MONITORING AND MANAGING PLANT DIVERSITY IN FIELD MARGINS IN SOUTHERN ENGLAND

Claudia Havranek

Department of Plant Sciences, University of Oxford

Magdalen College





Thesis submitted for the degree for Doctor of Philosophy

Trinity Term 2019

Acknowledgements

The greatest thanks are due to Dr Catherine Wills, without whom this work would not have been possible. The knowledge, support and enthusiasm which she shared throughout my D.Phil. have been invaluable.

For assistance with fieldwork and on the Estate, thank you to Owain Turner, Ellen Stickland, Robert Hobill, David Hathaway, Sue Trafford and the Trustees of the HDH Wills Trust.

Thank you to my supervisor, Professor Stephen Harris, and to other advisors, especially Dr Lindsay Turnbull, Dr Max Bodmer, Dr Louise Hill, Dr Zoë Goodwin and Dr Nick Kruger.

To John, Marlene, Olivia, Hugo and Poppy Havranek, Professor Robert Scotland, Gem Toes, Dr Becky Capel, Dr Rachel Wheatley and Joe Keefe, all of whom were with me when I was rolling with the punches: thank you.

Finally, to the team from Magdalen College, who have always been in my corner, thank you Professor Andrew Smith, Professor Liam Dolan, Dr Mark Pobjoy, Dr Sandy Hetherington and to the undergraduates I have had the pleasure of calling my students.

This research was funded by an Oxford-HDH Wills 1965 Charitable Trust Scholarship.

This thesis is dedicated to Margaret Mansfield,

who inspired a love of knowledge and biology.

Copyright (©) Havranek 2020. All rights reserved.

Contents

List of figures **6**
List of tables **8**
List of appendices **10**
ABSTRACT 11
GLOSSARY 12

1 CHAPTER 1: INTRODUCTION 13
1.1 A global and national problem **13**
1.2 Arable field margins and hedgerows **14**
1.2.1 Why are field margins and hedgerows valued? 16
1.2.2 Environmental targets for field margins and hedgerows 17
1.2.3 Agri-environmental schemes for field margins 19
1.3 Monitoring plant diversity in field margins **23**
1.3.1 Indicator taxa: birds, bats, butterflies and plants 23
1.3.2 Indicator plant species 25
1.3.3 Plant monitoring schemes 25
1.3.4 Citizen science for plant surveys 28
1.4 Measures of diversity **28**
1.4.1 Species diversity indices 29
1.4.2 Plant community composition 29
1.5 Ecological theories explaining plant community composition in field margins **30**
1.5.1 Niche theory 30
1.5.2 Trait-based ecology 31
1.5.3 Intermediate disturbance hypothesis 32
1.5.4 The Theory of Island Biogeography 32
1.5.5 Neutral theory 32
1.6 Research summary **34**
1.6.1 Study sites 35

2 CHAPTER 2: THE MARGIN-LEVEL FACTORS AFFECTING PLANT DIVERSITY IN FIELD MARGINS OVER TWO YEARS 38
2.1 Chapter summary **38**
2.2 Introduction **39**
2.3 Methods **43**
2.3.1 Methods overview 43
2.3.2 Study site 43
2.3.3 Margin Identification 44
2.3.4 Vegetation sampling 44
2.3.5 Margin characteristics surveys 47
2.3.6 Analysis 49
2.4 Results **49**
2.4.1 Plant community composition 50
2.4.2 Margin width 53
2.4.3 Adjacent land use 56
2.5 Discussion **58**
2.5.1 The impact of margin characteristics on plant community composition 58
2.5.2 Margin width 59
2.5.3 Adjacent land use 60
2.5.4 Conclusions 61

3 CHAPTER 3: THE FACTORS AFFECTING PLANT DIVERSITY IN FIELD MARGINS OVER FOUR FARMS IN OXFORDSHIRE, ENGLAND 62
3.1 Chapter summary 62
3.2 Introduction 63
3.3 Methods 65
3.3.1 Methods overview 65
3.3.2 Study site 65
3.3.3 Margin identification 66
3.3.4 Vegetation Sampling 66
3.3.5 Margin characteristic surveying 68
3.3.6 Analysis 71
3.4 Results 72
3.4.1 Variation in field margin plant species richness over four farms 72
3.4.2 Margin characteristics and plant community composition 75
3.5 Discussion 77
3.5.1 Field margin plant diversity over four farms 77
3.5.2 Margin characteristics and plant community composition 78
3.5.3 Farm identity and plant community composition 79
3.5.4 Conclusions 80

4 CHAPTER 4: THE ASSOCIATIONS BETWEEN FIELD MARGIN STRUCTURE AND BUTTERFLY DIVERSITY IN FIELD MARGINS 81
4.1 Chapter summary 81
4.2 Introduction 82
4.3 Methods 84
4.3.1 Methods overview 84
4.3.2 Study site 84
4.3.3 Margin selection 85
4.3.4 Margin structure surveys 85
4.3.5 Vegetation surveys 87
4.3.6 Butterfly surveys 87
4.3.7 Analysis 87
4.4 Results 88
4.4.1 Effects of margin characteristics on butterfly community composition 89
4.4.2 Effects of margin characteristics on butterfly species richness 92
4.4.3 The presence of food plants and associated butterfly species 94
4.5 Discussion 96
4.5.1 Field margin structure and butterfly community composition 96
4.5.2 Field margin structure and butterfly species richness 97
4.5.3 Primary food plant presence and butterfly species identities 98
4.5.4 Conclusions 99

5 CHAPTER 5: DIFFERENCES IN THE PLANT RECORDS OF FIELD MARGINS SURVEYED VIA DIFFERENT METHODS 100
5.1 Chapter summary 100
5.2 Introduction 101
5.3 Methods 105
5.3.1 Methods overview 105
5.3.2 Study sites 106
5.3.3 Margin identification 106
5.3.4 Survey methods 107
5.3.5 Analysis 109
5.4 Results 110
5.4.1 Survey time 110

5.4.2 Species richness....111
5.4.3 Plant families....114
5.4.4 CSR plant strategy....116
5.5 Discussion 116
5.5.1 Survey effort....117
5.5.2 Differences in species richness....117
5.5.3 Differences in species identities....117
5.5.4 Conclusions....119

6 CHAPTER 6: GENERAL DISCUSSION 120
6.1 Overview 120
6.1.1 Factors affecting plant diversity in field margins....120
6.1.2 Field margin structure and butterfly diversity....121
6.1.3 Monitoring plant diversity in field margins....122
6.1.4 Emerging technologies....122
6.2 General conclusions 124

List of figures

1.1 Photos of field margins from farms surveyed in this thesis…… 15

1.2 The principal components of an arable field margin……16

1.3 Pathways to impact for field margins……17

1.4 Entry-Level stewardship options available for margin management in 2005…….. 22

1.5 A satellite imagery map of Oxfordshire within the UK……36

1.6 A satellite imagery map of Oxfordshire and neighbouring counties……36

2.1 A satellite image of the farm with the locations of each potential field margin……44

2.2 The set up of hedgerow and margin surveys……45

2.3 The quadrat placement to sample plant communities from across the width of the field margin……..46

2.4 A CCA ordination diagram (axis 1 and 2) of plant communities and 12 explanatory variables (2015)……51

2.5 A CCA ordination diagram (axis 1 and 2) of plant communities and 12 explanatory variables (2016)……52

2.6 The relationship between overall margin width and mean margin plant species richness surveyed in 2015……53

2.7 A CCA ordination diagram (axis 1 and 2) of 257 plant communities, plant species and explanatory variables, margin width and quadrat position……55

2.8 A CCA ordination diagram (axis 1 and 2) of plant communities, plant species and explanatory variables, adjacent land use and quadrat position……57

3.1 The quadrat placement to sample plant communities from across the width of the field margin…….. 67

3.2 The plant species richness in field margins over four different farms (A, B, C, D)…….. 73

3.3 Non-metric dimensional scaling (two dimensions) of plant communities across four farms, with Bray-Curtis dissimilarity index…… 74

3.4 A CCA ordination diagram (axis 1 and 2) from the simplified CCA, containing 11 margin characteristics…… 76

4.1 A satellite image showing surveyed margins, across the 1,600 ha mixed arable farm in West Oxfordshire, England…….. 85

4.2 The field margin survey set up…… 86

4.3 A CCA ordination diagram (axis 1 and 2) of butterfly communities recorded in 60 margins and five field margin structure characteristics…… 91

4.4 The butterfly species richness surveyed in field margins with three different adjacent land uses……93

4.5 The linear relationship between plant species richness and mean butterfly species richness observed in field margins…… 93

4.6 A scatterplot to show the relationship between margin vegetation height and butterfly species richness…… 94

5.1 The field margin survey set up, with 100 m walking transects or 30 m walking transects……108

5.2 The quadrat positions in quadrat surveys……108

5.3 The time taken to survey three 1 m x 1 m quadrats and one 100 m transect in the same margin, by four different surveyors…… 110

5.4 The log survey area-log species richness relationship for each of the three survey methods, over 42 field margins surveyed in 2016……112

5.5 The log survey area-log species richness relationship for each of three survey methods, over three field margins, undertaken by five surveyors in 2017…… 113

5.6 The log survey area-log species richness relationship for each of three survey methods, over 19 field margins, over four farms (A, B, C, D) in 2017……114

5.7 Ternary plots to show the Grime's CSR plant strategy of species more likely to be found by either transect or quadrat survey method……116

List of tables

1.1 A summary of English agri-environmental scheme options relevant to field margins and hedgerows offered in 2019……..20

1.2 The UK biodiversity indicator assessment……..24

1.3 A description of five nationwide plant monitoring schemes which may contain plant records from field margin surveys within their databases……27

1.4 The three plant life-history strategies defined by Grime *et al.* (1988)……31

1.5 A comparison of farm size, between the county of Oxfordshire, and the South East of England……..37

1.6 A description and the location of farms visited in Oxfordshire……37

2.1 A list of 12 margin characteristics, describing the margin and hedgerow boundary and quadrat position within the field margin……42

2.2 Conversion of the DOMIN scale to percentage cover…… 46

2.3 Recorded field margin characteristics for each plant community surveyed……48

2.4 The mean species richness and the number of species recorded in margin surveys, over the two years of sampling at the farm…… 50

2.5 The contribution of the first three CCA axes to explaining field margin plant community composition, in 2015 and 2016……51

2.6 The contribution of the first three CCA axes to explaining field margin plant community composition with margin width and quadrat position……56

2.7 The results of a two-way ANOVA testing the effects of adjacent land use, year, and an interaction effect, on margin plant species richness…… 56

2.8 The contribution of the first three CCA axes to explaining field margin plant community composition with adjacent land use and quadrat position……..58

3.1 The number of field margins and plant communities (quadrats) surveyed at each farm……67

3.2 The 12 margin characteristics surveyed, associated with each plant community sampled……..70

3.3 The results of four mantel correlation tests, between plant community dissimilarity (Bray-Curtis dissimilarity index) and geographic distance (km) between sample sites within each farm…….. 75

3.4 The contribution of the first three CCA axes to the full CCA…….. 75

3.5 The contribution of the first three CCA axes to the simplified CCA…….. 76

4.1 The number of field margins surveyed, associated with each adjacent land use and margin aspect…… 85

4.2 The recorded field margin structure characteristics with details of survey method…… 86

4.3 The mean abundance, species richness, and overall abundance of butterfly species observed, over three adjacent land use types in 288 field margin surveys…….. 89

4.4 The contribution of the first three CCA axes to explaining variation in butterfly community composition…….. 92

4.5 A linear model to show the correlations between five margin structure characteristics and butterfly species richness…….. 92

4.6 A quadratic model to describe the relationship between butterfly species richness and herbaceous vegetation height…….. 94

4.7 The significance of associations observed between presence of butterfly species and presence of larval or adult food plant species…….. 95

4.8 Contingency tables showing the frequency of field margins with primary food plant species presence or absence, and butterfly species presence or absence…….. 96

5.1 The factors reported to affect plant species records…….103

5.2 A summary of how factors commonly reported to affect plant records were accounted for or included in the design of this study…….106

5.3 A summary of the field margin surveys undertaken…….106

5.4 A summary of the three survey methods used in this study to survey field margin plant diversity (quadrats, 30 m walking transect, 100 m walking transect)…….107

5.5 The mean plant species richness per field margin recorded with three different survey methods…….112

5.6 The mean number of species identified by volunteer surveyors and an experienced surveyor, via three survey methods, across the same three field margins…….112

5.7 Plant species more likely to be identified by quadrats or 30 m transect surveys per field margin, grouped by family…….. 115

List of appendices

Appendix 1
Supplementary methods and results for Chapter 2.

Appendix 2
Supplementary methods and results for Chapter 3.

Appendix 3
Supplementary methods and results for Chapter 4.

Appendix 4
Supplementary methods for Chapter 5.

Appendix 5
Plant species lists from the surveys undertaken in Chapters 2, 3, 4, and 5.

Abstract

Biodiversity is severely threatened by human activity, with one of the greatest threats coming from agriculture. To reduce the impacts of agriculture on biodiversity, one conservation strategy is to exclude strips of land with herbaceous vegetation from production, termed field margins. Conserving field margins provides a valuable habitat for plant and animal species, and is therefore predicted to boost biodiversity. However, despite being a widely implemented conservation strategy, regular monitoring of plant diversity in field margins is lacking, and the ecological impacts of field margin management are not well understood. This thesis aims to further our understanding of ecologically effective ways to monitor and manage field margin plant diversity, based on three years of fieldwork across four farms in Oxfordshire, England.

Based on this fieldwork, four main findings are presented. Firstly, I found that over two years of surveying only a limited amount of variation in plant community composition can be explained by margin-level characteristics. This suggests that margin-level management can only have a limited impact. Secondly, I observed little spatial variation in plant communities between different farms in the same county. This suggests that management recommendations for plant diversity in field margins can be generalised across farms within a region. Thirdly, I observed higher butterfly species richness in field margins with higher plant species richness and intermediate vegetation height. This suggests that management of plant height and diversity will have a positive effect on butterfly diversity. Finally, I found that assessing plant diversity using either transect or quadrat survey methods resulted in biases in the plant species recorded. This suggests that plant surveys in field margins should use both transects and quadrats, to reduce bias in plant species lists. Together, these findings provide ecological evidence to improve conservation efforts for farmland biodiversity, through monitoring and management of field margins.

Glossary

Agri-environment schemes: Payment schemes available to farmers and land managers, for looking after the natural environment on their farmland (Natural England, 2009).

Arable field margins: The herbeacous strip between a field boundary structure (e.g. hedgerow) and adjacent land use such as crop, grassland, woodland or road (Greaves & Marshall 1987). Arable field margins are part of agri-environmental schemes, and a Biodiversity Action Plan priority habitat.

Community composition: The species and relative abundance of each species in a community.

Hedgerows: A line of trees or shrubs, making a boundary, over 20 m long. Gaps in the boundary must be less than 20 m wide (JNCC, 2011). Hedgerows are part of agri-environmental schemes and a Biodiversity Action Plan priority habitat.

UK Biodiversity Action Plan priority habitat*:* Habitats identified as the most threatened and requiring conservation action. In 2007 there were 65 habitats. Whilst the UK has since developed the UK Post-2010 Biodiversity Framework*,* the tools developed in the UK Biodiversity Action Plan priority habitats and species framework are still used (JNCC, 2019c). Arable field margins and hedgerows are Biodiversity Action Plan priority habitats.

National Vegetation Classification: A classification and description of all the plant communities of Britain (Rodwell, 2006).

Plant structural diversity: Diversity in the macro-structure of plants. In the case of field margins, this may, for example, refer to diversity in herbaceous vegetation height.

Species diversity: The variety and abundance of species in a defined unit of study (Magurran, 2013). Species diversity may be described by an index, combining species richness and species abundance. It is also used to refer to any measure of diversity in a chosen assemblage, including species richness.

Species richness: The number of species in a chosen assemblage (Magurran, 2013).

Chapter 1: Introduction

1.1 A global and national problem

The United Nations Food and Agriculture Organisation has called for a 60% increase in world food production by 2050 (FAO, 2009). At the same time, biodiversity is severely threatened by human activity, including agriculture (Wilson 1989; Thompson and Jones 1999; Sala *et al.* 2000; Johnson *et al*., 2017; Tilman *et al.,* 2017).

Nearly 40% of land globally is committed to agriculture, with five million hectares of land converted to agriculture annually (FAOSTAT, 2015). In order to maximise global and local biodiversity, conservation within agroecosystems needs to be addressed. The idea of viewing agroecosystems as opportunities for conservation has been considered over the past decade, with ongoing debate over how best to conserve biodiversity in agricultural systems (Phalan *et al.*, 2011, 2016; Egan and Mortensen, 2012; Grau, Kuemmerle and Macchi, 2013; Phalan, Green and Balmford, 2014). To meet these demands for food production and conservation, it is essential to improve our understanding of the land management strategies that can benefit biodiversity in productive, agricultural landscapes.

Nationally, agriculture is an integral part of the UK landscape. UK agriculture has undergone notable changes in intensity and environmental impacts since the agricultural revolutions of the 17th and 18th centuries (Jones, 2016). The current state of UK agriculture has been shaped by an EU-based Common Agricultural Policy, since 1957 (EFRA committee, 2013). UK farming is responsible for a total income of £4,697 million, with agriculture contributing 0.51% to the national economy (figures for 2017–2018 (Defra, 2019a)). Whilst the economic contribution appears small, in 2017, farming accounted for an estimated 466,000 jobs in agriculture, and over 3.5 million jobs in the agri-food sector (NFU, 2017). The UK has 61% self-sufficiency in all foods, and 75% sufficiency in indigenous foods (House of Lords, 2017).

Agricultural land in the UK offers a significant opportunity for conservation; 72% of land is committed to agriculture, covering an area of nearly 17.5 million hectares (Defra, 2018a). The majority of England's National Parks are in upland areas (Defra, 2010) and so lowland farms must balance their role in conservation with their primary role of food production. The UK government has supported farming and conservation on the same land through the EU-led agri-environmental schemes, as part of the Common Agricultural Policy (Natural England, 2009).

Currently, there is significant opportunity for the UK to redevelop their agricultural policy. As a result of the UK having voted in favour of leaving the EU, once the UK has left, it will no longer be subject to the Common Agricultural Policy (Defra, 2018b). It has been recognised by UK government representatives that the Common Agricultural Policy was set up in a very different economic and political post-war climate to now. Leaving the EU may offer an opportunity to overhaul the outdated aspects of the Common Agricultural Policy (Gove, 2018).

Currently, the Common Agricultural Policy is administered individually by the devolved administrations of England, Scotland, Wales and Northern Ireland. In the event of BREXIT, each country will be affected differently (Miller, 2015), and so the government is considering each devolved administration as an independent stakeholder (Defra, 2018b; Downing, Coe and Uberoi, 2018). England therefore has the opportunity to develop their own ecologically beneficial agri-environmental scheme, as part of a new agricultural policy.

One way in which conservation on agricultural land in the UK is being addressed is through the increase of arable field margins under agri-environmental scheme management (Natural England, 2009). Arable field margins and hedgerows are an important part of England's current conservation strategy in lowland farms, having been identified as the only Biodiversity Action Plan habitats (areas of conservation concern) in arable farmland (JNCC, 2019c). With an opportunity to develop new

agri-environmental policy, scientific studies can contribute towards understanding the ecological role and impact of management on field margins within the agricultural landscape.

To provide the context for the work presented in this thesis, a summary of the role of field margins in conservation on English lowland farms is presented here. Firstly, field margins are defined and their ecological and policy relationship with hedgerows are addressed. Then the value of field margins in terms of biodiversity conservation and other ecosystem services is discussed. The environmental targets that field margins address and the specific elements of agri-environmental policy relating to field margins and hedgerows are next outlined. Then, the progress towards environmental targets in field margins are discussed. Measures of diversity which can be used to report on changes in field margin diversity are then summarised. Finally, the ecological theory which may be used to explain differences in the plant composition of field margins is discussed.

1.2 Arable field margins and hedgerows

Biodiversity Action Plan habitats are those identified by Defra as semi-natural habitats under the greatest threat, and requiring conservation action (JNCC, 2016). Two habitats in arable farmland have been identified as UK Biodiversity Action Plan priority habitats: arable field margins, and hedgerows (JNCC, 2019c). Between 1992 and 2012, UK conservation priorities were guided by the UK's Biodiversity Action Plan, which highlighted target species and habitats for conservation (JNCC, 2018). The post-2012 framework for conservation in agricultural land has been built off the Biodiversity Action Plan framework (JNCC, 2019b). In considering opportunities for changes in agri-environmental scheme policy, a focus on arable field margins is therefore critical to ensure areas of greatest conservation concern are managed.

