for modelling rather than large sample areas. Although predicted number of undetected fledged broods can be calculated for each species (method described in Sage et al., 2011), which of the territories or boundaries recorded as unsuccessful might have undetected success cannot accurately be predicted. The problems and uncertainties caused by detectability are highlighted in the discussion.

3.5.2. Number of Juveniles
The maximum number of juveniles recorded from each successful territory was extracted, and the means calculated. All successful territories recorded on hedgerows were included, and broods of parents which did not initially have territories on surveyed boundaries which had moved onto boundaries from surrounding areas with fledglings to forage. Site means were displayed with mean number of fledglings per nesting attempt from the BTO’s Nest Record Scheme (NRS) for that species (http://www.bto.org/birdtrends2010). The most recent calculation of mean number of fledglings per nesting attempt was used, which ranged from 2007-2010. Fledglings per nesting attempt and the measure of productivity calculated in this study are not directly comparable, however relative performance of birds from national trends can be compared to relative performance on site.

3.6. Detectability
The extent of bias caused by detectability in this study is assessed post-hoc by calculation of number of successful territories likely to have been missed, based on the probability of detecting a successful brood for each species (probabilities taken from Sage & Powell, in press). They give error for nest success but cannot be meaningfully extrapolated to productivity calculations.

All statistical tests were conducted in R 3.0.3 (R Development Core Team, 2014).
4. Results

4.1. Nest Success

A total of 204 territories were found on the 39 boundaries. Overall number of territories for each species and how many were successful and unsuccessful is shown in Table 4.1. Chaffinch and dunnock were the most abundant species, with 40 and 39 territories respectively. There were several species with very few territories, including both species classified as farmland (goldfinch and greenfinch) and woodland (robin, song thrush, willow warbler and wren). In total 56% of territories were successful, with success rate differing by species. Proportions of nest success and nest failure for each species are shown in Figure 4.1. For species with >5 territories, great tits and blue tits had the highest nest success rates (100%), and for species with >15 territories tree sparrows and blackbirds were most successful (88% and 81% respectively). The lowest success rate was in yellowhammers (35%). The number of successful territories and total number of territories recorded on each hedgerow for woodland and farmland species can be found in Appendix I.

Table 4.1. Numbers of territories for each species found occupying the study site and frequency of successful and unsuccessful breeding outcomes.

<table>
<thead>
<tr>
<th>Species</th>
<th>Successful Breeding</th>
<th>Unsuccessful Breeding</th>
<th>Total Breeding Pairs</th>
<th>Percentage Success Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackbird</td>
<td>21</td>
<td>5</td>
<td>26</td>
<td>81%</td>
</tr>
<tr>
<td>Blue Tit</td>
<td>6</td>
<td>0</td>
<td>6</td>
<td>100%</td>
</tr>
<tr>
<td>Chaffinch</td>
<td>18</td>
<td>22</td>
<td>40</td>
<td>45%</td>
</tr>
<tr>
<td>Dunnock</td>
<td>18</td>
<td>21</td>
<td>39</td>
<td>46%</td>
</tr>
<tr>
<td>Goldfinch</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>50%</td>
</tr>
<tr>
<td>Great Tit</td>
<td>6</td>
<td>0</td>
<td>6</td>
<td>100%</td>
</tr>
<tr>
<td>Greenfinch</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0%</td>
</tr>
<tr>
<td>Robin</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>67%</td>
</tr>
<tr>
<td>Song Thrush</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>100%</td>
</tr>
<tr>
<td>Tree Sparrow</td>
<td>15</td>
<td>2</td>
<td>17</td>
<td>88%</td>
</tr>
<tr>
<td>Whitethroat</td>
<td>13</td>
<td>11</td>
<td>24</td>
<td>54%</td>
</tr>
<tr>
<td>Willow Warbler</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>100%</td>
</tr>
<tr>
<td>Wren</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>67%</td>
</tr>
<tr>
<td>Yellowhammer</td>
<td>11</td>
<td>20</td>
<td>31</td>
<td>35%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>118</strong></td>
<td><strong>86</strong></td>
<td><strong>204</strong></td>
<td><strong>58%</strong></td>
</tr>
</tbody>
</table>
Figure 4.1. Proportion of successful and unsuccessful territories for each species. Width is proportional to number of samples.

4.2. Territory Models

The sum of Akaike weights for variables included in the territory modelling are shown in Table 4.2. For the all species analysis, models did not show any variables included as credible predictors of nest success. In the farmland species models, hedge volume shows evidence of explaining nest success, with increased nest success being associated with greater hedge volume (Figure 4.2). In the woodland species analysis number of territories overlapping with a pair’s territory was a good indicator of nest success. Increasing numbers of territories was associated with increased nest success (Figure 4.3).
Table 4.2. Sum of Akaike weights of evidence (wi) for each predictor variable in the territory information theoretic models. Values >0.5 are in bold.

<table>
<thead>
<tr>
<th>Territory models</th>
<th>Hedge volume</th>
<th>No of overlapping territories</th>
<th>Vegetation width</th>
<th>No Brassica headlands</th>
<th>Feeder presence</th>
<th>Trees</th>
<th>Proximity of woods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum of Akaike weights of evidence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All species</td>
<td>0.46</td>
<td>0.48</td>
<td>0.27</td>
<td>0.28</td>
<td>0.28</td>
<td>0.40</td>
<td>0.35</td>
</tr>
<tr>
<td>Farmland species</td>
<td>0.56</td>
<td>0.27</td>
<td>0.26</td>
<td>0.32</td>
<td>0.46</td>
<td>0.26</td>
<td>0.25</td>
</tr>
<tr>
<td>Woodland species</td>
<td>0.29</td>
<td>0.74</td>
<td>0.27</td>
<td>0.39</td>
<td>0.27</td>
<td>0.25</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Figure 4.2. The effect of hedge volume on breeding success for farmland bird species.
The sum of Akaike weights for variables used in field boundary models is summarised in Table 4.3. In the all species models, only territory density appears to be a good predictor of nest success, with greater territory density being associated with higher nest success (Figure 4.4). Territory density was also a good predictor of woodland bird nest success (Figure 4.5). Additionally in woodland species, trees showed a positive impact on nest success, with more trees increasing nest success (Figure 4.6). In farmland species models, density of hedgerow vegetation and proportion of territories on the headland being held by woodland species show evidence of explaining nest success. Nest success decreased with a greater proportion of territories held by woodland birds on the hedgerow (Figure 4.7) and nest success increased with greater density of hedgerow vegetation (Figure 4.8).
Table 4.3. Sum of weights of evidence ($w_i$) for each predictor variable in the boundary information theoretic models.

<table>
<thead>
<tr>
<th>Boundary models</th>
<th>Hedge area</th>
<th>Density of hedgerow vegetation</th>
<th>Territory density (100m)</th>
<th>Woodland birds proportion</th>
<th>Vegetation width</th>
<th>Feeder presence</th>
<th>Trees</th>
<th>woods</th>
<th>Proximity of woods</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Species</td>
<td>0.35</td>
<td>0.37</td>
<td><strong>0.65</strong></td>
<td>0.23</td>
<td>0.3</td>
<td>0.27</td>
<td>0.5</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>Farmland species</td>
<td>0.29</td>
<td><strong>0.52</strong></td>
<td>0.29</td>
<td><strong>0.59</strong></td>
<td>0.26</td>
<td>0.38</td>
<td>0.29</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>Woodland species</td>
<td>0.27</td>
<td>0.26</td>
<td><strong>0.61</strong></td>
<td>0.3</td>
<td>0.4</td>
<td>0.23</td>
<td><strong>0.77</strong></td>
<td>0.22</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.4. The Effect of territory density on proportion of territories successful in all species.
Figure 4.5. The effect of territory density (number of territories /100m) on breeding success in woodland species.

Figure 4.6. The effect of number of trees on breeding success in woodland birds.
Figure 4.7. The effect of proportion of territories held by woodland species on breeding success in farmland birds.

Figure 4.8. The effect of density of hedge row vegetation on breeding success.
4.4. Productivity of Species

The range of maximum number of juveniles seen for each species is shown in Figure 4.9. The mean maximum number of juveniles seen for each species is displayed in Table 4.4. The mean number of juveniles per nesting attempt based on the BTO’s nest record scheme are also shown (http://www.bto.org/volunteer-surveys/nrs). These are not directly comparable, as the nest record scheme encompasses nests that fail as well as successful nests, however gives a rough idea of productivity on the study site compared to national productivity for a given species.

![Box plot of maximum number of juveniles per species](image)

*Figure 4.9. Maximum number of juveniles for each species with over 10 territories.*
Table 4.4 Mean values for each species of maximum number of juveniles and average number of juveniles per nesting attempt from the BTO’s Nest Record Scheme (http://www.bto.org/volunteer-surveys/nrs)

<table>
<thead>
<tr>
<th>Species</th>
<th>Mean number of juveniles</th>
<th>Average number of juveniles per nest attempt from BTO nest record scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackbird</td>
<td>1.8</td>
<td>1.9</td>
</tr>
<tr>
<td>Blue tit</td>
<td>4.5</td>
<td>6.3</td>
</tr>
<tr>
<td>Chaffinch</td>
<td>2.1</td>
<td>1.46</td>
</tr>
<tr>
<td>Dunnock</td>
<td>1.8</td>
<td>1.72</td>
</tr>
<tr>
<td>Great tit</td>
<td>4.6</td>
<td>5.38</td>
</tr>
<tr>
<td>Tree Sparrow</td>
<td>3</td>
<td>3.7</td>
</tr>
<tr>
<td>Whitethroat</td>
<td>1.7</td>
<td>3.4</td>
</tr>
<tr>
<td>Yellowhammer</td>
<td>1.5</td>
<td>0.94</td>
</tr>
</tbody>
</table>

4.5. Detectability

Probability of detecting a fledged brood has been shown to differ between species (Sage & Powell, in press). Based on detectability rates for 2 surveys per week, the number of successful territories undetected for each species in this study was estimated (Table 4.5). These values are likely to be slight overestimates, as for the majority of the survey period 3 surveys per week were carried out, therefore increasing probability of detection. Detectability rates were taken from Sage & Powell (in press). The majority of species show no bias in nest success, however chaffinch, dunnock and yellowhammer species are likely to show a downward bias when considering proportion of successful nests.