There are several definitions of field margins used in conservation policy and the scientific literature. Under the UK Biodiversity Action Plan framework, arable field margins are defined as 'herbaceous strips or blocks around arable fields that are managed specifically to provide benefits for wildlife' (JNCC, 2008). They make up the herbaceous strips, often at the outer edge of a crop field, closest to the field boundary (Figure 1.1). Arable field margins are often found next to the field boundary, which may be marked out by a hedgerow. In UK policy, the Biodiversity Action Plan definition states that two metres from the middle of the hedgerow (or any other living boundary, such as a line of trees) is considered to be part of the living boundary habitat (not the arable field margin). Beyond the two metres, the herbaceous strip between the crop field and living boundary habitat is defined as the arable field margin (JNCC, 2008). This limit was decided to provide an 'arbitrary boundary to divide hedgerows from adjacent features such as field margins' (Biodiversity Reporting and Information Group to the UK Standing Committee, 2007, p. 155).

Ecologically, definitions which consider the entire width of herbaceous vegetation as a field margin are more useful, as species are not limited by the two-metre-defined width of the hedgerow boundary structure. The entire width of the herbaceous strip may act as a unit of habitat. Greaves & Marshall (1987) define a hedgerow as 'the boundary' and the herbaceous strip and farm tracks adjacent to the boundary as a 'boundary strip'. Other definitions of field margins and hedgerows use the terms interchangeably. Dowdeswell (1987) defines a hedgerow as both the herbaceous vegetation strip and hedge. Hackett & Lawrence (2014) describe field margins as the area of land at the connection between arable crops and field boundary structures (such as other crops, hedgerows, woodlands).

This thesis addresses field margins from an ecological view point, and so field margins here refer to the herbaceous strip between a field boundary structure (e.g. hedgerow) and adjacent land use (*sensu* Greaves and Marshall 1987, Figure 1.2). Whilst field margins and hedgerows are often linked, both ecologically and in terms of policy, the ecological principles which govern the woody structure of a hedgerow are likely to be different to those which govern the herbaceous ground species in

margins. Hedgerows are therefore considered in terms of their relationship with field margins, and how, as adjacent features, hedgerows may affect field margins.

A



B



Figure 1.1 Photos of field margins from farms surveyed in this thesis. A) Shows a field margin between a crop and a hedgerow at Farm A, the main study farm in this thesis. B) Shows a field margin between a crop and a hedgerow at Farm B. Credit: Claudia Havranek.

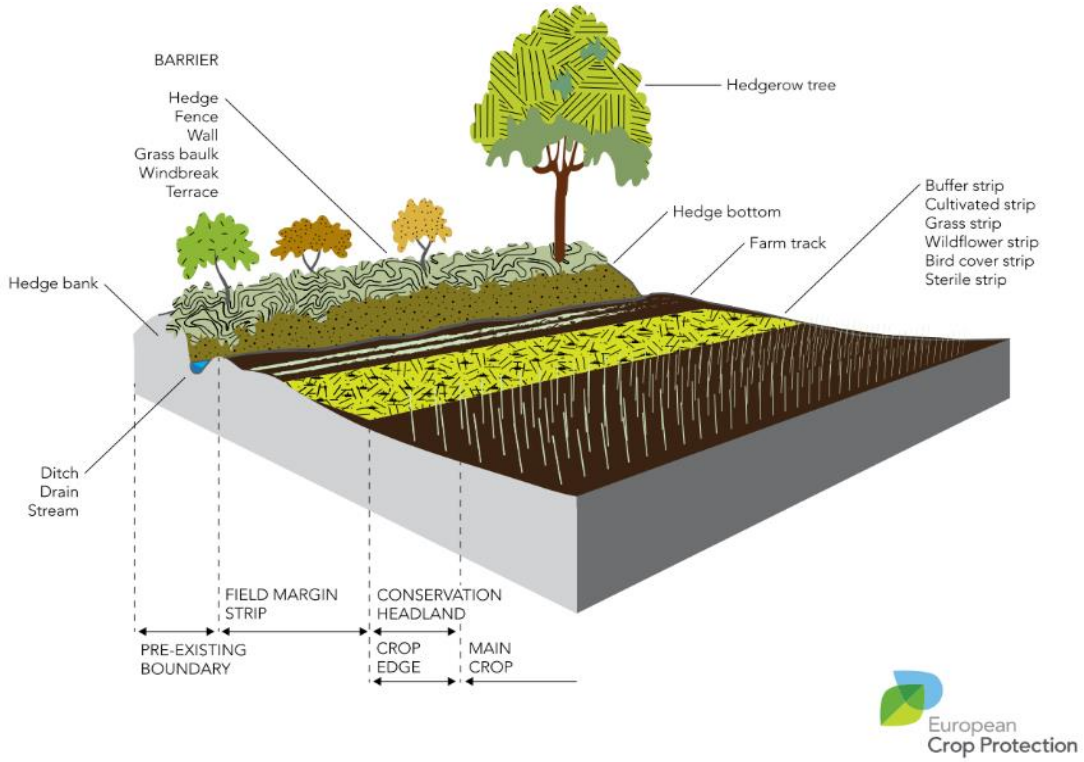
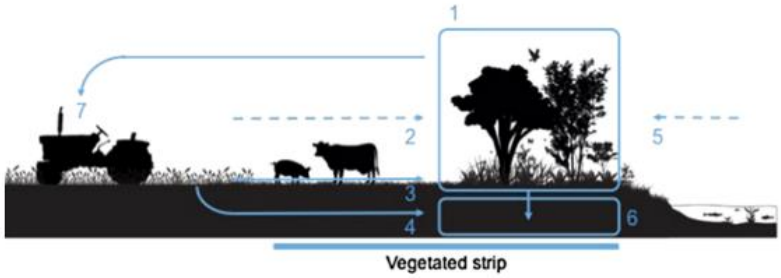


Figure 1.2 The principal components of an arable field margin. From Hackett and Lawrence, 2014 p. 7, after Greaves and Marshall, 1987; Marshall and Moonen, 2002.

1.2.1 Why are field margins and hedgerows valued?

Field margins and hedgerows are ubiquitous in English lowland agriculture, and are considered part of the cultural landscape. Whilst other countries across Europe may have some margins and hedgerows, the extent of these features across the UK landscape give them a value as part of the cultural heritage of the UK agricultural landscape (Baudry, Bunce and Burel, 2000; Borin *et al.*, 2010). Field margins and hedgerows are valued both for the individual species they support, as well as for the ecosystem services they provide (Figure 1.3).

The ecosystem services provided by field margins can be beneficial to agricultural production and to the wider landscape (Hackett and Lawrence, 2014; Mitchell *et al.*, 2015; Haddaway *et al.*, 2018). Services which support agricultural production include pollination services and pest control. By offering a suitable habitat for invertebrates, field margins may increase levels of pollination and pest control in crop fields (Hackett and Lawrence, 2014). Other ecosystem services offered may reduce the environmental impact of intensive agriculture on the wider landscape. Together, field margins and hedgerows have been shown to reduce runoff of fertilisers (Borin *et al.*, 2010), spray drift of pesticides (Reichenberger *et al.*, 2007; Lazzaro, Otto and Zanin, 2008), and soil erosion (Hackett and Lawrence, 2014).



Pathways to impact:

1. Presence of habitat
2. Interception of chemical drift
3. Overland flow/surface unoff
4. Subterranean flow (sublateral flow, artificial drainflow, shallow groundwater flow)
5. Interception of wind
6. Interaction with the soil
7. Agronomic

Figure 1.3 Pathways to impact for field margins. By Neal Haddaway, from Haddaway et al., (2018), p. 2.

Field margins are also valued as habitats for rare species. Field margins and hedgerows provide a habitat for species to forage, nest and shelter (Verboom and Huitema 1997; Marshall, West, and Kleijn 2006; Vickery, Feber, and Fuller 2009). Arable field margins are particularly valued if they host rare arable plant species (JNCC, 2008), such as red hemp-nettle *Galeopsis ladanum var. angustifolia* (Ehrh. ex Hoffman.) Gaud and corn chamomile *Anthemis arvensis* L. (Plantlife, 2014a). They are also valued for hosting breeding populations of crop-nesting birds such as corn bunting *Emberiza calandra* L. or are used as forage for specific bumblebee species (JNCC, 2008).

The role of field margins in supporting biodiversity in agricultural land extends beyond the land they cover, by connecting up patches of natural land. To ensure survival of species at a landscape scale, margins and hedgerows contribute by acting as both a refuge themselves and connecting natural patches together, such as woodlands (Barr *et al.* 2005; Hackett and Lawrence 2014). Hedgerows and margins connect refuges for mobile species, supporting population dynamics and colonisation patterns (Burel and Baudry 1990; Barr and Gillespie 2000; Baudry, Bunce, and Burel 2000; Meek *et al.* 2002).

1.2.2 Environmental targets for field margins and hedgerows

Whilst the future of agri-environmental schemes is uncertain due to the UK having voted to leave the EU, the environmental targets which the UK has committed to extend beyond EU membership (Defra, 2018c). Agri-environment schemes are used to guide the management of field margins, to ensure they continue to offer ecosystem services, especially hosting rare species (Defra, 2018c). These schemes can be used to address two current environmental targets (the Water Directive and the UK Greenhouse Gas Emissions targets) and two current conservation targets (the Aichi Biodiversity targets and the Global Strategy for Plant Conservation targets).

The Water Framework Directive was developed to protect the ecological health of rivers, lakes, estuaries, coastal and groundwater (Defra, 2014a; Water Environment (Water Framework Directive) (England and Wales) Regulations 2017). With some of the reductions in water quality attributed to agricultural practices (Jones, Silcock and Uetake, 2015), one measure of agri-environmental scheme success is progress towards improved water quality. Field margins and hedgerows can contribute towards this target by reducing spray drift and leaching (Reichenberger *et al.*, 2007; Lazzaro, Otto and Zanin, 2008). However, the extent to which field margins and hedgerows contribute towards this target is difficult to quantify, and the potential for impact is largely dictated by the location of farms, in high priority Catchment Sensitive Areas (Defra *et al.*, 2019).

Greenhouse gas emissions targets provide another potential marker of agri-environmental scheme success. Agriculture is a major producer of greenhouse gases, and UK and EU papers cite agriculture as a target area to reduce greenhouse gas emissions (Defra, 2011a). Between 2014 and 2020, €104 bn (25%) of the Common Agricultural Policy allocation is estimated to be related to climate (European Commission, no date), to mitigate and adapt to climate change, caused in a large part by agriculture-related greenhouse gas emissions (European Commission, 2015).

Biodiversity conservation targets and agri-environmental schemes are strongly linked. The Aichi Biodiversity targets form part of the Convention on Biological Diversity, with the aim of creating an international framework to protect biodiversity (CBD, 2016). Currently, the UK is aiming to meet the biodiversity targets agreed as part of the Aichi Biodiversity goals (to be met by 2020) (Defra, 2018d). The most relevant targets for agri-environmental scheme management of field margins are Target 3, Target 7 and Target 8.

Target 3 works towards the elimination of incentives which are harmful for biodiversity (CBD Secretariat, 2010a). For agriculture, progress towards this target relates to the decoupling of agricultural support from production in 2003, and the introduction of greening measures in 2013 (JNCC, 2019a). Progress has been reported towards this target, but at an insufficient rate, in part due to a recent decrease in the area of land under agri-environmental scheme agreements, and declines in farmland biodiversity (JNCC, 2019a).

The aim of Target 7 is that 'By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity' (CBD Secretariat, 2010a). Progress towards this target has also been reported to be at an insufficient rate, due to the recent declines in the area of land managed under agri-environmental schemes, as well as declines in species diversity, especially farmland birds (JNCC, 2019a).

The aim of Target 8 is that 'By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity' (CBD Secretariat, 2010a). Run-off from high input agricultural land can make its way into natural land and waterways, and damage habitats. The Water Framework Directive was developed to provide a legal framework in which to address this problem (Defra, 2014a; Water Environment (Water Framework Directive) (England and Wales) Regulations 2017). As with the other targets, progress has been reported, but at an insufficient rate (JNCC, 2019a).

Over the same ten-year time frame as the Aichi Biodiversity targets, the Global Strategy for Plant Conservation aims to understand, conserve and sustainably use the world's plant diversity (CBD Secretariat, 2011). Agri-environmental schemes in field margins and hedgerows may be used to work towards two of the 16 Global Strategy for Plant Conservation targets. Target 6 aims for at least 15% of each ecological region or vegetation type to be secured through effective management or restoration (CBD Secretariat, 2010b). Target 7 aims for at least 75% of known threatened plant species to be conserved in situ(CBD Secretariat, 2010b). With these targets in mind, agri-environmental schemes are part of England's response to addressing these challenges.

Mid-term progress towards Targets 6 and 7 of the Global Strategy for Plant Conservation in the UK has been assessed by Plantlife, who report limited progress (Plantlife, 2014b). These assessments have been made based on area of land in agri-environmental schemes (Defra, 2018d). Suggested next steps to make progress towards Target 6 include ensuring there are 'more fallow margins on arable land' (Plantlife, 2014b). The recommendations made by Plantlife for Target 7 suggest a focus on ensuring that threatened species are properly reflected in legislation, with the corn marigold *Glebionis segetum* (L.) Fourr. used as an example of one such species. Overall, progress towards the Global Strategy for Plant Conservation targets is unfavourable with limited ecological progress from agri-environmental schemes, especially of Entry-Level agri-environmental schemes (Plantlife, 2014b).

The impacts of field margins as habitats for the conservation of plant diversity, are focussed on in this thesis.

1.2.3 Agri-environmental schemes for field margins

Traditionally, field margins and hedgerows have offered popular agri-environmental scheme options for farmers. However, over the past five years the total land under agri-environmental schemes has decreased (Defra, 2018d). Current policy aims to maximise areas of margins and hedgerows in agricultural land, with payments for planting and managing field margins and hedgerows (Defra, 2019b).

The agri-environmental scheme options for field margins (as an ecological habitat unit) are often linked or combined with hedgerow policy options, due to cross compliance (JNCC, 2008). Outlining the offerings for field margins is therefore done here alongside the offerings of hedgerows. An English Nature report in 2009 on the effectiveness of agri-environmental schemes in England reported that 41% of hedgerows are managed under agri-environmental scheme, with 6% restored in the last 10 years (Natural England, 2009). In 2007, there were approximately 477,000 km of hedgerows in Great Britain (Carey *et al.*, 2008), and this figure is likely to now be greater, with policy focussing on increasing hedgerows. Due to the requirement of a two-metre buffer zone around hedgerows (HGCA, 2005), these figures may also reflect conservation trends of field margins too. Between 1999 and 2019, £228 million has been paid out as part of agri-environmental scheme options relating to field margins and hedgerows (Natural England, 2019).

For field margins and hedgerows to be part of agri-environmental schemes in England, there are a variety of management requirements. The main agri-environmental scheme options relating to field margins and hedgerows are outlined below.

Many farms are currently committed to agri-environmental schemes called the Environmental Stewardship Scheme, which ran from 2005 (Natural England, 2009). From 2020 onwards, a new agri-environmental scheme called the Countryside Stewardship Scheme (alongside the Basic Payment Scheme) is offered, and will include mid tier, higher tier, wildlife offers and Capital Grants (including the Hedgerows and Boundaries Grant) (Defra, 2019b; Defra *et al.,* 2019). The new Basic Payment Scheme is equivalent to the old Entry Level Scheme (a lower payment level), and the new Countryside Stewardship Scheme is equivalent to the old Higher-Level Scheme (a higher payment level). A summary of the agri-environmental schemes options, relevant to margins and hedgerows, offered under the new Countryside Stewardship Scheme and Basic Payment Scheme is given in Table 1.1.

Agri-environmental Scheme			
Basic Payment Scheme	**Countryside Stewardship Scheme**		
Ecological Focus Areas: at least 5% of total eligible arable land must be an Ecological Focus Area to be eligible for the Basic Payment Scheme. Includes the following options for field margins: Buffer strips or field margins Adjacent hedges or trees in a line AB1 Nectar flower mix planting in margins AB8 Flower rich margins and plots AB16 Autumn sown bumblebird mix SW1 4-6 m buffer strip on cultivated land	Mid Tier: Five-year agreements for environmental benefits in the wider countryside. Aimed to manage land for wildlife, including providing nectar and pollen for insect pollinators and nesting and winter food for farmland birds Options include: AB1 Nectar flower mix planting in margins AB8 Flower rich margins and plots BE3 Management of hedgerows SP9 Threatened species supplement (only for corn bunting and brown hair streak butterfly) SW1 4-6m buffer strip on cultivated land BN5 Hedgerow Laying BN6 Hedgerow Coppicing BN7 Hedgerow Gapping-up BN8 Hedgerow supplement – casting up BN10 Hedgerow Supplement – Top Binding and Staking BN11 Planting new hedges If paid under the Basic Payment Scheme, ineligible for Mid Tier payments.	Wildlife Offers – Arable Offer: Five-year agreements, with targeted options aimed to suit specific farming practices, designed to be simpler to apply for. Options include: AB1 minimum 1% or 1 ha per 100 ha of farmed land Nectar flower mix. AB8 minimum 1% or 1 ha per 100 ha of farmed land Flower-rich margins and plots. minimum 2% or 2 ha per 100 ha of farmed land Winter bird mix AB11 Cultivated areas for arable plants SW1 4-6-m buffer strip on cultivated land	Hedgerow and boundaries grant: Short-term (two-year) capital grants to restore existing boundaries and bring environmental and landscape benefits. Includes hedgerow gapping, coppicing and laying.

Table 1.1 A summary of English agri-environmental scheme options relevant to field margins and hedgerows offered in 2019. Information from (Defra 2019b, 2019c, 2019d, 2019e; Rural Payments Agency 2019).

Whilst the Environmental Stewardship Schemes will no longer be offered, analysis of the impacts of the 15-year-long Environmental Stewardship Schemes on biodiversity in field margins is important, to see what can be learnt about the efficacy of these schemes. Whilst the name of the scheme is changing, many of the policy offerings relating to field margins as part of the Environmental Stewardship Schemes will continue into the Countryside Stewardship Schemes, but with a simplified application process (Defra *et al.,* 2019).

The current Environmental Stewardship Schemes (offered to 2020) are divided into two categories: Entry-Level Stewardship and Higher-Level Stewardship. There are many options available relating to arable field margins, from Entry-Level schemes where land is simply left out of cultivation, to Higher-Level options with specific management requirements, such as sowing floristically enhanced grass margins. The Environmental Stewardship Schemes offered a complex and varied range of management requirements, relating to margins and hedgerows (summarised in Figure 1.4). Cross-compliance of management strategies of hedgerows and field margins can be required as part of agri-environmental schemes (HGCA, 2005).