Accuracy of estimating nest productivity is likely to have amplified error for species which have lower probabilities of detecting a brood. For all species, estimates of number of juveniles produced will be an underestimate, though it is likely that for some species there
will be a greater error than for others. For blue tits, great tits and tree sparrows which a high probability of detecting a brood, juveniles are more visible, therefore it is likely there will be the lowest error in estimating number of juveniles produced. However, for species with lower detectability, such as dunnocks, chaffinches, blackbirds and yellowhammers, the underestimation of number of juveniles will be greater.

Table 4.5. Probability of detecting a successful nest for each species and predicted number of undetected nests on the sample site based on these probabilities. Probabilities taken from estimates made in Sage & Powell (in press).

<table>
<thead>
<tr>
<th>Species</th>
<th>Reported detectability with 2 surveys per week</th>
<th>Predicted undetected successful territories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackbird</td>
<td>0.7</td>
<td>1-2</td>
</tr>
<tr>
<td>Blue Tit</td>
<td>1.0</td>
<td>0</td>
</tr>
<tr>
<td>Chaffinch</td>
<td>0.76</td>
<td>5</td>
</tr>
<tr>
<td>Dunnock</td>
<td>0.67</td>
<td>7</td>
</tr>
<tr>
<td>Goldfinch</td>
<td>0.77</td>
<td>0</td>
</tr>
<tr>
<td>Great Tit</td>
<td>1.0</td>
<td>0</td>
</tr>
<tr>
<td>Greenfinch</td>
<td>0.87</td>
<td>0</td>
</tr>
<tr>
<td>Robin</td>
<td>0.8</td>
<td>0</td>
</tr>
<tr>
<td>Song Thrush</td>
<td>0.84</td>
<td>0</td>
</tr>
<tr>
<td>Tree Sparrow</td>
<td>1.0</td>
<td>0</td>
</tr>
<tr>
<td>Whitethroat</td>
<td>0.8</td>
<td>2</td>
</tr>
<tr>
<td>Willow Warbler</td>
<td>0.6</td>
<td>0</td>
</tr>
<tr>
<td>Wren</td>
<td>0.75</td>
<td>0</td>
</tr>
<tr>
<td>Yellowhammer</td>
<td>0.73</td>
<td>5</td>
</tr>
</tbody>
</table>
5. Discussion

5.1. Field Boundary Habitat Associations

In this study the effects of field boundary habitat on breeding success were investigated at a fine spatial scale. In farmland songbird communities, there are species usually typical of woodland habitat and species more dependent solely on farmland habitat, classified into the BTO’s farmland and woodland habitat indices (DEFRA & JNCC 2012; Table 3.1). It was revealed that ‘woodland’ and ‘farmland’ species show responses in nest success to different field boundary variables. For farmland birds, elements of hedgerow quantity and quality have greatest impact on nesting success rates, but for woodland birds increasing numbers of trees is the key factor for increasing breeding success. These findings reflect the results of a review by Hinsley and Bellamy (2000) which found hedge size and tree presence are the most important variables positively influencing species richness and abundance of breeding birds in hedgerows.

Several woodland species found on farmland, for example great tits, blue tits and chaffinches, are dependent on arboreal invertebrates and have been shown to have positive associations with trees in boundaries (Whittingham et al., 2001; 2009). This is a likely explanation for finding increased breeding success in woodland species with greater numbers of trees on boundaries. Hedge volume but not hedge area increased breeding success in farmland birds, which could be related to a greater total volume of hedgerow in which birds can forage, rather than a simple 2-dimensional measure. Volume of hedgerow in a territory will depend somewhat on how long the territory held is, but also on size of hedgerows available. Greater density of hedgerow vegetation was another factor found to increase breeding success in farmland birds. Denser hedgerows may provide better cover from predators, reducing predation rates of eggs and chicks (Whittingham & Evans, 2004).

Studies measuring abundance of species, or analysing where species set up territories, tend to make the underlying assumption that individuals will be found at greater density in habitat of higher quality, including a more abundant food supply. This could be expected to result in a higher rate of breeding success. In this study however, many variables shown to
be important in habitat association studies were not found to have associations with
breeding success.