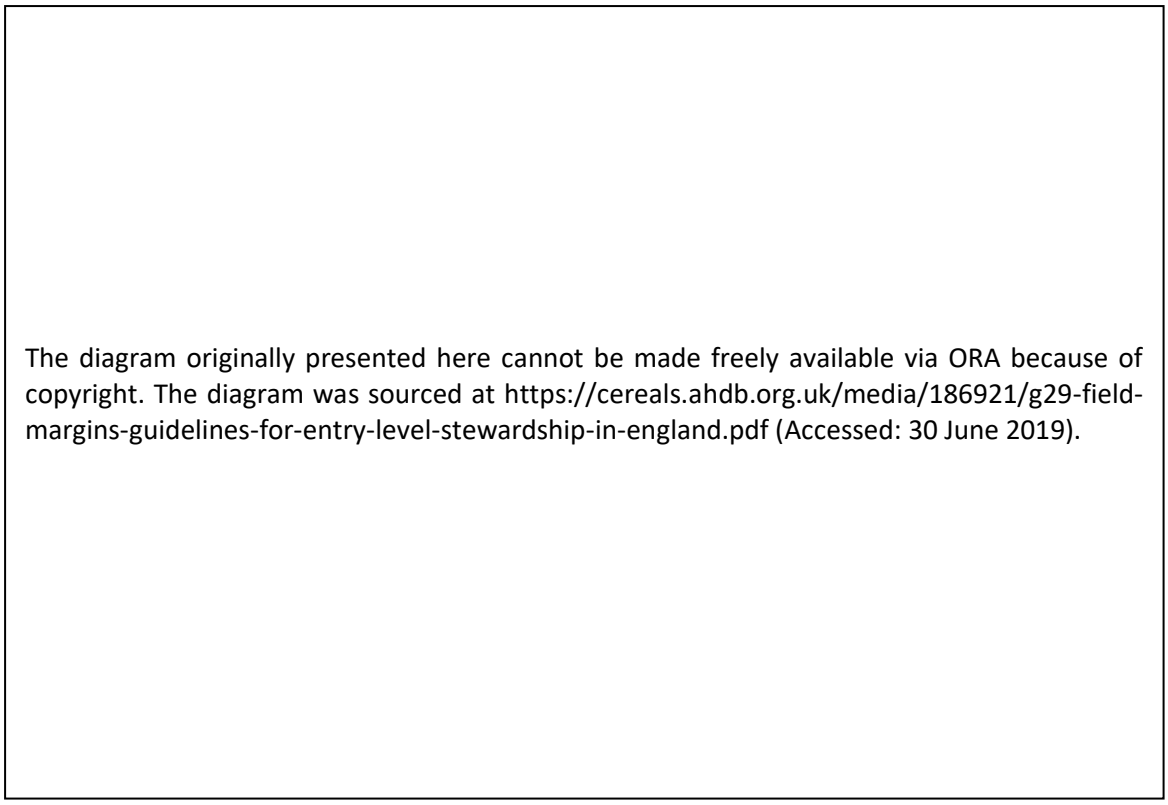


Figure 1.4 Entry-Level Stewardship options available for margin management in 2005 (adapted from HGCA 2005).

Environmental Stewardship Schemes are normally conducted on a 2-10-year basis. Most schemes relating to margins pay for strips 4-6 m wide, to be cut by a certain date, and managed according to specific requirements (HGCA, 2005). Hedgerow grants require a two-metre-wide protection zone from the centre of the hedge, and Entry-Level schemes pay for enhanced hedgerow management, such as reduced cutting frequency to improve winter berry forage, and restrictions on cutting dates to protect nesting birds (Natural England, 2009). This requirement for a two-metre protection zone links hedgerows and margins in current agri-environmental scheme policy, as hedgerows of less than four metres wide will include a herbaceous strip as part of the hedgerow conservation unit (HGCA, 2005). Payments are also made for hedgerow planting and restoration, including coppicing, laying and gapping-up, in most Higher-Level agreements (Natural England, 2009).

Payments for margins and hedgerows are based on area. Hedgerows are paid based on unit length, with one metre of length of hedgerow worth 10 square-metres of area (Defra, 2014b). Margin payments are made based on the type of margin available: margins paid as fallow land are paid based on overall area, whilst margins paid as buffer strips are paid per metre length (Rural payments agency, 2017).

In 2006, 22% of UK hedgerows were considered to be of 'favourable condition'. The management prescriptions associated with hedgerow management are to encourage hedgerows to be classified as of 'favourable condition' (these conditions can be found listed in the National Hedgerow Survey Handbook, pp.132-134 (Defra, 2007)). Of these factors of hedgerows in 'favourable conditions', two relate to adjacent arable field margins: a requirement of undisturbed (uncultivated) ground at least two metres wide; a requirement of perennial herbaceous vegetation cover either side of the hedgerow of one metre wide (Defra, 2007).

The management of margins and hedgerows is linked, due to both their proximity in farm landscapes, and policy requirements for agri-environmental scheme.

1.3 Monitoring plant diversity in field margins

Monitoring changes in plant diversity is one way to assess the ecological success of agri-environmental schemes. Not only is plant conservation a key international target, highlighted through the Global Strategy for Plant Conservation (CBD Secretariat, 2010b), but their role as primary producers means changes in plant diversity will affect the diversity of other species in field margins. Indeed, it has even been suggested that plants can indicate changes in land use intensity, landscape structure and habitat characteristics in agricultural land (Aavik and Liira, 2009) and can be used as an indicator of local organism biodiversity in agricultural land (Duelli and Obrist, 1998).

In this thesis, the evaluation of conservation success in field margins through monitoring plant diversity is explored. In this section, to understand the role of plant surveys in reporting conservation progress, indicator taxa for biodiversity in agricultural land currently used in UK policy are explored, and specific plant species which can be used as indicators are discussed. Finally, current plant monitoring schemes and the use of citizen science for plant surveys on agricultural land are considered.

1.3.1 Indicator taxa: birds, bats, butterflies and plants

At an EU level, there are 15 environmental Common Agricultural Policy context indicators used to evaluate the Common Agricultural Policy. Only one addresses specific taxa: the farmland bird index (European Commission, 2018). The progress of farmland birds has been tracked over the past 40 years (Defra, 2015a) and widely evaluated (Donal, Green and Heath, 2001; Bradbury *et al.*, 2004; Billeter *et al.*, 2008; Defra, 2015b; European Commission, 2018). The farmland bird index is used as an indicator of overall farmland biodiversity trends (European Commission, 2018). Farmland birds are used due to their widespread range, mobility and specialist habitat requirements (Gregory, Noble and Custance, 2004). However, extrapolations from indicator species should be approached with caution, since their ecological representativeness for other taxa may be limited (Lawton and Gaston, 2001; Thomas *et al.*, 2004).

At a national level, the UK utilises four indicators as farmland biodiversity indicators: farmland birds; insects of the wider countryside (butterflies); mammals of the wider countryside (bats); and until 2007, plant diversity (Defra, 2018d). Trends of change in the three assessed indicators are shown in Table 1.2.

Indicator / measure(s)		Long-term change[2]	Short-term change[3]
C4. Status of UK priority species	C4a. Relative abundance	⊗ 1970–2015	⊗ 2010–2015
	C4b. Distribution	≈ 1970–2016	≈ 2011–2016
C5. Birds of the wider countryside and at sea	C5a. Farmland birds	⊗ 1970–2015	⊗ 2010–2015
	C5b. Woodland birds	⊗ 1970–2015	≈ 2010–2015
	C5c. Wetland birds	≈ 1975–2015	≈ 2010–2015
	C5d. Seabirds	Not Assessed	Not Assessed
	C5e. Wintering waterbirds	✓ 1975/76–2014/15	⊗ 2009/10–2014/15
C6. Insects of the wider countryside	C6a. Semi-natural habitat specialists	⊗ 1976–2017	≈ 2012–2017
	C6b. Species of the wider countryside	⊗ 1976–2017	≈ 2012–2017
C7. Plants of the wider countryside		Under development	
C8. Mammals of the wider countryside (bats)		✓ 1999–2016	✓ 2011–2016

Key to changes in indicator: ⊗ Decreased; ✓ Increased; ≈ No change

[2] Long-term – an assessment of change since the earliest date for which data are available, although if the data run is for less than ten years a long-term assessment is not made.
[3] Short-term – an assessment of change over the latest five years. For a very few indicators the short-term change is over a longer time-period as a result of the frequency of update of the data upon which the indicators are based.

Table 1.2 The UK biodiversity indicator assessment. Assessment of change in abundance and diversity of species in the wider countryside (farmland) from Defra (2018d, p. 5).

Beyond government reports, the success of agri-environmental schemes is reported in the scientific literature for similar taxa. Across Europe, the success of agri-environmental schemes for species beyond farmland birds has reported mixed results (Peach *et al.*, 2001; Carey *et al.*, 2003; Bradbury *et al.*, 2004; Carvell *et al.*, 2006; Kleijn *et al.*, 2006). Benefits have been shown for specific taxa, such as birds (Peach *et al.*, 2001; Bradbury *et al.*, 2004), with results being conditional on factors such as scale (Bradbury *et al.*, 2004). Failures of agri-environmental schemes have been suggested for uncommon species or for all species (Kleijn *et al.* 2001).

Assessing changes in plant diversity on farmland, alongside birds, bats and butterflies, may tell us different information about changes in biodiversity and habitat quality in farmland.

1.3.2 Indicator plant species

Monitoring changes in plant diversity can be done through surveys of all plant species in an area, or through surveying a limited group of species, as indicators of overall plant trends. Indicator species may be indicative of the state of the environment, environmental change or biodiversity (Lawton and Gaston, 2001) and be quicker and easier to survey.

Most plant species found in agricultural land can be described as agrotolerant species, able to tolerate agricultural disturbances, as opposed to 'nature value' species, such as habitat specialists and rare arable weeds (Aavik and Liira, 2009).

The National Hedgerow Survey protocol records the presence of plant species indicative of nutrient enrichment in field margins (Defra, 2007). As part of the survey, the percentages of nettles *Urtica spp.*, cleavers *Galium aparine* L. and docks *Rumex spp.* in arable margins adjacent to hedgerows is estimated to the nearest 5%. Presence of 20% or more of these nutrient enrichment indicator species indicates nutrient enrichment in the soil (Defra, 2007), which may be due to agricultural practice in adjacent fields.

The National Plant Monitoring Scheme also involves recording indicator species, with a suite of 30 species per habitat type being surveyed to indicate trends in plant diversity (National Plant Monitoring Scheme, 2015). The National Plant Monitoring Scheme identified 30 key indicator species for arable field margins: 11 positive wildflower species, 14 positive indicator species, four negative wildflower species and one negative indicator species (Pescott *et al.* 2019). In this scheme, indicator species were selected by experts based on their frequency in other habitats and expected frequency in arable field margins.

1.3.3 Plant monitoring schemes

The UK Biodiversity Indicators are published annually to report on progress towards the Aichi Biodiversity targets, with the most recent report from 2018 (Defra, 2018d). Six indicators, as part of the UK Biodiversity Indicator report, are specifically relevant to agri-environmental schemes in field margins: B1a 'Area of land in agri-environmental schemes'; C5a 'Farmland birds'; C6 'Insects of the wider countryside (butterflies)'; C7 'Plants of the wider countryside'; C8 'Mammals of the wider countryside (bats)'; D1c 'Status of pollinating insects' (Defra, 2018b). Five of these indicators are based on monitoring changes in species diversity of certain taxa, to establish changes in biodiversity. The sixth indicator, reporting on the area of land in agri-environmental schemes, reports on one aspect of agri-environmental scheme success. This target (B1a) is not explored in this thesis, as progress towards this target is driven by social, rather than ecological, aspects of agri-environmental schemes.

Whilst plants are included in the UK Biodiversity Indictor framework, trends in plant diversity are not currently reported under C7 'Plants of the wider countryside'. Data for this used to be collected as part of the Countryside Survey, however the last survey took place in 2007, and no new survey has taken place since (Defra, 2018d). This lack of data provides a challenge, as evaluation of progress towards the Global Strategy for Plant Conservation is reported purely on area of land under agri-environmental schemes (Plantlife, 2014b; Defra, 2018d), with no reflection of the state of the land.

Given the lack of plant data currently available through the UK Biodiversity Indicator framework via the Countryside Survey, other sources of plant data are now being considered. It has been suggested that a plant index based on data from the new, volunteer based National Plant Monitoring Scheme will be developed to fill this gap (Defra, 2018d).

In England, there are five main sources of plant survey data, which may contain plant records from arable field margins. The five sources of plant data are: BSBI distributions (Botanical Society of Britain and Ireland, 2017); Countryside Survey (Maskell *et al.,* 2008); National Hedgerow

Monitoring (Defra, 2007); National Plant Monitoring Scheme (National Plant Monitoring Scheme, 2018); and the Rare Arable Flower app (CEH, 2016). A description of these five plant survey schemes and their survey methods, which have occurred across England, are described in Table 1.3. These schemes are conducted over different scales, using different survey methods and different surveyor work forces. Due to these differences in the survey methods used to survey plant diversity, different biases may occur in each data set (Kirby *et al.* 1986; Rich and Woodruff 1992; Yoccoz, Nichols, and Boulinier 2001; Buckland *et al.* 2007).

Monitoring the impacts of agri-environmental schemes on biodiversity, to record progress towards international biodiversity targets, relies on monitoring the correct taxa, at appropriate intervals, and with an appropriate workforce.

Survey name	Years run	Survey method	Survey area	Survey workforce
BSBI distribution maps (Botanical Society of Britain and Ireland, 2017)	Constant data collection, data is classed into: pre-1929, 1930-1969, 1970-1986, 1987-1999, 2000-2009, 2010-2019.	Volunteers report current species presence within 2 km x 2 km square, online, via the iRecord app, email, or via 'Mapmate'. Historical sources include herbarium digitalisation projects.	2 km x 2 km tetrad squares, covering the whole of Britain	35 million biological records in the database (April 2016), reported by volunteers. Only volunteer names are recorded. Records are curated and corrected by BSBI county recorders and taxon referees. Photos can be submitted to confirm identification.
Countryside Survey (Maskell *et al.*, 2008)	1978, 1990, 1998, 2007	Plant species presence and abundance was collected in up to 29 plots per 1 km square surveyed. Plot size varied between 2 x 2 m for field margins (up to 15 per square) to 10 x 1 m alongside hedgerows (2 per square). Up to two 2 m x 2 m plots per square, and up to three per field (limited by margin width). Quadrats placed 3 m from centre of hedge, and at 6 m intervals thereon.	256 - 289 1 km squares in England, selected by random stratified sample. The same squares were resurveyed each year.	Trained surveyors who had undergone an intensive four-week training programme. Quality assurance checks were performed by experts at some survey squares. 64 surveyors were split into 16 teams in 2007.
National Hedgerow Monitoring (Defra, 2007)	Constant data collection	Optional ground flora surveys. Ground flora species per 30 m hedgerow section recorded. Species presence and cover is desirable to record, but the protocol acknowledges that this requires good identification skills. % cover to the nearest 5% is recorded, or 1% if less than 5%. Two 2 m x 1 m quadrats recorded per 30 m section, with the 2 m axis running down the line of the hedgerow.	Nationwide.	Volunteers, no training offered. Field supervision by experienced surveyors recommended.
National Plant Monitoring Scheme (National Plant Monitoring Scheme, 2018)	Annually; 2015-present	Three 5 m x 5 m quadrats and two 25 m x 1 m linear plot surveys for each 1 km square, with two visits per season. Linear plots follow the side of the arable field. In arable field margins, linear plots extend 1 m from the edge of cultivated area in the crop. Three survey levels (Wildflower level, Indicator level and Inventory level). Either all species recorded or a suite of up to 30 indicator species, listed for each habitat type. Abundances estimated on the DOMIN scale.	Nationwide, across 1 km squares.	Volunteers, offered a six-hour training course. Data verification of species beyond their known range and randomly by experts for 39% of all records.
Rare Arable Flower App, Biological Records Centre (CEH, 2016)	Constant data collection, 2016-present	Volunteers report the presence of rare arable flowers, via the Rare Arable Flower app. Data will then be used to build a map of distribution, trends and important sites, as part of iRecord.	Nationwide.	Currently contains 62 records submitted by volunteers. Records are reviewed and verified by an expert.

Table 1.3 A description of five nationwide plant monitoring schemes which may contain plant records from field margin surveys within their databases.

1.3.4 Citizen science for plant surveys

Defra has stated that by 2020 the National Plant Monitoring Scheme will have collected sufficient data to report on plant diversity as a UK Biodiversity Indicator (Defra, 2018d). The National Plant Monitoring Scheme is a citizen-science scheme which uses volunteers to collect data across a 1 km square, using quadrat and transect survey methods (National Plant Monitoring Scheme, 2018).

Using volunteer-based monitoring methods will allow plant data to be collected and reported on, where there are insufficient funds directed to conservation (Karp *et al.*, 2015). However, in using a large number of different surveyors, and using volunteers as opposed to a small number of experts (as in the Countryside Survey (CEH, no date)), the data sets generated are subject to different biases. In using volunteers rather than experts, species are at risk of being misidentified or overlooked (Ratnieks *et al.*, 2016). It is difficult to make generalisations about the quality of data collected as volunteers will be of varied experience and expertise.

Inter-observer differences in plant surveys have been recognised as a major factor in affecting the plant community composition and plant diversity recorded, across a variety of biomes (Goodfellow and Peterken, 1981; Kirby *et al.*, 1986; Rich and Woodruff, 1992; Prosser and Wallace, 2008; Ratnieks *et al.*, 2016). Whereas in the Countryside Survey, where surveys were performed by 64 surveyors (CEH, no date), the National Plant Monitoring Scheme relies on over 2000 volunteers to perform the surveys (Pescott 2015). Surveys which report on changes in plant diversity over time, especially where surveyors change between subsequent surveys, may be reporting on both real changes in plant diversity as well as changes due to inter-surveyor differences. Analysing and understanding the biases introduced into a data set from survey methods and the surveyor workforce allows the appropriate conclusion to be drawn from the data. An analysis of the biases of two years of the National Plant Monitoring Scheme has been conducted, which suggests that the greatest bias in species richness recorded in these surveys was in managed grassland habitats, especially those grazed or mown (Pescott *et al.* 2019). This suggests that plant records from National Plant Monitoring Scheme surveys in field margins (containing many grassland plants, and with mowing management) may be particularly biased.

Deciding on the most appropriate workforce for monitoring plant species diversity in field margins will be a result of multiple trade-offs. It is likely that with restrictions on funding, the government will have to utilise some manner of volunteer workforce in order to allow survey data to be gathered across England. However, this must be done with an appreciation for the biases in the data collected, based on surveyor differences.

1.4 Measures of diversity

Once surveys are complete, there are a range of ways to report plant survey data, for assessing change in levels of diversity and the quality of field margin habitats. Where plant species presence and abundance per unit area is recorded, plant diversity trends can be quantified by a variety of metrics. Metrics can be useful to compare field margins over different geographical areas or monitoring changes over time.

Whilst using a single measure to quantify diversity in a community is useful, different metrics will emphasise different aspects of diversity (Magurran, 2013) and so no single measure of biodiversity will fully summarise trends (Hill *et al.*, 2016). Species richness, species abundance and species diversity are measures of alpha diversity, the diversity in a site or habitat at a local scale (Whittaker, 1972).

In this thesis, species richness and community composition, as well as the identity of species (classified into families and CSR strategy) are compared. This combination of metrics allows both quantitative and qualitative comparisons of plant communities in field margins to be made.

1.4.1 Species diversity indices

Species richness is here defined as 'the number of species of a given taxon in the chosen assemblage' (Magurran, 2013). Species richness is the simplest measure of diversity and has been used in monitoring biodiversity in agricultural land in scientific studies (Duelli, 1997; Moonen and Marshall, 2001; Büchs, 2003). As the UK flora is well-documented, potential disputes over species identities or divisions are less frequent, and so using species richness as a measure of species diversity is less affected by these problems, compared to other flora (Magurran, 2013). One consideration when using species richness to compare diversity in different areas is that species richness levels will be highly dependent on sampling effort (Nilsson and Nilsson, 1985; Archaux *et al.*, 2006; Kéry *et al.*, 2006; Chen *et al.*, 2013; Iknayan *et al.*, 2014), which is often not reported.

In a community, the abundance of each species is unlikely to be equal. Species abundance is often expressed as a percentage or proportion, relative to other species in the community (Magurran, 2013). Species abundance distributions can be used to describe how niche space is divided in a community (Silvertown, 2004). Species abundance can also be used to identify where species are locally rare, which may be of conservation concern. Between communities, comparisons of species abundance will only be meaningful where species richness does not vary greatly between communities (Magurran, 2013).

In field margin surveys, understanding the evenness of species (measured through abundance) is useful where abundance is linked to specific species of interest, or if it is interpreted alongside species richness. Heterogeneity measures of species diversity combine species richness and species abundance (Magurran, 2013). Different species diversity indices emphasise either species richness or species abundance, and so different indices may be more appropriate depending on the research question (Magurran, 2013; Hill *et al*., 2016). High species diversity may result from a high number of different species, or high evenness. Low species diversity will occur where there are few species, possibly with high dominance of one or a few species. Simpson's diversity and Shannon's diversity are among the most common diversity indices which combine species richness and species abundance (Morris *et al.*, 2014). Understanding and identifying differences in species richness and species abundance can be used to predict changes in species diversity indices.

Species diversity can be affected by changes in species richness or species abundance or both. To understand what explains changes in species diversity, it may be necessary to understand changes in species richness and species abundance independently. Species diversity indices are not reported in this thesis, in favour of the simplest metrics of species diversity: species richness.