Proximity of a woodland edge has been linked to increased abundance of birds on farmland
and territory selection (Aronld, 1983; Whittingham et al., 2009). Nearby woodland may be
expected to increase breeding success in woodland birds as it provides access to primary
foraging habitat, however there was no evidence of an impact on breeding success. Brassica
fields were found to be the second strongest predictor of territory occurrence in
Whittingham et al. (2009), yet no effect of brassica headlands was seen on breeding success
in this study. Feeder presence and brassica headlands may be more likely to be linked to
over-winter survival than increasing breeding success, as they provide grain and seeds for
adults: an often limited food source in winter (Siriwardena, Calbrade & Vickery, 2008).
Width of the field margin vegetation adjacent to hedgerows was also not found to be
correlated with increased breeding success. Several studies have shown high invertebrate
abundance in unsprayed field margins. (Chiverton & Sotherton, 1991; Vickery, Carter &
Fuller, 2002) and that field margins are an important foraging area for several species
(Cracknell, 1986, Morris et al., 2001) and are consequently predicted to be prime foraging
habitat. It may be that the effect of vegetation width would only be seen for individual
species, as whilst field margins are important foraging areas for some species, others will
use field margins to forage very rarely, or not at all (Cracknell, 1986; Whittingham et al.,
2001). The type and diversity of planted strips may also have an impact on breeding success,
but were not recorded in this study.

The absence of effects of variables seen in this study does not necessarily mean they have
no impact on breeding success. This study is of narrow scope, carried out over a small area
on farmland which has applied high quality conservation practices. Chamberlain et al. (2000)
suggest a threshold for critical amounts of high quality habitat or food resources needed to
sustain populations. Similarly, a threshold could apply to breeding success rates. The effects
of a threshold may only become clear when sampling over a greater range of variable
values, for example by including farms with little or no management on field margins.

Hinsley & Bellamy (2000) state that due to high mobility, it cannot be assumed that the
habitat use of birds within a particular hedgerow will be limited to the adjacent land use,
and therefore determining relationships with variables at this level can be difficult. Given
this, whilst variables with a strong effect on breeding success may still be seen, variables with a weaker effect may only become apparent at much larger sample sizes than used here. Studying the same variables over a greater spatial range with a larger sample size could reveal additional results not seen this study.

A previously undocumented result for farmland species was that with an increasing proportion of woodland species on the hedgerow, farmland species show decreasing nest success. Competition between the two groups is a possible explanation for this result, however is unlikely, as although all species recorded feed their young on invertebrates, where these are foraged for will differ. In summer 75% of chaffinch foraging trips were in trees and bushes (Whittingham et al., 2001), whereas yellowhammers forage primarily in fields and field margins (Perkins et al., 2002). Most other bird species stay closer to the hedge, using the hedgerow, ground below the hedgerow and field margins to collect food (Cracknell, 1986). It is therefore more likely that a higher proportion of woodland birds represents a habitat increasingly similar to scrub or woodland, which becomes less suitable for farmland species to live on and poorer quality for breeding. Notably though, breeding success did not increase for woodland species with increasing proportions of territories held by woodland species, as might be expected for hedgerow more similar to scrub habitat. It is unclear why this might be.

The positive relationship between territory density and woodland species breeding success suggests that for this group density could be a good indicator of habitat quality for breeding. This relationship was not seen for farmland birds, which highlights that studies measuring abundance or habitat associations alone in the breeding season should be wary of concluding that this habitat will be the best for breeding. Whittingham et al. (2005) found that territory positioning of birds over-wintering in the same area can be related to where abundant winter food supplies are, which does not necessarily reflect where good breeding supplies will be. Alternatively, the explanation could lie on interplay between habitat quality and competition for resources. If individuals preferentially choose to set up territories on higher quality habitat, a greater density of birds will be expected to occur. Where a greater density of birds occurs, there will be more competition between individuals exploiting the same resources, which is likely to have a negative effect on breeding success, as resources become are depleted (Cody, 1981). Habitat quality could therefore become ‘masked’ by the
effects of competition, resulting in observed breeding success being a poor reflection of habitat quality.

5.2. Number of Juveniles Fledged

This study also calculated average number of juveniles per successful territory seen for each species. As would be expected, number of juveniles differed by species. Relative differences in productivity from this study were in line with relative differences in national numbers of juveniles produced per breeding attempt. Ideally a measure of detectability is incorporated into analysis, but wherever this is not possible caution should be taken with regards to interpreting results. Lower detectability of juveniles is likely to amplify error when estimating brood size, to a currently unknown extent. Highly vocal or gregarious species have a high probability of being detected, but quieter or more secretive species are less often seen. Nonetheless, all estimates of productivity are likely to be negatively biased. Therefore when comparing average number of juveniles per successful territory in this method to methods which observe nests, caution must be taken in considering whether these represent actual differences, as juvenile counts reflect detectability of the species as well as breeding performance. Detectability may also differ due to certain habitat features, for example tall trees, therefore with amplified error number of juveniles per territory is likely be an unsuitable measure to associate with features.

When considering national trends of increase or decline, it is important to recognise that what proportion of nests are successful and number of juveniles produced are just two of several factors which might affect national population trends. Post-fledging survival and survival of adults over winter will also affect population size, and a failure at any point in the demographics of the population could be the cause of a downward population trend (Newton, 2004). An observed low nest success might not result in a declining population if post-fledging survival and adult survival are high. Indeed nationally, blackbirds, chaffinches and dunnocks have low numbers of juveniles per nesting attempt compared to some species in this study, but increasing population trends over the last 4 decades have been observed. Conversely, despite having a comparatively high number of juveniles per nesting attempt at a national level, tree sparrows have experienced one of the greatest recent songbird declines in the UK (http://www.bto.org/birdtrends2010). Siriwardena et al. (2000)

35
found population declines observed in farmland birds were explained very poorly by breeding performance, and in fact for some species, including tree sparrow and yellowhammer, breeding performance increased when populations were in decline. For several species, winter survival rather than breeding success is expected to be the main factor limiting population growth (Vickery et al., 2004; Siriwardena, Calbrade & Vickery, 2008).

Nonetheless, nest success and productivity are potential important contributors to population changes, and low observed breeding success could be one possible explanatory factor when considering populations currently in decline. Moreover, even in cases where winter survival or post-fledging survival are the primary limiting factors, alleviating this factor may just reveal an element of breeding success as a new barrier to population increase (Vickery et al., 2004). Ensuring conservation practices are in place that allow survival and encourage the highest possible breeding success will in combination result in the highest rate of increase when populations start to expand.

In yellowhammers, ‘the most probable limiting demographic factor’ based on a literature review was winter survival (Vickery et al., 2004), however yellowhammers have also been calculated to have nest success and productivity too low to sustain current population levels (Bradbury et al., 2000). Low nest success and productivity were also found in this study, but BTO NRS data show number of juveniles per breeding attempt has been low since records were first being collected, varying approximately between 0.9 and 1.5. This suggests that compared to other species, yellowhammers have intrinsically low breeding success and productivity, even where high level conservation practices are carried out. It would therefore be expected that even when survival is not limiting and conditions are suitable for breeding, yellowhammer populations will take a long time to recover. For tree sparrows however, both nationally and on the study site nest success and productivity appear to be high, therefore when survival is no longer a limiting factor populations are likely to increase rapidly.

5.3. Conservation Suggestions

Some of the conservation suggestions arising from these findings are similar to those stipulated by other studies on birds occupying field boundaries. Hedgerow size and tree
presence are the field boundary factors most commonly found to be linked to territory selection and bird abundance (eg MacDonald & Johnson, 1995; Moles & Breen, 1995; Whittingham et al., 2009) Similarly in this study, number of trees in boundaries is shown to be important, but only for woodland species. Hedgerow volume in a territory is one of the boundary features shown to be important for farmland birds. This is slightly different from the usual hedgerow size measurements found to be important (height/width/area), and is likely to reflect a combination of hedgerow size and area of hedge available to forage in. Hedgerow density, though not unseen to have effect on bird communities (eg MacDonald & Johnson, 1995) is less commonly found as an important factor. Thus to increase the breeding success of farmland birds, management should be encouraged to provide moderate to large sized hedges with appropriate cutting regimes and low gappiness of hedges, including filling in gaps with new hedge plants when old ones die.

Maintaining hedgerows on field margins is supported through Environmental Stewardship schemes in England, and the new Greening payment scheme in Scotland. On arable lowland farms, Entry Level Stewardship (ELS) is open to all farms, Organic Entry Level Stewardship (OELS) is open only to organic farms and Higher Level Stewardship (HLS) is open only to farms in certain areas or with certain prerequisites (Natural England, 2009). The HLS package for farmland birds requires populations of at least 3 of the ‘Arable Six’ (tree sparrow, lapwing, grey partridge, turtle dove, corn bunting and yellow wagtail), or in special cases a regionally important breeding population of one of these species (Phillips, Willmott & Grice, 2013). Options for supporting hedgerow management are present in all three of the stewardship schemes open to lowland arable farms. ELS and OELS offer ‘enhanced hedgerow management’ as an option, whilst the HLS offers further development through ‘management of hedgerows of very high environmental value’. Recent reform to the Common Agricultural Policy (CAP) have introduced Greening payments, one of which is providing Ecological Focus Areas (EFAs) which requires managing 5% of the farmland area for wildlife. Field margin features, including hedgerows, of between 1m and 20m count towards EFAs (Scottish Government, 2014).

Although planting or keeping hedgerows is supported by UK agri-environment schemes (AES), the specific composition of hedges is not specified. Guidance and support should be provided to farmers entering stewardship or greening schemes to ensure management of
hedgerows is appropriate. Over- or under-management has been shown to reduce the quality of hedges for birds (Lack, 1987; MacDonald & Johnson, 1995), and can reduce both the volume and density of hedge, as well as affecting the scrubbiness of habitat. Over-management, involving cutting hedges too small, could reduce the hedge area so invertebrate populations are smaller and cover could become inadequate for escaping predators, whilst under-management may let hedges grow out too much to become scruffy with lose cover closer to the ground (MacDonald & Johnson, 1995; Whittingham & Evans, 2004). Whilst under-management is usually considered less detrimental than over-management, this study shows farmland bird breeding could suffer from under-management of hedgerows if this produces scrub-like habitat and reduces hedge density. Correct management, can provide large areas of hedgerow with good cover, which is likely to increase breeding success of farmland birds, but with poor management, qualities of hedgerows found to be important in this study for increasing breeding bird success could be compromised.