1.4.2 Plant community composition

Species richness, abundance and diversity indices do not provide information on species identities. Two field margins may have the same levels of species richness and species abundance, but different species present, resulting in different communities (Hill *et al.,* 2016). Changes in species classified into groups, or via community composition dissimilarity can be used to establish differences related to species identities.

Comparisons of plant diversity in arable field margins can be assessed qualitatively, considering species identities. This may be particularly important in biodiversity monitoring for conservation (Su *et al.*, 2004; Hill *et al.*, 2016). Habitat quality can be determined by the species identities; for example conservation targets for hedgerows, as part of the Biodiversity Action Plan, placed an emphasis on the composition of native woody plants in hedgerows (Defra, 2007). Species within a community can be classified as a marker of habitat quality. For example, the presence of species classified as nationally rare or Red List species have been used indicate higher quality habitats in agricultural land (Weibull and Ostman, 2003). Alternatively, species can be classified according to their traits, such as Grime's competitor-stress tolerator-ruderal (CSR) classification system (Grime, Hodgson and Hunt, 1988).

Community composition is the named species and relative abundance of each species sampled in a community. Quantitative comparisons can be made between field margin community compositions through dissimilarity matrices. Community composition can be visually plotted in multi-dimensional space, which can then be used to identify communities which are compositionally similar. This provides the basis for the ordination techniques used in this thesis.

Plant communities in Britain have been categorised into 286 communities under the British National Vegetation Classification (NVC) system (Rodwell, 2006). Field margins in lowland farming are likely to be have plant communities which can be characterised as mesotrophic grasslands, calcicolous grasslands or vegetation of open habitat community types (Rodwell, 1992, 2000). The National Plant Monitoring Scheme predicts that arable field margins should be mainly characterised by NVC open habitat communities OV1-11, 13-17 (National Plant Monitoring Scheme, no date). Details of open habitat communities are described in Rodwell (2000).

The distribution of plant communities within an area can be characterised as a mosaic, following an ecotone, or split into distinct groups (Rodwell, 2006). The linear structure of field margins means that different plant communities are likely to be found in strips, running parallel to the crop edge. For example, a distinct area next to a track may be characterised by OV22 *Poa annua-Taxacum officinale agg.* type, whereas the middle strip of a margin may be characterised by MG5 *Cynosauraus cristatus-Centauarea nigra* grassland (described in Rodwell, 1992, 2000) due to different levels of disturbance. The linear nature of field margins and the plant communities within them meant that when devising the National Vegetation Classification in arable land, rectangular samples (instead of 2 m x 2 m quadrats) of equivalent area were used to characterise these communities. Care must be taken when designing both survey and analysis methods to compare plant communities in field margins, to ensure that data from different plant communities are not combined, conflating plant communities (Rodwell, 2006).

1.5 Ecological theories explaining plant community composition in field margins

Ecological theory is important to understand why certain management methods may affect biodiversity in field margins, and to what extent it is possible to predictably manage field margin plant communities. Research in field margins aimed to inform management for conservation relies on the assumption that there is some predictability in the responses of plant communities to management. The extent to which deterministic models can be used to explain plant community composition reflects the extent of ecological success we can expect from management under agri-environmental schemes in field margins.

The factors which control the relative abundance of plant species are important in understanding what affects plant community composition in field margins. Community Assembly Theory suggests that interspecific competition plays a role in determining community composition, characterised by niche processes and trait-based theory, as well as an effect of chance. The theories most relevant to the research in this thesis are: niche theory, trait-based ecology, the intermediate disturbance hypothesis and the Theory of Island Biogeography. These theories are discussed here, in reference to how they may explain differences in plant diversity in field margins.

1.5.1 Niche theory

The plant communities found in field margins can be explained, in part, by niche theory (Hutchinson, 1957). Each plant species can be described by their ecological attributes, which can be plotted in multidimensional space, with their niche described by the location in multidimensional space (Silvertown, 2004). A species fundamental niche can be described by the ratios of essential resources required for a species survival, in the absence of competition. In plant communities in field margins, the realized niche, the ecological niche space which a species fills in the presence of competition (Hutchinson, 1957), is likely to be more relevant.

Niche theory has been applied to species diversity in farmland when analysing the impact of conservation (Kleijn *et al.,* 2011). Kleijn *et al.* (2011) suggests that intensification and increased agricultural specialisation reduces the number of available ecological niches and so fewer species can compete and reproduce. Increasing heterogeneity, in contrast, increases the number of niches. In field margins, wider margins may contain more niches. The area of the field margin closest to a crop, for example, will be subject to run-off of fertilisers (Sheppard *et al.*, 2006), and so is likely to be subject to different phosphorous levels to further away from the margin edge, and so offers a different niche. The patterns of plant diversity in field margins observed in this thesis may be explained for, in part, by niche theory.

1.5.2 Trait-based ecology

Trait-based ecology has followed on from niche theory, as a way of categorising species according to a set of their traits, and describing the niche a species is suited to. Trait-based ecology offers a way to generalise rules about how species respond to change, offering a species based approach which can be used to understand plant communities (McGill *et al.*, 2006). For example, in intensively farmed land, plants traits associated with high nutrient availability are well represented (Smart *et al*., 2006). Two commonly used trait-based schemes for plant species are Ellenberg values (Ellenberg, 1974) and Grime's competitor-stress tolerator-ruderal (CSR) plant strategy (Grime, 1977). Both of these trait-based schemes were used when developing the Countryside Survey Vegetation system (Bunce *et al*., 1999).

Ellenberg values are used to plot abiotic factors of species, which together can be used to estimate the abiotic characteristics of a site, and describe the niche (Ellenberg, 1974). Factors used to calculate Ellenberg indicator values include light, temperature, moisture and nitrogen, which together describe the ecological realised niche value of a species at a site (Ellenberg, 1974).

An alternative trait-based scheme used to describe species in the British flora is Grime's CSR plant strategy (Grime, 1977; Table 1.4). Grime (1977) suggested that all plant species could be categorised according to three main life-history strategies: competitor, stress-tolerator or ruderal. In 1988, Grime *et al.* assessed all British plants according to 20 characteristics (classed as morphological, physiological, life-history and miscellaneous) which then determined their life-history strategy. Grime's CSR strategy considers the life-history strategy of a plant, which can then be used to interpret plant community composition in field margins, in terms of interspecific competition. CSR life-history has been used to explain the rarity and abundance of species in Northern England, which found that land use was the main influence of species abundance, and agricultural fertilisers and disturbance had resulted in rare species being characterised as stress tolerant and limited to islands of low productivity countryside (Hodgson, 1986).

		Intensity of Stress	
		Low	High
Level of Disturbance	Low	Competitors	Stress-tolerators
	High	Ruderals	Not a viable strategy

Table 1.4 The three plant life-history strategies defined by Grime et al. (1988).

From the plot-based vegetation surveys conducted across the UK under the Countryside Survey, analysis of the vegetation communities allowed for a new vegetation system to be developed. The aim of this new vegetation classification was to ensure that there was an appropriate classification to assess changes in the more disturbed plant communities of the wider countryside (Bunce *et al.,*

1999). In arable farmland, plots in hedgerow, field boundary and arable field margins were used to assess changes in vegetation stock or extent (e.g. gain or loss of hedgerows), and vegetation quality (Firbank *et al.,* 2003). To assess the latter, the Countryside Survey Vegetation system was developed based on a statistical classification of each vegetation plot surveyed in the 1978 and 1990 Countryside Surveys. Eight Aggregate Classes, with 100 vegetation classes, were identified (Bunce *et al.,* 1999). Direction comparisons in the new Countryside Survey Vegetation system classes were drawn with National Vegetation Classification (Rodwell, 1992), acknowledging that there may be no direct comparisons as the NVC was developed more for semi-natural vegetation. Each class was characterised in terms of CSR plant strategy (Grime *et al*., 1988) and Ellenberg indicator values (Ellenberg, 1974). The Countryside Vegetation System recalibrated Ellenberg indicator values for British plants (Hill *et al.,* 1999).

More recently, a functional classification of hedgerow herbaceous vegetation was developed, to inform objectives for a national strategy of vegetation restoration. Critchley *et al.* (2013) found that hedgerow herbaceous vegetation could be classified into six broad groups, based on species' functional characteristics, mainly grouped by soil nutrients, soil pH, light availability, disturbance and grazing tolerance.

1.5.3 Intermediate disturbance hypothesis

The intermediate disturbance hypothesis explains species richness, rather than dominance of a single species (Grime, 1973; Connell, 1978), and may be used to understand species richness in field margins. Levels of disturbance of a habitat can increase the number of niches in a habitat, through creating new microsites, allowing invasion by new species (Grime, 1973; Connell, 1978). Field margins, as managed sites, are moderately disturbed habitats. Disturbance may be from annual mowing of a field margin, walking or riding over margins, or from use of a margin as a track when cutting hedgerows. These activities may increase species richness in a habitat.

1.5.4 The Theory of Island Biogeography

At a larger scale, MacArthur and Wilson's (1967) Theory of Island Biogeography offers an equilibrium theory which explains the observation that smaller islands and more remote islands supported fewer species. Differences in species number based on island size are due to higher rates of extinction in smaller islands, due to smaller population sizes and greater competition for limited resources. Fewer species in more remote islands are attributed to lower rate of immigration to an island, but the same rate of extinction for an island of any given size (MacArthur and Wilson, 1967). In the case of field margins, a margin (with adjacent hedgerows) may be considered an island of natural land within the agricultural landscape. Remoteness may be connectivity to other field margins, and distance from other 'natural' patches in the landscape, such as woodlands. The Theory of Island Biogeography predicts that as field margin area and connectivity increases, field margin species richness also increases.

1.5.5 Neutral theory

An alternative to the theories discussed above is neutral theory, where communities are determined by stochasticity, specifically via dispersal, ecological drift and historical inertia (Hubbell, 2001). Neutral theory states that all species are competitively equivalent, and communities are unpredictable. Simulations of neutral communities result in all but one species drifting to extinction.

Indeed, it is possible that instead of opposing theories, niche theory and neutral theory occupy extreme ends of a continuum (Gravel *et al.*, 2006). Whilst it is clear that species are not ecological identical (as stated by neutral theory), the idea that plant communities may be determined by stochasticity is not limited to the neutral theory. Niche theory can also be unpredictable, where stochastic events affect community assembly in a deterministic but unpredictable way. An experiment in semi-arid grasslands showed that climate variability adds stochastic variation to

niche-based community assembly (MacDougall, Wilson and Bakker, 2008). In this scenario, whilst stochasticity plays a role, community assembly is niche-based. Random, unexplained variation is still likely to be present in communities which have been driven by niche-based theory. In field margins it is therefore likely that some proportion of differences in plant communities can be explained using deterministic theory, and some proportion will change stochastically. Understanding how much variation in plant diversity in field margins can be controlled deterministically may be used in guiding management requirements in field margins.

1.6 Research summary

This thesis addresses what factors affect plant diversity in field margins, how butterfly and plant diversity in field margins is related, and how the plant diversity of field margins can be monitored. The focus on plant diversity was chosen due to many arable plant species being under threat (Sutcliffe and Kay, 2000; Plantlife, 2014b), and for the importance of plant diversity for the survival of other farmland species (Verboom and Huitema, 1997; Marshall, West and Kleijn, 2006; JNCC, 2008; Vickery, Feber and Fuller, 2009; Hackett and Lawrence, 2014), also reported to be in decline. Studies of field margins across a range of geographical locations and years are important, as work on the ecology of field margins has implications for future national agri-environmental policy. This study is distinctive because the data presented is from Oxfordshire, a different geographical area to previous studies, and few studies on field margins have been reported from 2010 onwards.

This thesis addresses four main questions. Firstly, to what extent can field margin characteristics (such as hedge height, margin width) be used to explain field margin plant diversity over two years? Secondly, does field margin plant diversity differ spatially between farms in the same region, in relation to field margin characteristics? Thirdly, what is the relationship between butterfly diversity and plant structural diversity and plant species diversity in field margins? Fourthly, how does the use of different survey methods affect field margin plant records? The four data chapters are summarised below.

In Chapter 2, I present two years of observational data from field margins on a large, mixed-arable farm in Oxfordshire. These data are analysed to determine whether there is a relationship between margin-level characteristics and plant community composition in field margins. These margin-level characteristics can either be easily managed (attributes indicative of management, such as hedge height) or are difficult to change (attributes indicative of environmental variables, such as the field margin aspect). This chapter follows on from previous, single-year field margin studies (Le Coeur, Baudry and Burel, 1997; Moonen and Marshall, 2001; Deckers, Hermy and Muys, 2004; Hovd and Skogen, 2005). I seek to establish the extent to which margin-level characteristics can explain variation in plant community composition, and whether the importance of these margin characteristics vary year-to-year, over two years.

In Chapter 3, I present observational data from four farms in Oxfordshire, to establish whether there are spatially correlated differences in field margin plant diversity across farms in the same county. This question was addressed to see if findings from Chapter 2 were applicable across a wider spatial scale. To determine whether the same margin-level characteristics are important across different farms, I explore the relationship between plant community composition and margin-level characteristics over the four farms. This chapter follows on from two previous studies in different areas of Europe, which report on the relationship between the plant diversity recorded, and the farm in which a field margin is surveyed. One study was conducted in Wiltshire, England (Moonen and Marshall, 2001) and one was conducted in Northern Brittany, France (Le Coeur, Baudry and Burel, 1997). The work presented here goes further than these previous studies, to explore whether spatial correlations in plant communities explain variation in plant communities between farms.

In Chapter 4, the relationship between butterfly diversity and plant diversity is explored, through observational surveys of butterfly diversity in field margins at a large farm in Oxfordshire. The research in this chapter was undertaken to establish how differences in plant diversity in field margins may affect other species, which rely on field margin plants for survival. Butterfly data are collected and reported by Defra as part of the UK Biodiversity Indicator report, although plant diversity trends are currently not reported (Defra, 2018d). Butterfly diversity and plant diversity may be strongly correlated since butterflies have specific habitat and food plant requirements. The relationship between butterfly diversity and field margin structure, in terms of both plant structural diversity and food plant presence, is explored. This work follows on from a study in Cambridgeshire,

England, which found a positive correlation between plant species richness and butterfly species richness in field margins (Croxton *et al.*, 2004). The present study goes further by presenting an in-depth analysis to establish whether there is a relationship between food plant presence and butterfly presence, at the margin scale.

In Chapter 5, I explore the differences in plant lists produced via three survey methods. This was addressed as survey methods are important for both field margin conservation and future observational scientific studies. Field margins were surveyed with both walking transects of 30 m and 100 m, and three 1 m x 1 m quadrats, across farmland in Oxfordshire. The plant species lists produced using walking transects and quadrats are compared, to establish what biases are introduced to data sets using each method. Within the scientific literature, there is a prevalence of using quadrats for studies in field margins, however the use of walking transects (as commonly used to survey butterflies) may contribute to a clearer picture of plant diversity in field margins. This data builds on previous studies which have compared the impacts of survey methods on plant species lists in other habitats, such as woodlands (Kirby *et al.*, 1986) and alpine summits (Burg *et al.*, 2015), to determine whether similar biases are observed in plant species lists from field margins.

1.6.1 Study sites

The research described in this thesis has been conducted on four, commercial, mixed arable farms, each significantly over 100 ha, in Oxfordshire, England (Figure 1.5, Figure 1.6). Consequently, in government surveys, they are classified as large farms (a farm size of over 100 ha). 32% of farms in Oxfordshire are of this farm size ((Defra, 2016b), Table 1.5). These large farms in Oxfordshire provided large areas managed in a uniform way, useful for the field margin surveys conducted in this thesis.

Oxfordshire provides a study county representative of South East lowland farming, with high levels of agri-environmental scheme uptake. In 2012, 51.5% of land (133,182 ha) in Oxfordshire was committed to agri-environmental scheme agreements (Natural England, 2012). Mean maximum air temperature is 15.5^{o}C and mean minimum air temperature is 7.2 ^{o}C at Radcliffe meteorological station, Oxfordshire (51^{o} 45’ 40 N, 1^{o} 15’ 50 W) (Oxford University, 2016a, 2016b). Total annual rainfall in Oxfordshire in 2015 (the first year of field work in this study) was 549.0 mm at Radcliffe meteorological station, Oxfordshire (Oxford University, 2016c).

The main study farm, Farm A, covers an area of 1,600 ha, over 18 times larger than an average English farm (in 2015, average farm size was 86.3 ha (Defra 2018c)). With the entire farm managed in the same way, this allowed comparisons of the role of environmental factors and management factors on field margins to be made more robustly than if multiple farms were visited.

The farms have been anonymised, as all farms subscribe to Higher-Level schemes. This was to ensure that the results presented here can be detailed, without revealing management issues. A comparison of the four farms is presented in Table 1.6.



Figure 1.5 A map of Oxfordshire (purple) within the UK (Ordnance Survey, 2019a). © Crown copyright and database rights 2019 Ordnance Survey (100025252).



Figure 1.6 A map of Oxfordshire and neighbouring counties (Ordnance Survey, 2019b). © Crown copyright and database rights 2019 Ordnance Survey (100025252).

Farm size	Oxfordshire - number of holdings (% of total holdings)	South East England - number of holdings (% of total holdings)
<5ha	8	11
5<20h	26	31
20<50ha	19	21
50<100ha	14	14
>100ha	32	23

Table 1.5 A comparison of farm size, between the county of Oxfordshire, and the South East of England (made up of 14 regions) (Defra, 2016b).

Farm	Location	Size	Land use	Management	National Vegetation Classification (Rodwell, 2006, JNCC, 2009)	Soil Type (Defra and Cranfield Soil and AgriFood Institute, no date)
A	West Oxfordshire	1,600 ha	Mixed arable farm, parkland, woodland.	Managed as part of agri-environmental schemes since 1997. Committed to Higher-Level schemes until 2020.	MG5 *Cynosurus cristatus-Centaurea nigra* grassland	Mainly shallow lime-rich soils over chalk or limestone Small amount of freely draining lime-rich loamy soils
B	South Oxfordshire	485 ha	Mixed arable farm, woodland, plantation, wetland.	Managed as a Trust to maximise wildlife.	MG5 *Cynosurus cristatus-Centaurea nigra* grassland M24 *Molinia caerulea-Cirsium dissectum* fen-meadow U1 *Festuca ovina-Agrostis capillaris-Rumex acetosella* grassland	Freely draining slightly acid but base-rich soils
C	North Oxfordshire	730 ha	Mixed arable farm, parkland, woodland.	Managed under Higher-Level schemes.	MG5 *Cynosurus cristatus-Centaurea nigra* grassland MG4 *Alopecurus pratensis-Sanguisorba officinalis* grassland	Mainly freely draining lime-rich loamy soils, with some freely draining slightly acid but base-rich soils
D	West Oxfordshire	1,215 ha	Mixed arable farm, permanent pasture, woodland.	Managed for Organic Entry-Level schemes since 2005.	MG5 *Cynosurus cristatus-Centaurea nigra* grassland	Shallow lime-rich soils over chalk or limestone

Table 1.6 A description and the location of farms visited in Oxfordshire.

Chapter 2: The margin-level factors affecting plant diversity in field margins over two years

Supplementary materials

Supplementary methods and results for this chapter can be found in Appendix 1. The plant species found are listed in Appendix 5.

2.1 Chapter summary

Plant species diversity in English field margins is in decline, but our understanding of the factors affecting plant diversity in field margins is limited to a few studies conducted over a single field season. Given that field margin agri-environmental schemes are targeted at two- to ten-year timescales, there is an urgent need for studies conducted over longer timescales.

In this chapter, I investigate plant species richness and community composition in field margins and the effect of a range of margin variables, over a two-year period. I present observational data on the impact of 12 margin variables on plant community composition in field margins at a 1,600 ha mixed arable farm in West Oxfordshire. Margin variables were classed either as environmental variables (field margin attributes not readily changed, e.g. aspect) or manageable variables (field margin attributes readily changed by farm management, e.g. margin width).

Plant community composition was analysed over 257 plant communities in 113 field margins, surveyed between May and August 2015. Plant community composition was significantly affected by 10 of the 12 margin variables tested, accounting for 18% of the total variation in plant community composition. Margin width and hedgerow characteristics had large relative impacts on the plant community composition sampled.