Planting or leaving trees in boundaries will increase breeding success of woodland birds. Although this is not an option within the stewardship schemes, it could be argued that farmland birds are a greater priority to manage for, since they are showing greatest current declines, whilst many woodland species occurring on farms are generalists with stable or increasing populations (http://www.bto.org/birdtrends2010).

Where locally high breeding success already occurs, especially in a species which has a nationally declining trend, the population probably has the potential to expand in this area if suitable actions are taken that also ensure reasonable survival rates. A holistic approach to conservation should be taken, combining management practices which will address both reproductive and survival needs. For tree sparrows, winter food supply and lack of mature or dead trees with holes in which to nest are key gaps in survival and reproduction needs. Leaving winter stubbles for food, providing supplementary feeding over winter and putting up nest boxes will increase winter supplies and suitable breeding cavity replacements (Vickery et al., 2004; Hertfordshire & Middlesex Wildlife Trust, 2006). Population recovery will be most effective when actions are implemented in areas where tree sparrows already show breeding success, and therefore the potential increase in population size.
Many non-migratory farmland species are relatively sedentary, usually not seen travelling more than a few kilometres (ringing data, Paradis et al., 1998), therefore long term management plans are essential to ensure habitat is suitable for long enough to see a reversal in trends locally. This is especially true for species with intrinsically low rates of increase, like yellowhammers.

5.4. Further Research Areas and Conclusion

Expanding the usage of this methodology, especially to within bird centred Non-Governmental Organisations (NGOs), will add to the current knowledge of factors affecting breeding success in birds found on farmland. Future work should concentrate on expanding the sample size and geographical range over which the data collection takes place. Inclusion of farms with different management practices and increased variation in measured boundary variables may help to detect even weaker effects of variables on breeding success. Expanding geographical areas surveyed will also enable quantification of nest success of species that were not found on this study site, for example corn bunting and turtle dove, which are farmland songbird species of conservation priority in the UK (Natural England, 2009). Increasing sample size could also allow for quantification of factors important in breeding success for individual species.

Using this method, comparisons of breeding success of whole communities and of individual species can be made between farms with different levels of conservation practices. There is a current debate over whether AES have had the desired outcome of supporting biodiversity, including bird populations (Kleijn & Sutherland, 2003; Kleijn et al., 2011). Knowledge of how well schemes support breeding potential of birds would contribute towards assessment of effectiveness of AES in general, and the different types of scheme. It is therefore recommended that breeding success of communities be assessed on farms with different management regimes, including farms with no management for wildlife.

Further research into detectability is also desirable, including considering whether there is a way of accurately estimating brood size from number of juveniles recorded in order to improve ability to document productivity.
Directly measuring the relationship between environmental variables and breeding success has potential to clarify effects of variables from previous research on habitat association using only occurrence data. This study has shown that variables most affecting breeding success differ between farmland and woodland species, and confirms that hedgerow size and trees are influential features on breeding success. It also finds that increased density of hedge vegetation has a positive impact on breeding success, whilst habitat more suitable for woodland birds becomes lower quality breeding habitat for farmland birds. Suggestions are therefore made for hedgerow management to encourage moderate to large sized hedgerows with good cover and low numbers of gaps. Guidance should to be made available to farmers entering into bird-focused AES on how to achieve this. Long term management plans and a holistic approach to management ensuring both breeding and survival needs are considered is advised.
References


### Appendix I - Feature composition of and breeding success on the 39 hedgerows surveyed

<table>
<thead>
<tr>
<th>Field ID</th>
<th>Hedge Length (m)</th>
<th>No of brassica headlands</th>
<th>Trees</th>
<th>Near to woods</th>
<th>Bush Height (m)</th>
<th>Bush Depth (m)</th>
<th>Bush Area (m²)</th>
<th>Hedgerow 1 width</th>
<th>Hedgerow 2 width</th>
<th>Feeders</th>
<th>No of farmland bird territories</th>
<th>Number of successful farmland birds</th>
<th>No of woodland bird territories</th>
<th>Number of successful woodland birds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>481</td>
<td>1</td>
<td>1-2</td>
<td>No</td>
<td>2.9</td>
<td>1.8</td>
<td>5.22</td>
<td>6.0</td>
<td>6.4</td>
<td>Yes</td>
<td>2</td>
<td>0</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>100E</td>
<td>466</td>
<td>0</td>
<td>1-2</td>
<td>Yes</td>
<td>1.5</td>
<td>1.6</td>
<td>2.40</td>
<td>3.0</td>
<td>0</td>
<td>Yes</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>101/114</td>
<td>294</td>
<td>2</td>
<td>0</td>
<td>Yes</td>
<td>1.8</td>
<td>2.5</td>
<td>4.50</td>
<td>7.1</td>
<td>7.6</td>
<td>Yes</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>101SE</td>
<td>472</td>
<td>1</td>
<td>0</td>
<td>No</td>
<td>1.1</td>
<td>1.4</td>
<td>1.54</td>
<td>8.8</td>
<td>0</td>
<td>Yes</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>103NE</td>
<td>349</td>
<td>1</td>
<td>1-2</td>
<td>No</td>
<td>2.2</td>
<td>1.9</td>
<td>4.18</td>
<td>7.9</td>
<td>0</td>
<td>Yes</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>106/117</td>
<td>587</td>
<td>0</td>
<td>5+</td>
<td>No</td>
<td>1.9</td>
<td>2.0</td>
<td>3.80</td>
<td>3.0</td>
<td>5.2</td>
<td>Yes</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>106NE</td>
<td>424</td>
<td>0</td>
<td>1-2</td>
<td>No</td>
<td>2.2</td>
<td>2.1</td>
<td>4.62</td>
<td>3.6</td>
<td>0.5</td>
<td>Yes</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>114NE</td>
<td>288</td>
<td>1</td>
<td>0</td>
<td>No</td>
<td>1.8</td>
<td>1.7</td>
<td>3.06</td>
<td>6.0</td>
<td>0</td>
<td>No</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>117SE</td>
<td>541</td>
<td>0</td>
<td>0</td>
<td>Yes</td>
<td>1.5</td>
<td>2.1</td>
<td>3.15</td>
<td>3.3</td>
<td>0</td>
<td>No</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>120NW</td>
<td>303</td>
<td>0</td>
<td>3-4</td>
<td>Yes</td>
<td>2.0</td>
<td>1.9</td>
<td>3.80</td>
<td>3.0</td>
<td>0</td>
<td>Yes</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>120SW</td>
<td>360</td>
<td>0</td>
<td>5+</td>
<td>Yes</td>
<td>1.7</td>
<td>1.6</td>
<td>2.72</td>
<td>5.0</td>
<td>0</td>
<td>Yes</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>21/26</td>
<td>572</td>
<td>0</td>
<td>0</td>
<td>No</td>
<td>2.0</td>
<td>2.0</td>
<td>4.00</td>
<td>4.2</td>
<td>5.7</td>
<td>Yes</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>21S</td>
<td>328</td>
<td>0</td>
<td>5+</td>
<td>No</td>
<td>1.3</td>
<td>1.2</td>
<td>1.56</td>
<td>3.8</td>
<td>0</td>
<td>No</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>22N</td>
<td>395</td>
<td>1</td>
<td>0</td>
<td>Yes</td>
<td>1.9</td>
<td>2.3</td>
<td>4.37</td>
<td>10.5</td>
<td>0</td>
<td>No</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>25NE</td>
<td>365</td>
<td>1</td>
<td>0</td>
<td>No</td>
<td>1.6</td>
<td>2.0</td>
<td>3.20</td>
<td>9.0</td>
<td>1.7</td>
<td>No</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>34/45</td>
<td>334</td>
<td>2</td>
<td>0</td>
<td>No</td>
<td>3.6</td>
<td>5.5</td>
<td>19.80</td>
<td>9.5</td>
<td>8.0</td>
<td>No</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>34W</td>
<td>510</td>
<td>1</td>
<td>1-2</td>
<td>No</td>
<td>2.3</td>
<td>2.4</td>
<td>5.52</td>
<td>8.4</td>
<td>2.3</td>
<td>No</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>35/47</td>
<td>203</td>
<td>1</td>
<td>5+</td>
<td>No</td>
<td>2.2</td>
<td>2.0</td>
<td>4.40</td>
<td>9.3</td>
<td>0</td>
<td>No</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>35/57</td>
<td>268</td>
<td>1</td>
<td>0</td>
<td>No</td>
<td>2.4</td>
<td>2.5</td>
<td>6.00</td>
<td>8.7</td>
<td>5.1</td>
<td>No</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>38/43N</td>
<td>322</td>
<td>2</td>
<td>1-2</td>
<td>Yes</td>
<td>3.3</td>
<td>3.0</td>
<td>9.90</td>
<td>8.9</td>
<td>11.6</td>
<td>Yes</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Code</td>
<td>Meter</td>
<td>Depth</td>
<td>Grade</td>
<td>Yes/No</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>--------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38/43S</td>
<td>317</td>
<td>2</td>