In 2016, partial repeats over 118 plant communities in 46 field margins were conducted. The relative importance of variables affecting plant community composition differed in the 2016 surveys compared to the 2015 surveys. In 2016, 10 variables were shown to impact plant community composition. However, in 2016, no single variable was associated with large relative impacts on plant community composition. Over the two years, a range of both environmental variables and manageable variables impacted plant community composition.

Due to previous studies reporting significant effects of margin width and adjacent land use on plant community composition, I investigated if these differences in community composition were also reflected in differences in plant species richness and species identities. Wider margins (a manageable variable) and adjacent land use of crops on either side (an environmental variable) were associated with significantly higher plant species richness, over both years. The higher plant species richness, observed in plant communities with crops on either side of the margin, was due to an increase in weedy species.

Over a two-year timescale, these results suggest that both environmental and manageable margin characteristics should be considered in the conservation of plant diversity in field margins. For the conservation of a range of field margin plant communities, these results suggest that no single factor can be the focus of future conservation plans, due to both year-to-year variation and the small relative effect of each variable independently. Instead, a conservation strategy with a focus on heterogeneity in margin characteristics may support a wider range of plant communities.

2.2 Introduction

Field margins are greatly valued as semi-natural habitats in England, but the area of field margins has been in decline since regular recording started in 1984 (Robinson and Sutherland, 2002). In line with this loss of area, the plant diversity in these field margins is also in decline (Stoate *et al.* 2001; Barr *et al.* 2005).

Declines in plant diversity in field margins is concerning, due to the ecological functions of margins in farm landscapes. While many of the plant species in field margins may be found across a range of habitats, plant species have a critical function on farmland as food sources and habitat for higher trophic levels (Feber, Smith and MacDonald, 1996; Carvell *et al.*, 2006; Carey *et al.*, 2008; Vickery, Feber and Fuller, 2009). Field margins and adjacent hedgerows support 130 Biodiversity Action Plan species (priority species for conservation) in the UK (Wolton, 2009).

In addition to providing habitats for biodiversity in farmland, field margins provide connectivity across landscapes, joining up meta-populations and allowing mobile species to navigate across farm landscapes (Verboom and Huitema, 1997; Baudry, Bunce and Burel, 2000; Wolton, 2009; Neumann *et al.*, 2015). High species diversity is associated with ecosystem resilience and better ecosystem functioning in agricultural land (Tscharntke *et al.*, 2005). In order to conserve the many ecosystem functions associated with field margins, from reducing soil erosion to reducing nitrogen runoff, it is therefore important to conserve plant diversity (Hackett and Lawrence, 2014; Haddaway *et al.*, 2018).

The loss of field margins and associated plant species is attributed to changes in agricultural practice. Across Europe, there is a strong relationship between agricultural intensification and the numbers of rare, threatened, or recently extinct arable plant species (Storkey *et al.*, 2012). Agri-environmental schemes aim to address the decline in plant species diversity in field margins. Farmers are paid for the creation and management of field margins, often in coordination with their adjacent hedgerows, over a two- to ten-year timescale (Natural England, 2009; Defra, 2019d). Between 1999 and 2019, £228 million in grant aid was paid out for hedgerow and field margin management under agri-environmental schemes (Natural England, 2019). Despite this large investment, the impacts of these agri-environmental schemes on plant diversity are unreported by the government (Defra, 2018d).

Multi-year Countryside Survey data, collected in 1978, 1984, 1990, 1998 and 2007, provide observational data on the general changes observed in vegetation in fixed plots (CEH, no date). Plot vegetation (species presence and relative abundance) has been collected across all habitat types in the UK, including in 10m x 1m linear hedgerow and boundary plots, and in the more recent 2007 survey, 2m x 2m field margin plots (Maskell *et al.,* 2008). This data has been frequently analysed in terms of landscape-level factors, such as area of vegetation managed under agri-environmental schemes (assessed according to the Countryside Vegetation System) (Carey *et al.,* 2002), spatial patterns of habitats (Firbank, 2005), intensively farmed land cover (Smart *et al.,* 2006), high-level landscape indicators of agricultural intensification (Firbank *et al.,* 2008). However, the vegetation plot surveys conducted as part of the Countryside Survey are not often analysed alongside local management factors or environmental factors, as these data are not collected as part of the Countryside Survey.

In the scientific literature, the management of field margins and adjacent hedgerows, as well as environmental factors, has been reported to affect herbaceous plant community composition in field margins (Moonen and Marshall, 2001; Deckers, Hermy and Muys, 2004; Hovd and Skogen, 2005). This suggests that the management of field margins through agri-environmental schemes should affect plant community composition in field margins.

Field margin and adjacent boundary structures can be described by two types of variables: environmental variables and management variables. Environmental variables are abiotic factors which are difficult to change, such as margin orientation. Management variables are variables which can be controlled actively through management practices, such as hedge cutting. Often, in place of direct measure of margin management, proxies for margin or hedgerow management are used (Defra, 2007). For example, if the management variable is hedge cutting, hedge shape may be used as a proxy. The use of proxies is especially useful where accurate management records may not exist for the data required. The proxies for management variables are described here as manageable variables.

Previous studies, conducted across a range of countries in Europe, and all over one field season, report a large range of variables which impact plant community composition in field margins. Adjacent land use, an environmental variable, has consistently been found to affect plant community composition in field margins (Le Coeur, Baudry and Burel, 1997; Moonen and Marshall, 2001; Hovd and Skogen, 2005). However, often few types of adjacent land uses are compared in the same study (two or three types), and the analysis of community composition, species richness and plant identities within communities are rarely done in the same study. Moonen & Marshall (2001) compare herbaceous plant species found in hedge-bottoms adjacent to dirt roads and sown strips, and found differences in plant community composition, and higher plant species richness adjacent to sown strips. They predicted this is due to the sown strip acting as a buffer, reducing fertiliser and herbicide drift.

Manageable variables reported to affect plant community composition in field margins include margin width and hedgerow structure (e.g. hedgerow height, hedgerow width, hedgerow integrity) (Le Coeur, Baudry and Burel, 1997; Moonen and Marshall, 2001). Le Coeur *et al.* (1997) reported effects of margin width on plant community composition. Moonen & Marshall (2001) reported an effect of margin width on plant community composition (with no discussion of impacts on specific species identities), and detected no significant effect of margin width on species richness. Margin management, such as margin mowing and sowing, has also been found to impact plant community composition (Le Coeur, Baudry and Burel, 1997; Moonen and Marshall, 2001; Hovd and Skogen, 2005).

However, the relative impacts of manageable and environmental variables on plant diversity in field margins have only been reported in single-year studies, not in multi-year studies. It is important that we understand the relative impacts of management factors (such as margin mowing and hedgerow cutting), and environmental variables, over the two- to ten-year timescale over which agri-environmental schemes are conducted. Understanding whether variables affect plant diversity in field margins in the same way year-to-year is critical in terms of how much we can extrapolate from previous scientific studies, as well as how prescriptive the management of field margins under agri-environmental schemes should be.

Previous studies have found that herbaceous field margin plant diversity is driven by a wide range of variables (Le Coeur, Baudry and Burel, 1997; Moonen and Marshall, 2001; Hovd and Skogen, 2005). It is likely that for some of these variables, year-to-year variation in their impacts on plant community composition will be observed. The most ecologically beneficial time to mow a field margin, for example, differs each year due to variation in phenology (Vickery, Feber and Fuller, 2009), primarily due to seasonal climate differences. Mowing time and frequency in field margins adjacent to roads affects plant flowering and seed production (Jantunen *et al.*, 2007). The optimal management strategy for field margins is therefore likely to be variable from year-to-year. This will then affect the animals which rely on field margin plants for habitat, feeding and reproduction, such as butterflies (Feber, Smith and MacDonald, 1996), birds (Vickery, Feber and Fuller, 2009) and bees (Carvell *et al.*, 2006).

In order to test the hypothesis that different environmental variables and manageable variables will affect plant community composition in different years, I surveyed plant diversity across field margins in two years (2015 and 2016). Each plant community surveyed was described by 12 environmental variables, manageable variables (indicative of margin management), and quadrat position. Details of each variable are given in Table 2.1. I conducted an observational study of the herbaceous plant diversity over 113 field margins in 2015 and 46 field margins in 2016, in a farm in Oxfordshire, England, in relation to these 12 variables.

To further understand how plant community composition changes with different environmental and manageable variables, I examined how changes in plant community composition were reflected in changes in species richness and in plant species identities, for two explanatory variables. The impacts of margin width and four types of adjacent land use were investigated as both have consistently been reported in previous studies to significantly impact plant community composition, but with little discussion on how this may also affect the identities of the plant species present, and the levels of plant species richness. I hypothesised that wider margins will have higher plant species richness than narrower margins, due to heterogeneity in conditions across margin width and a larger 'island' of natural land supporting higher species richness (as predicted by the Theory of Island Biogeography (MacArthur and Wilson, 1967). I also hypothesised that adjacent land use will impact plant species richness, with lower species richness associated with margins adjacent to crops on both sides, due to nutrient enrichment in the soil. I expected plant identities to vary with adjacent land use, with margins adjacent to roads to be characterised by weedy plant species, and margins adjacent to grassland to be characterised by grass species.

Variable	Variable type	Variable details
Adjacent Land use	Environmental	The two adjacent land uses on either side of the field margin and hedgerow boundary (e.g. crop-crop, crop-road) have been shown to affect plant community composition in margins (Le Coeur, Baudry and Burel, 1997; Moonen and Marshall, 2001; Hovd and Skogen, 2005).
Aspect	Environmental	Margin aspect (north facing, south facing, east facing, west facing) has been shown to affect plant community composition in margins with limited impact in one study (Hovd and Skogen, 2005) or to have no impact (Le Coeur, Baudry and Burel, 1997).
Bank Height	Manageable	Bank height will affect shading in adjacent margin. Boundary structure has been shown to affect plant diversity in margins (Le Coeur, Baudry and Burel, 1997; Marshall and Moonen, 2002).
Ditch	Manageable	Ditch presence and attributes have been shown to affect plant communities (Le Coeur, Baudry and Burel, 1997).
Fence	Manageable	Fencing can be used to gap up hedgerows. Fencing will affect shading in adjacent margin, as well as adding heterogeneity in the boundary structure. Boundary structure has been shown to affect plant diversity in margins (Le Coeur, Baudry and Burel, 1997; Marshall and Moonen, 2002).
Hedge Characteristics	Manageable	Boundary structure (e.g. height, width) has been shown to affect plant diversity in margins (Le Coeur, Baudry and Burel, 1997; Marshall and Moonen, 2002).
Hedgerow Shape	Manageable	Indicative of hedgerow trimming regime (Defra, 2007). Boundary structure has been shown to affect plant diversity in margins (Le Coeur, Baudry and Burel, 1997; Marshall and Moonen, 2002).
Hedgerow Type	Manageable	Indicative of age of hedgerow and active management through cutting and planting. Boundary structure has been shown to affect plant diversity in margins (Le Coeur, Baudry and Burel, 1997; Marshall and Moonen, 2002).
Herbaceous Vegetation Height	Manageable	Indicative of intensity of grazing or mowing management in the field margin (Defra, 2007). Mowing is shown to be a factor affecting plant diversity in margins (Hovd and Skogen, 2005; Jantunen *et al.*, 2007).
Indicator Species	Manageable	Indicative of nutrient enrichment from fertilisers being spread into the field margin, beyond the edge of the crop (Defra, 2007). Nutrient enrichment ground flora indicator species used by Defra in hedgerow surveys are nettles *Urtica* spp., cleavers *Galium aparine* and docks *Rumex* spp. (Defra, 2007).
Margin Width	Manageable	Margin width has been shown to affect plant diversity in margins (Le Coeur, Baudry and Burel, 1997; Moonen and Marshall, 2001). Margin width is managed as part of agri-environmental schemes. Wider margins result in higher payments (Rural payments agency, 2017).
Quadrat Position		Quadrats in different areas of the field margin record different plant communities, due to different niches across the margin width. Factors vary across the width of the margin e.g. greater shading next to hedgerow, greater levels of disturbance next to crop. To ensure heterogeneity in plant communities across the width of the margin is recorded, three quadrats were surveyed to sample these different communities.

Table 2.1 A list of 12 margin characteristics, describing the margin and hedgerow boundary and quadrat position within the field margin, which were recorded to accompany each of 257 plant communities across 113 margins surveyed in this study.

2.3 Methods

2.3.1 Methods overview

To investigate if environmental variables and manageable variables effect plant diversity in field margins across multiple years, I conducted a two-year observational study. I surveyed field margin plant diversity and 12 margin characteristics, across a 1,600 ha mixed arable farm in Oxfordshire, England. Variables were included because they had previously been shown to impact plant community composition in single-year studies.

Two environmental variables were selected which have previously been reported to impact plant community composition in field margins: adjacent land use and margin aspect. Nine manageable variables were selected as a proxy for management factors previously reported to impact plant species in field margins. The manageable variables included were: bank height, ditch presence, fence presence, hedge characteristics (hedgerow dimensions and gappiness), hedgerow shape, hedgerow type, herbaceous vegetation height, presence of indicator species (indicative of nutrient enrichment), and margin width. Quadrat position was recorded, to reflect the location of the plant community sampled across the width of the field margin. Details of each variable and reasons for their inclusion in the analysis are listed in Table 2.1.

I surveyed flowering plant species in 257 plant communities in 113 margins in summer 2015, with randomly selected partial repeat surveys of 118 plant communities in 46 margins in summer 2016. Margin characteristics were recorded once only for each margin, in 2015. To observe the differences in plant communities in field margins with different characteristics, I recorded plant species richness and community composition in up to three 1 m x 1 m quadrats per margin.

2.3.2 Study site

This study was conducted at a 1,600 ha mixed arable farm in West Oxfordshire. The farm is very large, far above the threshold for 'largest farm' size category of >100 ha, defined by Defra (2018a). It is managed as a commercial farm, with arable crops, woodland, and cattle and sheep grazing. The most common arable crops grown on this farm are oil-seed rape, wheat and barley. Field size ranged from 0.4 ha to 38.1 ha, with most fields 10 ha to 25 ha. The farm has been managed as part of agri-environmental schemes since 1997, and is committed to Higher-Level schemes until 2020. As part of the Higher-Level scheme agreements, hedgerows and margins are maintained and managed on the farm.

The farm is set mainly on flat, shallow lime-rich soil over chalk, with a small amount of the farm on freely draining lime-rich loamy soil. The National Vegetation Classification (Rodwell, 1992) class of vegetation on the farm is mapped as predominantly MG5 *Cynosurus cristatus-Centaurea nigra* grassland (JNCC, 2009). MG5 grasslands have experienced declines due to drainage, ploughing, reseeding, and high fertiliser use rates, to less than 6,000 ha across England. MG5 grassland does not contain any rare species, but does contain many native plants, valued as habitat for fungi, invertebrate, mammal and bird species. This community type is considered a priority habitat type (Natural England, 2013).

2.3.3 Margin Identification

To identify potential field margins that could be surveyed, satellite imagery was used (Google Earth Pro, 2015). In May 2015, I visited all the field margins identified via satellite imagery across the farm to verify identification (Figure 2.1). On-site visits were used to identify which field margins and hedgerows fulfilled the essential assessment of a hedgerow boundary structure described in The Hedgerow Survey Handbook (Defra, 2007). Only field margins adjacent to hedgerows were surveyed, to allow comparisons of the impact of different hedgerow structures on field margin plant communities. Field margins were excluded for being less than 30 m long or where hedgerows were misidentified as a row of trees. Hedgerows on the edge of the farm, where field margins on both sides could not be surveyed, were also excluded. 113 field margins were positively identified on-site to survey.

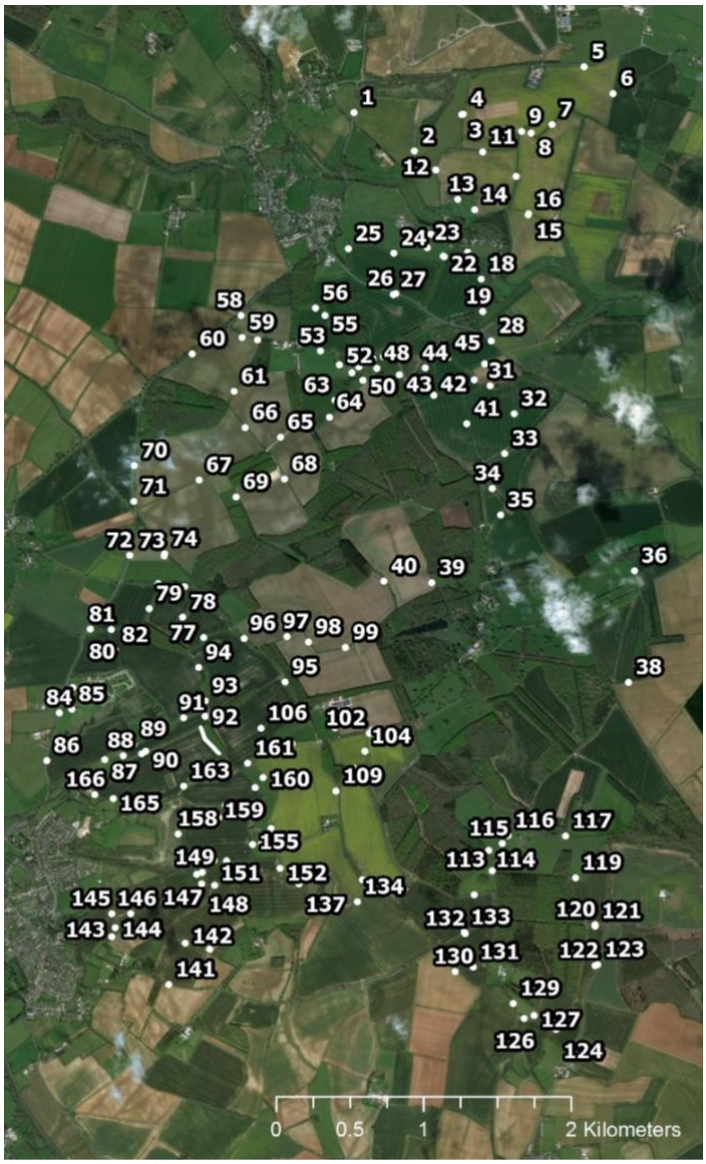


Figure 2.1 A satellite image of the farm with the locations of each potential field margin (Google Earth Pro, 2015). *All numbered field margins were visited in 2015 and of these 113 margins were then selected to survey in on-site visits.*

2.3.4 Vegetation sampling

To survey the plant species richness and plant community composition in field margins, margins were visited once a year between May and August, for two years. In 2015, I surveyed plant communities in 257 quadrats over 113 field margins. In 2016, I surveyed plant communities in 118 quadrats over 46 field margins. Margins revisited in 2016 were randomly selected via random number generation, and balanced for two categorical environmental variables (firstly for margin aspect, and then adjacent land use). A smaller sample size was used in 2016 as analysis of a random selection of 118 plant communities from the 2015 data showed this sample size to give similar results.

Plant diversity was surveyed in the herbaceous ground vegetation layer between the hedgerow and the adjacent land use (Figure 2.2). Margins varied in length, but were at least 30 m long. Margins of more than 100 m were split into sections of equal length, as recommended for hedgerow surveys in The Hedgerow Survey Handbook protocol (Defra, 2007). Each margin or margin section was surveyed across the width, at one random point in its length, determined using random number generation. The plant diversity survey location was recorded via GSP coordinates to revisit in subsequent years.



Figure 2.2 The set up of hedgerow and margin surveys. Field margin side A always refers to the field margin in which the herbaceous plant community surveys takes place.

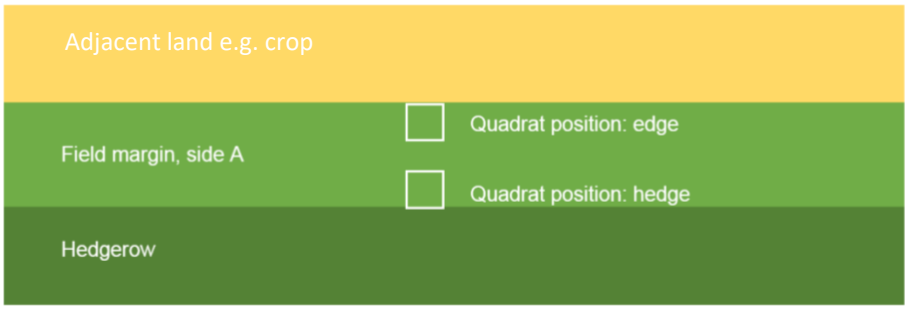
Up to three 1 m x 1 m quadrats were surveyed in each margin, limited by margin width. All margins were at least 1 m wide. Margins 1-1.9 m wide were surveyed with one quadrat, 2-2.9m wide were surveyed with two quadrats, and ≥3 m were surveyed with three quadrats. The position of the three survey quadrats within the margin (quadrat position) was designed to ensure that any heterogeneity in plant species diversity across the width of the margin was recorded. One quadrat was placed directly next to the hedgerow (quadrat hedge), one quadrat directly next to the crop field (quadrat edge), and one quadrat in the middle of the field margin (quadrat middle) (Figure 2.3).

Where the adjacent land use was grassland, there was no clear land-use change to delimit sampling. In this case, three quadrats were surveyed at 1 m intervals (one quadrat surveyed directly next to the hedgerow, one 2 m away from the hedgerow, and one 4 m away from the hedgerow). This was comparable to a 5 m wide margin, as the mean margin width at this farm was 4.50 ±2.62 m (mean ±SD).

A



B



C



Figure 2.3 The quadrat placement to sample plant communities from across the width of the field margin. A) Shows the quadrat placement for wide margins of more than 3 m. B) Shows the quadrat placement for margins between 2 and 3 m wide. C) Shows the quadrat placement for margins less than 2 m wide.

In each quadrat, all plant species were identified to the species level, using Rose and O'Reilly (2006). The relative abundance of each plant species in the quadrat was recorded on the 10-point non-linear DOMIN scale (Table 2.2), as described in the National Vegetation Classification Users' handbook (Rodwell 2006, *sensu* Dahl & Hadac 1941).

DOMIN Scale	**Range (%)**	**Mid-range value (%)**
10	91 – 100	95.5
9	76 – 90	83
8	51 – 75	63
7	34 – 50	42
6	26 – 33	29.5
5	11 – 25	18
4	4 – 10	7
3	<4 (many individuals)	3
2	<4 (several individuals)	2
1	<4 (few individuals)	1

Table 2.2 Conversion of the DOMIN scale to percentage cover.

2.3.5 Margin characteristics surveys

To observe the relationship between plant community composition and margin characteristics, I surveyed all plant communities for 12 environmental variables, manageable variables and quadrat position, in 2015 (Table 2.3). All margin characteristics recorded over a 30 m section of the margin were surveyed within 15 m either side of the point of the margin vegetation survey.

Variable	Variable type	Levels / Range	Survey method
Adjacent land use	Environmental variable; categorical	Crop-crop, crop-road, grass-crop, grass-road (as defined in Defra 2007)	Field observation
Aspect	Environmental variable; categorical	N = north, S = south, E = east, W = west	Determined on a map
Bank height	Manageable variable; continuous	a = side a, b = side b; to nearest 25 cm. Range: 0 – 200 cm	Measured bank height at point of margin vegetation survey
Ditch	Manageable variable; categorical	present, absent	Field observation
Fence	Manageable variable; categorical	present, absent	Field observation
Hedge characteristics	Manageable variable; categorical / continuous	height to nearest 50 cm. Range: 100 – 500 cm width to nearest 50 cm. Range: 100 – 600 cm % gaps, range: 0 – 60% height to base of hedgerow to nearest 25 cm, range: 0 – 125 cm gaps of >5 m	Estimations for a 30 m section of the hedgerow: Hedge height: field observation, average height of hedgerow excluding banks and hedgerow trees Hedge width: field observation, average hedgerow width % gaps: field observation, % gaps in hedgerow estimated Height to base of hedgerow: average height to base of hedgerow Gaps of >5 m: field observation, gaps >5 m recorded for 100 m length
Hedgerow shape	Manageable variable; categorical	a = trimmed and dense, b = intensively managed, c = untrimmed, d = tall and leggy, e = untrimmed, with outgrowth, h = other (described in Defra 2007, shown in Supplementary Figure 8.1)	Field observation
Hedgerow type	Manageable variable; categorical	A: shrubby hedgerow, B: line of trees, C: shrubby with line of trees (described in Defra 2007, shown in Supplementary Figure 8.2)	Field observation
Herbaceous vegetation height	Manageable variable; continuous	Mean height to the nearest 5 cm. Range: 5 – 65 cm	Measured mean height of herbaceous vegetation in the margin at point of margin vegetation survey
Indicator species	Manageable variable; percentage	nettles, docks, cleavers (%). Range: 0 – 80%	Field observation, estimating percentage of indicator species of nutrient enrichment (docks, nettles and cleavers) within a 30 m x 1 m linear plot at the hedgerow base
Margin width	Manageable variable; continuous	Single-sided margin width: a= side A (margin in which quadrats surveyed), b = side B (margin on other side of hedgerow); to nearest 25 cm; Figure 2.2. Used in all CCAs. Range: 100 – 1000 cm Overall margin width: total area of non-cropped land, calculated as width side A + width side B + hedgerow width; Figure 2.2. Used in linear regression. Range: 2075 cm - 3750 cm	Measured at point of margin vegetation survey
Quadrat position	Categorical	hedge, middle, edge; Figure 2.2.	Field observation

Table 2.3 Recorded field margin characteristics for each plant community surveyed. The survey method for each variable is described.

2.3.6 Analysis

2.3.6.1 Plant community composition

Differences in plant community composition were analysed using canonical correspondence analysis (CCA) from *vegan* package in *R* (Oksanen *et al.*, 2017). CCA is a method of constrained ordination, used to provide a descriptive, graphical summary of the main structure of the community data (Ter Braak, 1986). CCA shows the relationship of plant community composition in each surveyed margin, with the 12 named environmental variables, manageable variables and quadrat position.

Constrained correspondence analysis combined all 12 explanatory variables (listed in Table 2.3), to explain variation in plant community composition. To allow year-to-year comparisons to be made, two separate analyses were run, for the 2015 and 2016 plant surveys.

Two further CCAs were conducted, focussing on two explanatory variables (margin width and adjacent land use) and the identities of the plant species associated with them. Variation was explored at the plant community level and so quadrat position within the field margin (expected to impact plant community composition) was included as a variable for each plant community sampled. The first CCA explained variation in plant communities in terms of the margin width and quadrat position. The second CCA explained plant communities in terms of adjacent land use and quadrat position.

For all CCAs, three ANOVA-like permutation tests were run using sequential tests (999 permutations), to test the significance of: the overall CCA; each CCA axis; and each of the explanatory variables included in the CCA. The variance inflation factor was calculated for each explanatory variable in each CCA, as a measure of multicollinearity between variables.

2.3.6.2 Plant species richness

Mean plant species richness per field margin (mean species richness per m^2) was compared over the two years of sampling.

I analysed how field margin species richness changed with overall margin width. Overall margin width was calculated as the entire boundary structure (margin width on side A and side B, plus hedgerow width) (Figure 2.2). A linear model was run with margin width as a continuous explanatory variable, for the plant communities surveyed in 2015. To meet the assumptions of normality for this analysis, plant species richness was square-root transformed.

To test whether field margin species richness varied with adjacent land use from the 2015 and 2016 surveys, a 2-way ANOVA was conducted. In the two-way ANOVA, year was included as a factor with two levels, and adjacent land use was included as a factor with four levels.

2.4 Results

A total of 184 species were found, over the two years. In 2015, 173 species were recorded, over 2,381 plant records. The most common species found in 2015 were hogweed *Heracleum sphondylium* L.*,* cleavers *Galium aparine* L.*,* rough meadow-grass *Poa trivialis* L. and stinging nettles *Urtica dioica* L.*,* all found in over 100 of the 257 plant communities surveyed. 52 of the 173 species found were recorded in only one plant community.

In 2016, 89 species were recorded, over 954 plant records. The most common species found in 2016 were cleavers *Galium aparine* L., hogweed *Heracleum spondylium* L.*,* rough meadow-grass *Poa trivialis* L.*,* cow parsley *Anthriscus sylvestris* (L.) Hoffm.*,* and stinging nettles *Urtica dioica* L., all found in over 40 of the 89 plant communities surveyed. Of the 89 species found, 20 were found

only in one plant community. No Red List plant species were encountered in either year (listed in Cheffings and Farrell, 2006).

Similar plant species richness was observed over the two years of sampling, with a mean of 9.06 ±2.58 species and 7.41 ±1.95 species (mean ±SD) surveyed per m^2 per field margin in each year (Table 2.4).

Year	Number of plant communities surveyed	Number of different species recorded	Mean species richness per m^2 per margin ±Standard Deviation
2015	257	173	9.06 ±2.58
2016	118	89	7.41 ±1.95

Table 2.4 The mean species richness and the number of species recorded in margin surveys, over the two years of sampling at the farm.

2.4.1 Plant community composition

CCA was used to understand the structure of the plant community data and the main variables correlated with plant community composition. In 2015, 12 variables included in the model accounted for 18% of variation in plant community composition (Table 2.5). ANOVA-like permutation tests revealed that 10 of the 12 variables significantly affected plant community composition (at $p < 0.05$). Variables which did not significantly affect plant community composition were: hedgerow shape ($F_{4,227} = 1.20$, $p = 0.12$) and herbaceous vegetation height ($F_{1,227} = 0.83$, $p = 0.71$). The results of ANOVA-like permutation tests for all 12 explanatory variables in the 2015 CCA is given in Supplementary Table 8.1.

In 2016, 35.3% of variation in plant community composition was explained (Table 2.5). Ten of the 12 variables significantly affected plant community composition (at $p < 0.05$). Herbaceous vegetation height ($F_{1,89} = 1.07$, $p = 0.306$) and bank height ($F_{2,89} = 1.19$, $p = 0.112$) did not significantly affect plant community composition. The results of ANOVA-like permutation tests for all 12 variables in the 2016 CCA is given in Supplementary Table 8.2.

Inter-year variation is seen in the relative contribution of variables explaining plant community composition in the CCA ordination diagrams from the 2015 surveys (Figure *2.4*) and the 2016 surveys (Figure 2.5). The 2015 CCA ordination diagram (Figure 2.4), shows that axis 1 (accounting for the greatest amount of variation in plant community composition) represents characteristics descriptive of plant structure. Explanatory variables at opposite ends of each axis are associated with different plant communities. In axis 1, margin width is situated at one end of the axis, and hedge characteristics (specifically presence of gaps in the hedgerow) are situated at the other end of the axis. Axis 2 represents adjacent land use (specifically grass-road) and margin aspect (north facing margins) at one end of the axis, margin width at the other end.

The 2016 CCA ordination diagram (Figure 2.5) shows that axis 1 represents characteristics descriptive of boundary structure (margin width and hedgerow width) at one end of the axis, and margin quality (presence of indicator species (docks, indicative of nutrient enrichment) and presence of a ditch) at the other end of the axis. Axis 2 is descriptive of a large number of variables: presence of indicator species (docks, indicative of nutrient enrichment), margin width and presence of a ditch at one end of the axis. Hedge characteristics (height to base, presence of gaps) and presence of indicator species (nettles, indicative of nutrient enrichment) are at the other end of axis 2. The large number of explanatory variables suggest that each variable has a small, cumulative impact on plant community composition in field margins.

In both CCAs, from 2015 and 2016, variance inflation factors were less than 20 for all variables (Supplementary Table 8.3). Variance inflation factors were greater in 2016 compared to 2015, suggesting a greater effect of collinearity on the percentage variation explained in 2016.

Year		Overall model	CCA axis 1	CCA axis 2	CCA axis 3
2015	Variation explained	18.0%	2.0%	1.5%	1.5%
	Permutation test	**$F_{29, 227}$ = 1.71, p = 0.001**	**$F_{1, 227}$ = 5.49, p = 0.001**	**$F_{1, 227}$ = 4.18, p = 0.005**	**$F_{1, 227}$ = 4.09, p = 0.004**
2016	Variation explained	35.3%	3.4%	3.0%	2.9%
	Permutation test	**$F_{28, 89}$ = 1.73, p = 0.001**	**$F_{1, 89}$ = 4.71, p = 0.005**	**$F_{1, 89}$ = 4.13, p = 0.009**	**$F_{1, 89}$ = 3.93, p = 0.010**

Table 2.5 The contribution of the first three CCA axes to explaining field margin plant community composition, in 2015 and 2016. Significant variation explained by an axis, assessed via an ANOVA-like permutation test (999 permutations) at the p <0.05 level is in bold. 2015, n = 257. 2016, n = 118.

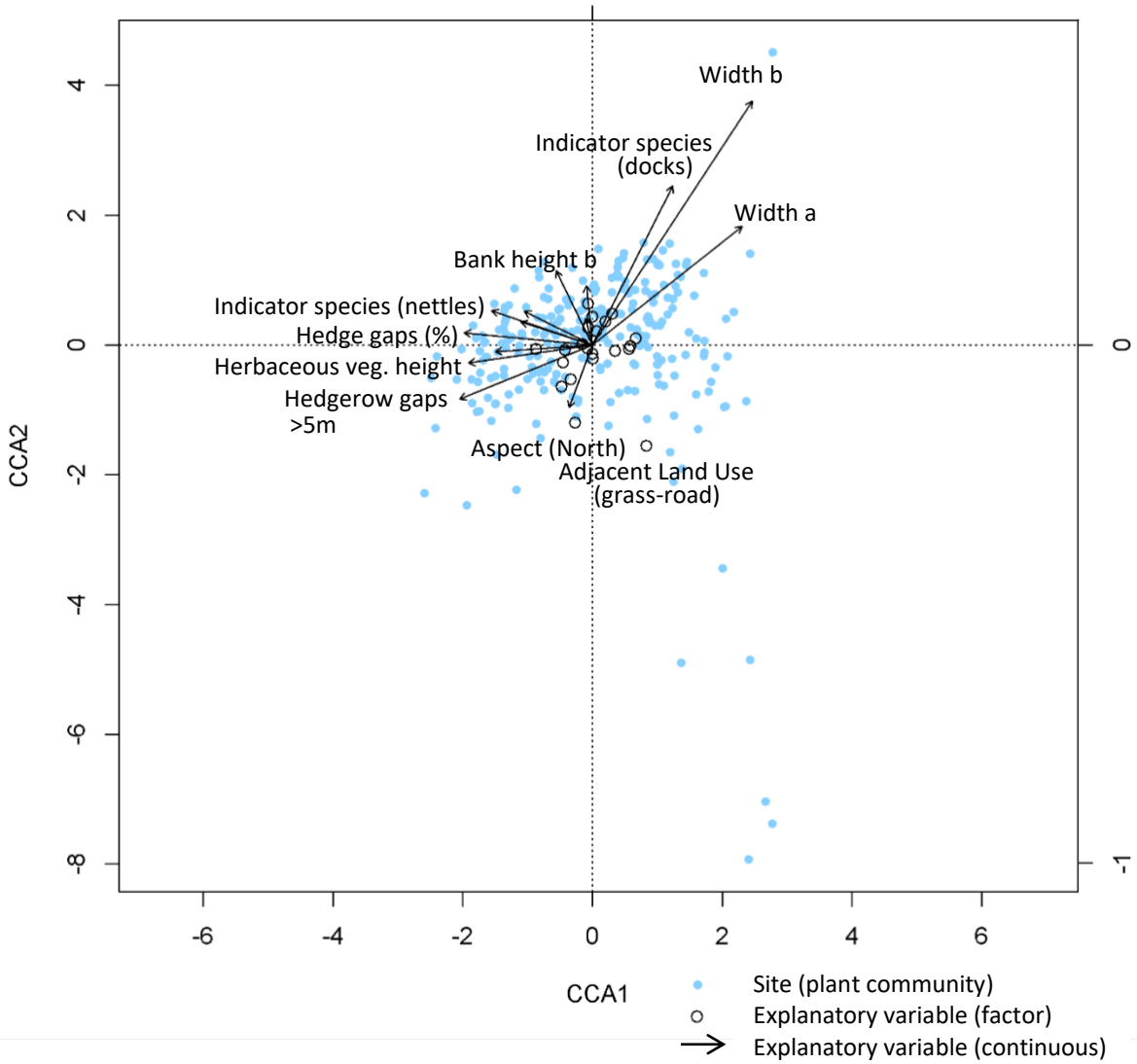


Figure 2.4 A CCA ordination diagram (axis 1 and 2) of plant communities and 12 explanatory variables. Data from 257 plant communities surveyed in 2015 is plotted. 18% of variation in plant community composition is explained for by the 12 variables in this CCA. Not all explanatory variable labels are shown, labels were prioritised based on the relative importance of each variable.

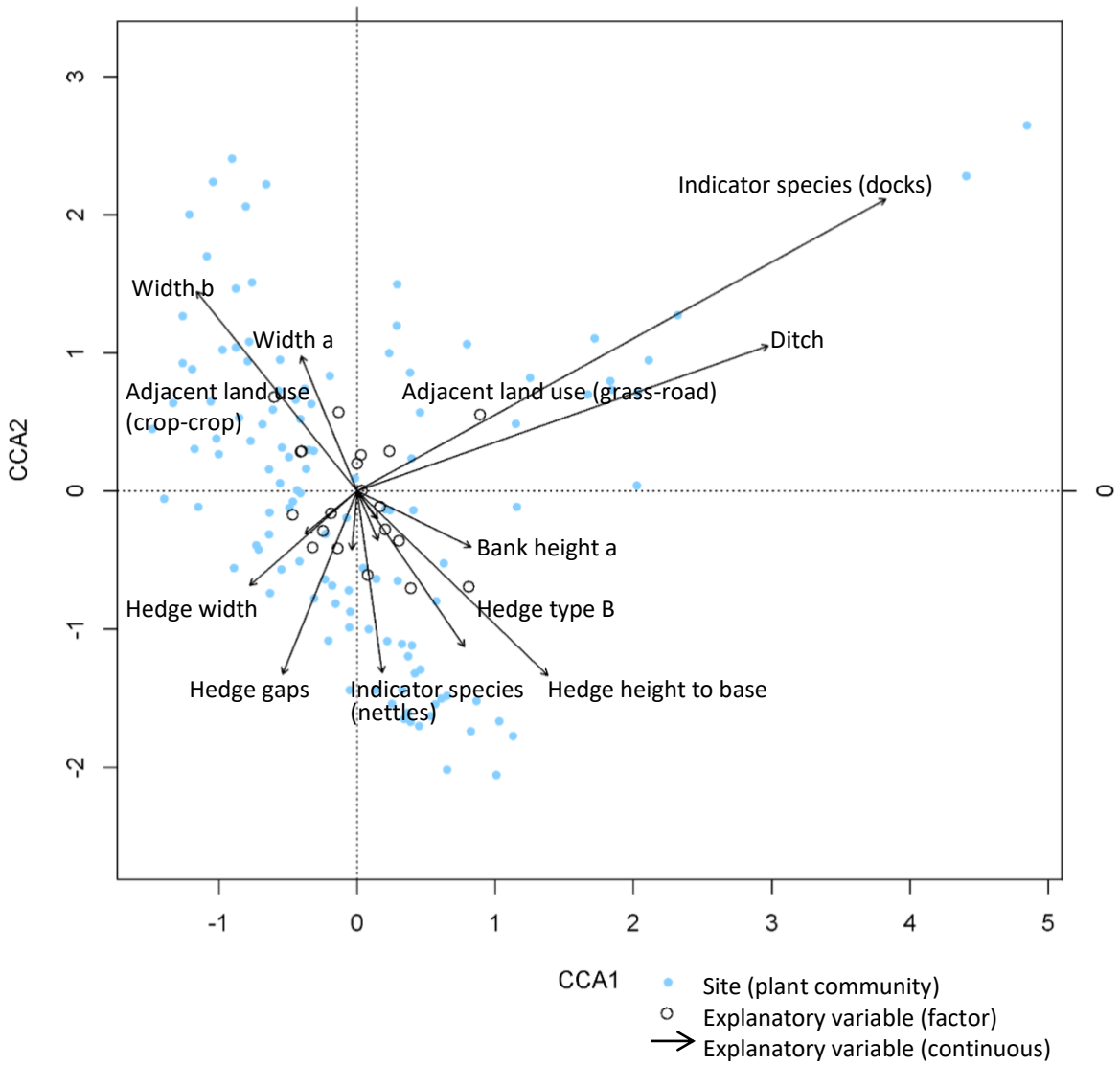


Figure 2.5 A CCA ordination diagram (axis 1 and 2) of plant communities and 12 explanatory variables. Data from 118 plant communities surveyed in 2016 is plotted. 35% of variation in plant community composition is explained for by the 12 variables in this CCA. Not all explanatory variable labels are shown, labels were prioritised based on the relative importance of each variable.