<td>0</td>
<td>Yes</td>
<td>2.7</td>
<td>2.2</td>
<td>5.94</td>
<td>10.0</td>
<td>Yes</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>45/57</td>
<td>401</td>
<td>2</td>
<td>0</td>
<td>No</td>
<td>2.5</td>
<td>2.4</td>
<td>6.00</td>
<td>6.8</td>
<td>Yes</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>45NW</td>
<td>310</td>
<td>1</td>
<td>3-4</td>
<td>Yes</td>
<td>2.7</td>
<td>2.4</td>
<td>6.48</td>
<td>8.4</td>
<td>0</td>
<td>Yes</td>
<td>2</td>
<td>1</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>47/59</td>
<td>319</td>
<td>1</td>
<td>0</td>
<td>Yes</td>
<td>1.8</td>
<td>1.9</td>
<td>3.42</td>
<td>7.6</td>
<td>4.8</td>
<td>No</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>56/38</td>
<td>334</td>
<td>2</td>
<td>3-4</td>
<td>Yes</td>
<td>1.8</td>
<td>1.9</td>
<td>3.42</td>
<td>7.1</td>
<td>7.6</td>
<td>Yes</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>56/72</td>
<td>226</td>
<td>0</td>
<td>0</td>
<td>No</td>
<td>1.9</td>
<td>1.9</td>
<td>3.61</td>
<td>3.0</td>
<td>4.5</td>
<td>Yes</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>57+73NE</td>
<td>393</td>
<td>0</td>
<td>0</td>
<td>No</td>
<td>1.5</td>
<td>1.5</td>
<td>2.25</td>
<td>0</td>
<td>0</td>
<td>No</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>5NW</td>
<td>507</td>
<td>1</td>
<td>5+</td>
<td>Yes</td>
<td>2.7</td>
<td>1.5</td>
<td>4.05</td>
<td>10.3</td>
<td>11</td>
<td>Yes</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>67/76</td>
<td>273</td>
<td>0</td>
<td>1-2</td>
<td>Yes</td>
<td>2.1</td>
<td>2.4</td>
<td>5.04</td>
<td>4.2</td>
<td>4.5</td>
<td>Yes</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>71/90</td>
<td>380</td>
<td>0</td>
<td>0</td>
<td>Yes</td>
<td>1.5</td>
<td>1.6</td>
<td>2.40</td>
<td>3.0</td>
<td>3.0</td>
<td>No</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>72NE</td>
<td>245</td>
<td>0</td>
<td>5+</td>
<td>Yes</td>
<td>1.7</td>
<td>1.6</td>
<td>2.72</td>
<td>4.9</td>
<td>2.8</td>
<td>No</td>
<td>1</td>
<td>0</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>7SW</td>
<td>379</td>
<td>1</td>
<td>5+</td>
<td>No</td>
<td>3.5</td>
<td>4.0</td>
<td>9.8</td>
<td>6.3</td>
<td>0</td>
<td>Yes</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>85/97/105</td>
<td>427</td>
<td>2</td>
<td>0</td>
<td>No</td>
<td>2.6</td>
<td>1.7</td>
<td>4.42</td>
<td>7.7</td>
<td>3.1</td>
<td>Yes</td>
<td>3</td>
<td>0</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>90NE</td>
<td>319</td>
<td>0</td>
<td>3-4</td>
<td>No</td>
<td>1.3</td>
<td>1.5</td>
<td>1.95</td>
<td>4.0</td>
<td>0</td>
<td>Yes</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>91/103</td>
<td>188</td>
<td>1</td>
<td>0</td>
<td>Yes</td>
<td>2.1</td>
<td>2.2</td>
<td>4.62</td>
<td>8.4</td>
<td>3</td>
<td>Yes</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>93SE</td>
<td>493</td>
<td>0</td>
<td>3-4</td>
<td>No</td>
<td>2.3</td>
<td>2.8</td>
<td>6.44</td>
<td>3.0</td>
<td>0</td>
<td>Yes</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>97/105</td>
<td>435</td>
<td>2</td>
<td>0</td>
<td>No</td>
<td>2.4</td>
<td>2.3</td>
<td>5.52</td>
<td>3.2</td>
<td>3.3</td>
<td>Yes</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>98/107</td>
<td>401</td>
<td>1</td>
<td>0</td>
<td>No</td>
<td>3.4</td>
<td>2.8</td>
<td>9.52</td>
<td>8.3</td>
<td>3.0</td>
<td>No</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>98NW</td>
<td>293</td>
<td>1</td>
<td>3-4</td>
<td>Yes</td>
<td>1.7</td>
<td>1.7</td>
<td>2.89</td>
<td>9.2</td>
<td>0</td>
<td>No</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>
Appendix II – Study Site and Species Territory Maps

Blackbird Territories

Data from April–July 2014, Created August 2014.
Projection - British National Grid.
Base map from Ordinance Survey.
Dunnock Territories

Data from April-July 2014, Created August 2014.
Projection - British National Grid.
Base map from Ordinance Survey.
Song Thrush Territories

Data from April-July 2014, Created August 2014.
Projection - British National Grid.
Base map from Ordnance Survey.
Tree Sparrow Territories

Legend:
- Purple: Tree Sparrow Territory
- Red: Unused Boundaries
- Light Green: Cereal field
- Pale Yellow: Brassica Field
- Orange: Pasture Field
- Light Brown: Bare Field
- Forest Green: Woods
- Light Grey: Grassy Land

Data from April-July 2014, Created August 2014.
Projection - British National Grid.
Base map from Ordinance Survey.
Willow Warbler Territories
Wren Territories

Data from April-July 2014, Created August 2014.
Projection - British National Grid.
Base map from Ordnance Survey.