2.4.2 Margin width

The relationship between overall margin width (margin width on both sides of the hedgerow, and hedgerow width) and plant species richness, and margin width and plant species identities were analysed. In 2015, narrow field margins (overall margin width of 5 m or less) had a lower mean plant species richness of 7.71 ±3.00 per m^2 (mean ±SD; n = 12) than wide field margins (overall margin width of 17.5 m or more) with a mean plant species richness of 12.90 ±2.88 per m^2 (n = 9). In 2016, narrow field margins had a mean plant species richness of 7.08 ±2.38 per m^2 (n = 6). Wide field margins had a mean plant species richness of 7.81 ±1.03 per m^2 (n = 7).

A linear regression showed a positive correlation between overall margin width and square root transformed plant species richness in 2015 (Figure 2.6). An increase in margin width correlated with an increase in square root transformed species richness (square root plant species richness = 2.54 + 0.040*margin width (m); adjusted $r^2 = 0.16$, $F_{1,111} = 22.62$, $p = 5.99 \times 10^{-6}$).

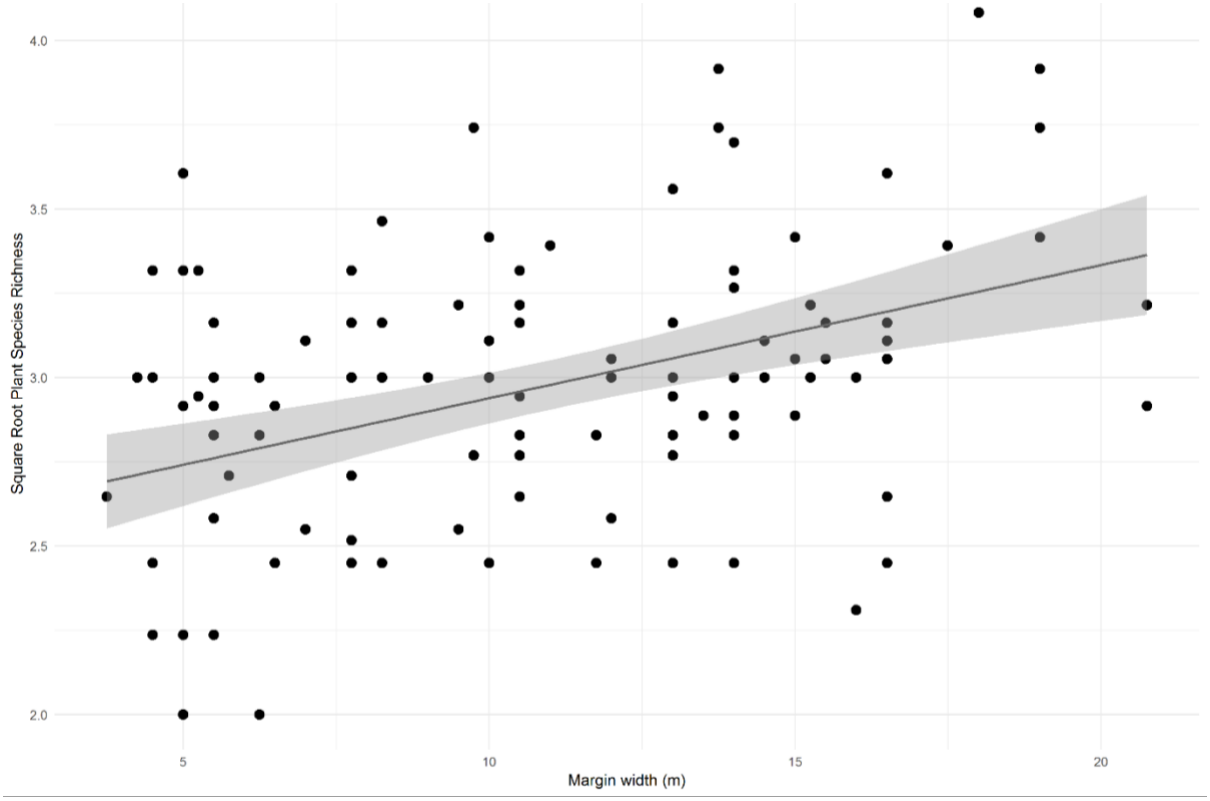


Figure 2.6 The relationship between overall margin width and mean margin plant species richness surveyed in 2015. The grey line shows a linear regression of overall margin width and species richness. The grey bar shows the 95% confidence interval around the linear regression line. Mean species richness for each field margin is plotted. n = 113.

The association between margin width and plant communities, visualised through CCA is shown in Figure 2.7A. This CCA model accounted for 3.2% of the variation in plant community composition ($F_{4,252}$= 2.11, p = 0.001) (Table 2.6). ANOVA-like permutation tests showed that both margin width ($F_{2,252}$ = 1.79, p = 0.001) and quadrat position ($F_{2,252}$ = 2.44, p = 0.001) significantly affect plant community composition (at p <0.05). Visual assessment of the CCA ordination diagram suggests that species do not show clear groupings of plant communities with margin width, but rather show a continuum from species associated with narrow margins to those associated with wide margins. Due to the small angle in the CCA plot between margin width on side A and side B, an increase in

margin width on both sides of the hedgerow resulted in similar changes in plant community composition. The association of plant species identities with margin width in 2015 in the CCA presented in Figure 2.7A is labelled in Figure 2.7B. In this CCA, the variance inflation factors associated with each explanatory variable were all low (<2, Supplementary Table 9.4).

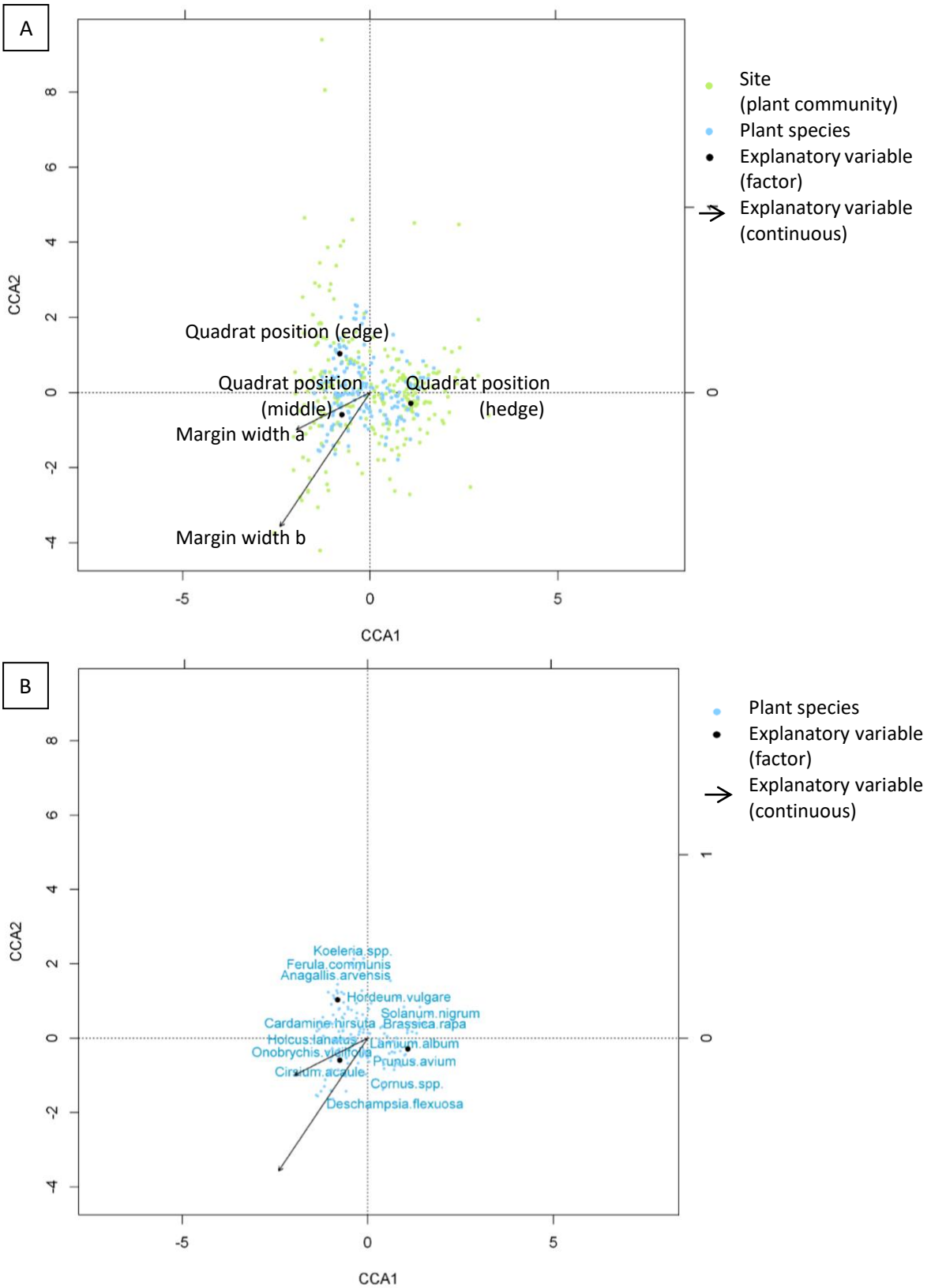


Figure 2.7 A) A CCA ordination diagram (axis 1 and 2) of 257 plant communities, plant species and explanatory variables (labelled), margin width (on either side of the hedgerow) and quadrat position. 3.2% of the variation in plant community composition is explained for by the two variables in this CCA. Plant communities were surveyed in 2015. B) A CCA ordination diagram (axis 1 and 2) of plant species (labelled) and explanatory variables, margin width and quadrat position. Explanatory variables are as labelled in Figure 2.7 A. Not all plant species are labelled.

	Overall model	CCA axis 1	CCA axis 2	CCA axis 3
Variation explained	3.2%	1.6 %	0.75%	0.50%
Permutation test	**$F_{4,252}$ = 2.11, p = 0.001**	**$F_{1,252}$ = 4.06, p = 0.001**	**$F_{1,252}$ = 1.96, p = 0.001**	**$F_{1,252}$ = 1.31, p = 0.093**

Table 2.6 The contribution of the first three CCA axes to explaining field margin plant community composition with margin width and quadrat position. Significant variation explained by an axis (ANOVA-like permutation test, 999 permutations) at the p <0.05 level are given in bold. n = 257

2.4.3 Adjacent land use

Adjacent land use was shown to impact plant community composition in both years, and was further analysed in terms of species richness and species identities. A two-way ANOVA, used to establish the impact of adjacent land use on margin species richness over the two years, showed a significant relationship between adjacent land use, year and an interaction effect between these two explanatory variables, on plant species richness (at p <0.05, Table 2.7).

	Degrees of freedom	F-value	p-value
Adjacent land use	3	8.53	**2.85×10^{-5}**
Year	1	22.9	**4.07×10^{-6}**
Adjacent land use: year	3	2.75	**0.0446**
Residuals	151		

Table 2.7 The results of a two-way ANOVA testing the effects of adjacent land use, year, and an interaction effect, on margin plant species richness. n = 159.

In 2015, field margins with crops on both side (crop-crop) had the highest mean species richness per m^2 of 11.20 ±2.60 species (mean ±SD, n = 28). Lower species richness was observed in grass-crop margins (8.54 ±2.14 species, n = 16), grass-road margins (8.31 ±2.10 species, n = 16) and crop-road margins (8.25 ±2.22 species, n = 53). In 2016, field margins with crops on both side (crop-crop) also had the highest mean species richness per m^2 of 7.80 ±2.21 species (n = 16). Similar levels of species richness were also observed in grass-crop margins (7.71 ±1.43 species, n = 8) and grass-road margins (7.67 ±2.20 species, n = 7). As in 2015, the lowest species richness was observed in crop-road margins (6.78 ±1.75 species, n = 15).

The association of plant species identities with different adjacent land use in 2015 was shown via CCA ordination plot (Figure 2.8A). The CCA model accounted for 5.0% of the variation in plant community composition (Table 2.8). ANOVA-like permutation tests showed that both adjacent land use ($F_{3,251}$ = 2.71, p = 0.001) and quadrat position ($F_{2,251}$ = 2.48, p = 0.001) significantly affected plant community composition in field margins (at p <0.05). In the CCA plot, species are shown to loosely cluster around different adjacent land uses (Figure 2.8B). The order in which adjacent land uses are listed along axis 2 (at the top, grass-road, then grass-crop, then crop-crop) is as expected, with species associated with grasslands furthest up axis 2 (e.g. Oatgrasses *Trisetum spp.,* bulbous buttercup *Ranunculus bulbosus* L.), and weedy species associated with crop-road adjacent land use (e.g. white dead-nettle *Lamium album* L. and forget-me-nots *Mysotis spp.*). Variance inflation factors associated with each variable in this CCA were very low, indicating no collinearity between variables (Supplementary Table 8.5).

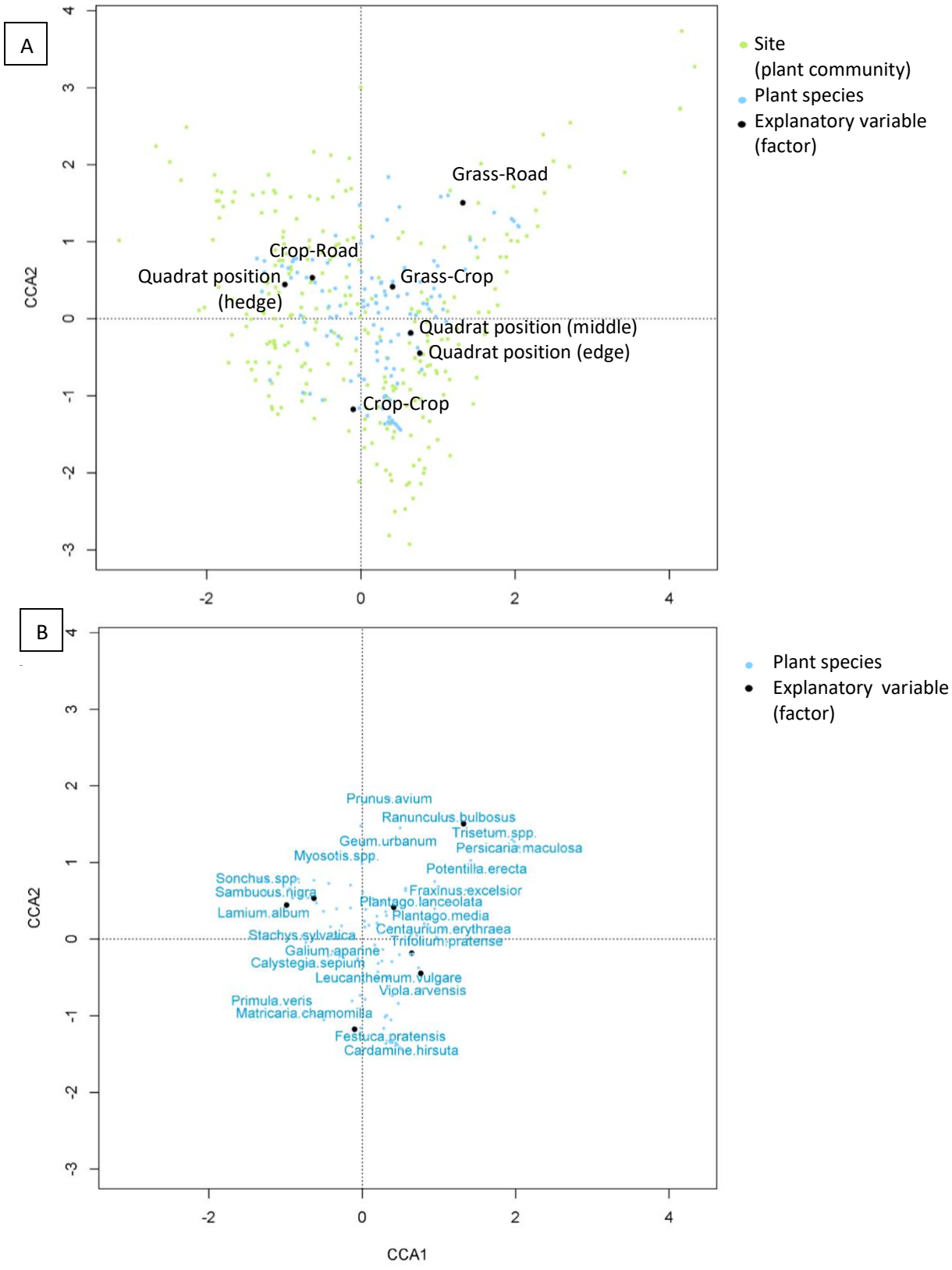


Figure 2.8 A) A CCA ordination diagram (axis 1 and 2) of plant communities, plant species and explanatory variables (labelled), adjacent land use and quadrat position. 5% of the variation in plant community composition is explained for by the two variables in this CCA. Margins were surveyed in 2015. n = 257. B) A CCA ordination diagram (axis 1 and 2) of plant species (labelled) and explanatory variables, adjacent land use and quadrat position. Explanatory variables are as labelled in Figure 2.8 A. Not all plant species are labelled.

	Overall model	CCA axis 1	CCA axis 2	CCA axis 3
Variation explained	5.0%	1.6%	1.3%	0.8%
Permutation test	**$F_{5,251}$ = 2.62, p = 0.001**	**$F_{1,251}$ = 4.22, p = 0.001**	**$F_{1,251}$ = 3.53, p = 0.001**	**$F_{1,251}$ = 2.17, p = 0.001**

Table 2.8 The contribution of the first three CCA axes to explaining field margin plant community composition with adjacent land use and quadrat position. Significant variation explained by an axis (ANOVA-like permutation test, 999 permutations) at the p <0.05 level are given in bold. n = 257.

2.5 Discussion

184 plant species were recorded over the two years of surveying in field margins across the farm. The number of plant species found was greater than that reported in previous single-year field margin studies; Marshall and Moonen (2001) reported 94 species in southern England, and Hovd and Skogen (2005) reported 153 species in Norway. However, the absence of any rare arable plants or Red List species on this farm in Oxfordshire, despite high numbers of species found, is concerning. One of the main aims of agri-environmental schemes for arable field margins, designated as a Biodiversity Action Plan habitat (JNCC, 2019c), is to increase the levels of rare arable plants (Plantlife, 2014b). These findings support previous studies which suggest that there are low numbers of rare species in field margins (Stoate *et al.* 2001; Barr *et al.* 2005).

2.5.1 The impact of margin characteristics on plant community composition

These results do not support the hypothesis that different margin characteristics will significantly affect plant community composition in different years, as nine of the 12 margin characteristics significantly impacted plant community composition in both 2015 and 2016. However, these results do suggest that in different years the relative impacts of these factors on plant community composition vary.

The impact of 12 variables on plant community composition was investigated across the two years, with 11 variables shown to affect plant community composition in at least one year. This supports previous studies which report these variables to be important (Le Coeur, Baudry and Burel, 1997; Moonen and Marshall, 2001; Hovd and Skogen, 2005). 11 of the 12 explanatory variables were recorded using Hedgerow Survey Handbook standard procedures (Defra, 2007), excluding quadrat position. Data collected as part of hedgerow surveys may be used to infer information about the herbaceous plant communities in field margins across England. Defra have coordinated results collected via the Hedgerow Survey protocols into an online database, with data from over 100 10 km grid squares across England and Wales (Hedgelink, 2008).

In 2015, the largest data set collected, 18% of variation in plant community composition was explained. This level of explanation of plant community composition is similar to other studies conducted in field margins (e.g. Moonen & Marshall, 2001 report 18%, Deckers *et al.*, 2004 report 19%).

In 2015, hedge characteristics (specifically gaps in hedgerow structure), adjacent land use, and margin width were visually identified from CCA as having a large relative impact on plant community composition. Hedge characteristics are likely to have been associated with differences in plant community composition by creating different niches across the field margin. Differences in the structure of hedges, for example gaps, height and width, will affect the shading of field margins, resulting in different niches in margins associated with different hedge characteristics, and

therefore different plant communities. The finding that adjacent land use impacts plant community composition is supporting by previous studies (Le Coeur, Baudry and Burel, 1997; Moonen and Marshall, 2001; Hovd and Skogen, 2005).

In 2016, there were no factors which could visually be identified as having a large, relative impact on plant community composition. Variables of relatively greater importance were: margin width, hedgerow structure (width, presence of gaps, height to base of hedgerow), presence of indicator species docks and nettles (indicative of nutrient enrichment), and presence of a ditch. This is likely to be due to each variable having a small, cumulative impact on plant community composition.

While the data presented here shows the same variables significantly affect plant community composition year-to-year, the relative contribution of these variables do vary. The multi-year study presented here does not conflict with previous single year studies, but does suggest further variation in the variables impacting plant community composition between years, even in the same plant communities. There is therefore no single management or environmental variable, identified in this study, on which future conservation in field margins can solely focus.

With a larger proportion of variation in plant community composition unaccounted for by the CCA models (e.g. 82% of variation is unaccounted for in 2015), this indicates that either there is considerable stochasticity in the system, or that an alternative variable was excluded from the analysis which could explain a large proportion of the variation. To explain further variation, the impact of factors measured at wider spatial scales, such as landscape heterogeneity, may provide further insight into what affects the plant diversity in field margins. Alternatively, it may be possible that in-depth site knowledge may explain some variation in plant community composition. For example, in 2015, plant communities that appeared to be outliers in the CCA plot (Figure *2.4*) all came from the same field boundary. These margins had been planted with EF4 Nectar Flower mix and intensively managed for biodiversity under Higher-Level scheme agreements. However, ten other field margins managed as part of the same scheme were not visually identified as outliers. This may suggest that future field margin conservation efforts could utilise site-specific knowledge, to explain variation in plant communities in field margins.

2.5.2 Margin width

These results support the hypothesis that wider margins are associated with higher plant species richness. When considering the overall margin width, in 2015, wider margins were shown to support a greater number of species (12.90 ±2.88 species per m^2 (mean ±SD) species were found in field boundaries of 17.5 m or greater, compared to 7.71 ±3.00 species per m^2 in field boundaries of less than 5 m). However, in 2016, a much smaller increase in species richness in wider margins was observed (7.81 ±1.03 species per m^2 were observed in wider margins, compared to 7.08 ±2.38 species per m^2).

These results are not in line with a previous farm survey, which found no effect of margin width on species richness (Moonen and Marshall, 2001). The findings presented here, reflecting differences in overall margin width, could be explained by considering margins and adjacent hedgerows as islands of natural land, within the farm landscape. Predictions based on Island Biogeography Theory (MacArthur and Wilson, 1967) for levels of diversity would suggest that wider margins support greater species richness. The increase in number of species does not plateau up to the maximum overall margin width observed on this farm (20.75 m). This suggests that the maximum potential number of plant species in field margins is not reached at this width. Further analysis is required to be able to make assertions on the optimum margin width, including a balancing factor for the length of the margin. Here, margin sections (up to 100 m long) were used as the individual margin unit as per the UK Hedgerow Survey Methods (Defra 2007).

Single sided margin width and quadrat position were associated with 3% of differences in plant community composition. When looking further into the relationship between single sided margin width and plant richness, this increase in species richness in wider margins was not associated with a gain of any specific species. An increase in margin width in both the field margin surveyed (side A) and the adjacent field margin (side B) was associated with similar changes in plant community composition. This suggests that changes in plant communities are affected by overall margin width, rather than single sided margin width. Analysed using single-sided margin width, wider margins were associated with the same range of species as narrower margins.

2.5.3 Adjacent land use

Adjacent land use and quadrat placement here accounted for 5% of the variation in plant community composition. Adjacent land use has been found in previous studies to be an important variable in determining plant diversity in both hedgerows and margins (Jobin, Boutin, and Desgranges 1997; Kleijn and Snoeijing 1997; Le Coeur, Baudry, and Burel 1997; Marshall and Moonen 2002).

These results do not support the hypothesis that crop-crop adjacent land use will be associated with the lowest field margin species richness. Margins with crops on either side had the highest number of species per m^2, with a mean of around 2.66 species more per m^2 than the next higher adjacent land use (grass-crop), according to data from 2015. In 2016, the increase in species richness is lower, with a mean increase of 0.09 species compared to the next higher adjacent land use (grass-crop). Analysis showed that not only is species richness affected by adjacent land use and survey year, but also by an interaction effect between year and adjacent land use. Adjacent land use is assumed to combine a variety of manageable variables indirectly, ranging from fertiliser drift, to the impact of mechanical operations (Le Coeur, Baudry and Burel, 1997). As adjacent land use describes, in part, management of adjacent land (which may spill over into the field margins) the year-to-year variability in differences in plant species richness observed could be because the same management practices affect plant species diversity differently in different years, due year-specific to differences in plant phenology.

Analysis of the species associated with crop-crop adjacent land use in 2015 showed weedy species were associated with this adjacent land use. This suggests that the higher number of species in field margins with crop-crop adjacent land use does not translate into the inclusion of rarer species. These weedy species are often associated with nutrient enrichment, which may be due to leaching of fertilisers (Marshall and Moonen 2002; Croxton *et al.* 2004). However, these results are not supported by studies which suggest drift of fertiliser and herbicide will reduce field margin plant species richness (Kleijn and Snoeijing 1997). Further research is required to determine why different adjacent land uses are associated with different levels of species richness.

These results support the hypothesis that different adjacent land use types are associated with different groups of species. Margins with the adjacent land use grass-road were associated with the presence of grassland species, e.g. Oatgrasses *Trisetum spp.,* bulbous buttercup *Ranunculus bulbosus* L.. Field margins with grass-crop adjacent land use were associated with a mix of grassland species and weedy species, and supported species as an intermediary between adjacent land use types grass-road and crop-crop. Crop-road is associated with crop edge and weedy species, such as white dead-nettle *Lamium album* L. and forget-me-nots *Mysotis spp..* These findings suggest that different plant species are more likely to be found in field margins with different adjacent land uses. Maintaining a variety of adjacent land uses is likely to maintain a wider range of plant species over a farm, which will support ecosystem resilience and functioning (Tscharntke *et al.*, 2005).

2.5.4 Conclusions

This work finds that field margin plant species richness and species composition is significantly affected by a wide range of margin characteristics. However, the margin characteristics investigated in this study only explain 18% of the variation in plant community composition in the largest data set presented; a large amount of variation in plant communities is not explained. Differences in the relative importance of explanatory variables were observed over two years, adding year-to-year variation to the margin-level characteristics which affect plant community composition in field margins.

A more in-depth analysis of two variables (margin width and adjacent land use) showed that higher plant species richness was associated with increased margin width and with field margins with crops as the adjacent land use on both sides. A focus on increasing margin width, and increasing the number of field margins with crops as the adjacent land use on both sides may therefore increase the plant species richness in field margins. However, wider field margins were associated with similar species identities as narrow margins, and margins with crops as the adjacent land use were associated with the presence of weedy species.

To preserve plant diversity in field margins, both management of field margin characteristics and the environmental characteristics associated with field margins included in this study are likely to have small, cumulative impacts. Due to year-to-year variability, and low contributions of each variable to explaining differences in plant community composition, no single factor included in this study can be the focus of field margin management.

Chapter 3: The factors affecting plant diversity in field margins over four farms in Oxfordshire, England

Supplementary materials

Supplementary figures and tables for this chapter can be found in Appendix 2. The plant species found are listed in Appendix 5.

3.1 Chapter summary

Field margin plants are valued in English farmland, and are reported to be in decline. The farm in which a field margin is located may affect the plant diversity, due to differences in both management and environmental factors. However, studies looking into the variables which affect plant diversity and community composition in field margins often do not include 'Farm' (the farm in which the survey occurs) in analysis. Understanding the effect of 'Farm' on plant diversity, and the differences in plant diversity between farms based on distance, may help in understanding at what spatial scale management prescriptions for the conservation of field margin plants should be targeted.

In this chapter, I investigate field margin plant species richness, and the relationship between plant community composition and 12 margin characteristics, over four farms. A total of 120 plant communities were surveyed in 47 field margins across four farms in Oxfordshire, England, between May and June 2017.

Field margin plant species richness was shown to vary between farms, with one farm having a mean of 2-3 species more per m^2 than observed at the other farms. The plant community composition observed in each farm were not shown to differ significantly. There was no evidence of spatial correlations between plant communities and geographic distance across the four farms. Within farms, a weak positive correlation between plant community dissimilarity and geographic distance between plant communities was observed in two of the four farms.

The margin characteristics (such as margin width and adjacent land use) associated with each plant community surveyed were analysed via canonical correspondence analysis (CCA). 40% of variation in plant community composition was explained by 10 of these margin characteristics, which significantly contributed to the CCA. Where 'Farm' was included in the CCA analysis, a further 4% of variation in plant community composition was explained. Due to collinearity between the variable 'Farm' and some margin characteristics, this suggests that 'Farm' may be used as a proxy to describe some margin-level characteristics. The factor 'Farm' may also represent farm-specific management not represented by the margin characteristics included in the analysis, or may represent environmental characteristics which vary between farms. The margin characteristics which made the greatest contribution to the CCA were descriptive of hedgerow structure and field margin state, and could be mediated by management.

These results suggest that inter-farm differences in plant communities in field margins are not great at the scale investigated here. Field margin management can be used to manage the plant communities within field margins, however a large amount of the variation observed in plant community composition (60%) is not explained by any of the variables in this study. Differences in plant communities in field margins, at the county-scale investigated here, are not large.

3.2 Introduction

Field margins are recognised as a key conservation feature in English lowland farms (Marshall and Moonen 2002; Hackett and Lawrence 2014; Haddaway *et al.* 2018). More than 37,000 km of grass margins have been actively managed and supported by financial incentives under current agri-environmental schemes (Defra, 2015c). However, in recent years agri-environmental schemes have become less popular (Defra, 2018d) and studies assessing the efficacy of these schemes for protecting biodiversity report mixed results (Kleijn and Sutherland 2003; Kleijn *et al.* 2006; Broughton *et al.* 2014; Batáry *et al.* 2015).

Field margins are valued both for supporting biodiversity (Boatman *et al.* 1994; Barr *et al.* 2005; Marshall, West, and Kleijn 2006; Vickery, Feber, and Fuller 2009), and for providing a variety of other ecosystem services (Hackett and Lawrence, 2014; Haddaway *et al.*, 2018). Within field margins, plant structure and composition is important for supporting other taxa by providing habitat, shelter and food (Verboom and Huitema, 1997; Marshall, West and Kleijn, 2006; Vickery, Feber and Fuller, 2009). Beyond supporting biodiversity, field margins provide multiple ecosystem services, ranging from reducing the transfer of pesticides, to reducing soil erosion (Hackett and Lawrence, 2014). Many of these ecosystems services are supported by the plant species present in field margins, for example the reduction of run-off from crop fields is attributed to interception by field margin plant species (Marshall and Moonen 2002).

Increased farming intensity through monoculture and reduced habitat heterogeneity is cited as a major reason for biodiversity loss on farmland across Europe (Andreasen, Stryhn and Streibig, 1996; Robinson and Sutherland, 2002; Butler, Vickery and Norris, 2007; Eggers, Unell and Pärt, 2011). Field margins in farmland increase the spatial heterogeneity in the landscape (Benton, Vickery and Wilson, 2003; Fahrig *et al.*, 2011). Increasing the amount of field margins in a landscape, and encouraging their good management, has the potential to positively impact farmland biodiversity (Hackett and Lawrence, 2014; Haddaway *et al.*, 2018). It is important to provide ecological evidence to understand if and to what extent management within and around field margins impact plant diversity in field margins. This may in turn improve the ecosystem services provided by field margins.

The impacts of field margin structure and the structure of adjacent features (such as hedgerows and adjacent land use) on plant diversity in field margins have been studied, but are not well understood (Marshall and Arnold 1995; Le Coeur, Baudry, and Burel 1997; Moonen and Marshall 2001; Deckers, Hermy, and Muys 2004). Previous studies have quantified the amount of variation in field margin plant community composition which can be accounted for by margin management and environmental factors. These studies have measured a variety of factors associated with field margins (e.g. field margin width, adjacent land use, hedgerow structure) and tried to establish how much variation in the plant communities in field margins can be accounted for by these factors, using ordination techniques. These studies have found that around 20% of the variation in field margin plant composition can be explained for by margin management and environmental factors (e.g. Le Coeur *et al.*, 1997 report 20% variation explained; Moonen & Marshall, 2001 report 18% variation explained; Deckers *et al.*, 2004 report 19% variation explained). In these studies, the remaining 80% of variation in plant community composition is unaccounted for. This makes recommendations for the management of field margins for plants difficult, as 80% of variation in plant communities could either be explained for by other management or environmental factors not included in the analysis, or be due to stochastic processes.

Few multi-farm studies have looked into the differences in field margin plant community composition (Le Coeur, Baudry and Burel, 1997; Moonen and Marshall, 2001). Farm identity may be an important factor as the location of the farm may represent a unique suite of environmental factors, as well as farm-specific management regimes. If this is the case, then farm identity may be

used as a proxy for farm-specific management and environmental factors, and may explain further variation in plant communities in field margins.

Le Coeur *et al.* (1997, 2002) report an effect of location in plant community composition in field margins in surveys conducted over three sites in northern Brittany, France. They found that landscape type (the grain size of the field mosaic, hedgerow network density and amount of grass versus crops), which differed between farms, had a large and significant effect on plant species composition in field margins (compared to margin structure, margin management and adjacent land use). Another study, conducted over two neighbouring farms in South England, included the factor 'Farm' in their analysis of field margin plant community composition. Inclusion of 'Farm' as a factor in their analysis accounted for a further 5.4% more variation in plant community composition than previous analysis, which excluded 'Farm' (Moonen and Marshall, 2001). The authors suggested that landscape level factors or spatial factors may be important in explaining this increase in the variation. If this is the case, one might expect that farms which are spatially closer together have a more similar plant community composition in field margins. However, no subsequent studies have looked into the relationship between distance and plant community composition in field margins, to see if the effect of 'Farm' is spatially correlated.

At a farm-scale, plant diversity has been shown to vary between farms in the same county. For example, in Oxfordshire, mapping of the National Vegetation Classification of plant types in 10 km squares shows different farms are dominated by different plant communities (JNCC, 2009). However, field margins are highly managed areas, covering a much smaller area, and so it is not clear if this difference in plant community composition observed at the 10 km square level will apply to field margins as well.

Differences in field margin management between farms are expected to vary. Previous studies have shown that field boundary structure, which is often determined by management, affects plant community composition in field margins. Hedge characteristics, such as hedgerow height and width were shown to be associated with different plant community composition in field margins (Le Coeur, Baudry and Burel, 1997; Moonen and Marshall, 2001).

Differences in plant diversity in field margins may also be due to environmental differences. Across England, differences in environmental factors such as soil type, rainfall and temperatures are shown to vary (DEFRA and Cranfield Soil and AgriFood Institute, no date; Met Office, 2019). At a landscape scale, soil, land cover patterns and land history have been postulated as factors which may be responsible for inter-farm differences in field margin plant community composition (Le Coeur, Baudry and Burel, 1997). If differences in plant community composition observed between farms are due to changes in the environment, farms which are further away from each other may have less similar plant communities. This may be due to spatial synchrony in environmental variables, such as climate, including differences in rainfall and temperature (Koenig, 1999). Within a county however, these differences are expected to be small.

To date, most studies which look into the effect of management (such as field margin mowing regime) and environmental variables (such as adjacent land use) on plant diversity in field margins do not consider the farm a field margin is in, or the distance between farms, in their analysis (Deckers, Hermy, and Muys 2004; Hovd and Skogen 2005; Marshall, West, and Kleijn 2006). A study over four farms is used here to see if differences in plant community composition in field margins is spatially correlated, and how much variation in plant community composition can be explained by margin characteristics. The 12 characteristics of each field margin investigated were: adjacent land use, aspect, bank height, farm, presence of a fence, hedge characteristics, hedgerow shape, hedgerow type, herbaceous vegetation height, presence of indicator species (indicative of nutrient enrichment), margin width, quadrat position (Table 3.2).

This study may be useful in understanding the extent to which field margin characteristics, which can be actively managed, are associated with differences in plant diversity. Understanding if, within a single county, there is large variation in the plant community composition in field margins, may help in understanding at what spatial scale agri-environmental schemes should target management prescriptions. At the moment, agri-environmental scheme options are offered at a national level in England (Rural Payments Agency, 2019). The four farms investigated in this study are in the same county, and between 17 and 48 km apart. If this spatial scale was shown to be ecologically relevant to field margin plant diversity, a county (as an administrative region) may be used to deliver agri-environmental schemes.

In order to test the hypothesis that farms closer together will have greater similarity in field margin plant community composition, an observational study over four farms in Oxfordshire was conducted. Plant species richness and community composition in field margins over the four mixed arable farms were compared. I also hypothesised that both margin characteristics and the farm surveyed (likely to be correlated with management and environmental variables) will account for variation in plant community composition in field margins. In order to test this, for each plant survey, a margin characteristic survey of 12 variables was conducted.

3.3 Methods

3.3.1 Methods overview

To assess if farms within the same region had similar field margin plant diversity, I conducted an observational study across four farms in Oxfordshire. I surveyed flowering plant species and margin characteristics in 47 field margins in May and June 2017. For each plant community surveyed, I recorded the exact location, so spatial distance between plant communities could be analysed. To observe if there were any differences in plant diversity in field margins across the four farms, I recorded plant species richness per field margin, and plant community composition in up to three 1 m x 1 m quadrats, per m^2 per field margin. I surveyed each field margin for 12 margin characteristics, which have been shown in previous studies to impact plant community composition in field margins. Some of the margin characteristics represent characteristics which can be managed (such as hedge height, through cutting). Some of the margin characteristics cannot be managed, but could be incorporated into agri-environmental schemes through incentivisation (such as higher payments for margins adjacent to crops and woodlands, rather than margins adjacent to crops and roads).

At each farm, 12 field margins were surveyed; data for one field margin at Farm B was lost so a total of 47 field margins are included in the analysis, rather than the 48 field margins surveyed.

3.3.2 Study site

Research was conducted over four farms in Oxfordshire, England (51° 42’ N, 1° 12’ W). Farms were chosen for being large mixed arable farms, with cattle and sheep grazing. All farms were committed to Higher-Level agri-environmental schemes, with hedgerows and field margins managed as part of these schemes. Farms were between 17 km and 48 km apart, in different areas of Oxfordshire. Farm D is managed as an organic farm, whilst farms A, B and C are managed conventionally.

All farms were over 100 ha, the most common farm size in Oxfordshire (Defra, 2016b). Farms A, C and D are found on lime rich soils, and Farm B is found on slightly acid but base-rich soil. All farms were largely flat. The National Vegetation Classification (Rodwell, 1992) of all farms are mapped as predominantly MG5 *Cynosurus cristus-Centaurea nigra* grassland (JNCC, 2009). Farm B also had M24 *Molinia caerulea-Cirsium dissectum* fen-meadow and U1 *Festuca ovina-Agrostis capillaris-*

Rumex acetosella grassland. Farm C also had MG4 *Alopecurus pratensis-Sanguisorba officinalis* grassland.

Fieldwork was conducted in May and June 2017 across the farms.

3.3.3 Margin identification

Surveyed field margins were selected using random number generation. At Farm A, previous on-site visits meant that 12 field margins were randomly selected from a full inventory of 113 field margins across the farm. At Farms B, C and D, all potential margins were identified off-site using satellite imagery (Google Earth Pro 2018). A list was created of all potential (or confirmed) field margins at each farm, and randomly ordered to visit using random number generation. All potential field margins were adjacent to hedgerows to allow an analysis of hedgerow characteristics on field margin plant community composition to be conducted.

On-site visits excluded field margins identified via satellite imagery where margins were less than 30 m long, or where hedgerows were misidentified and did not fulfil the essential assessment of a hedgerow described in The Hedgerow Survey Handbook (Defra, 2007). Field margins less than 100 m long were split into equal sections for surveying. Once 12 field margins at each farm had been successfully visited and surveyed, the farm survey was complete.

Field survey data from one field margin at Farm B was lost after surveying, so only 11 field margins from this farm were included in the analysis.

3.3.4 Vegetation Sampling

The herbaceous plant diversity in the field margins was assessed in 1 m x 1 m quadrats. For each field margin, up to three 1 m x 1 m quadrats were placed across the width of the margin, one nearest the field, one in the middle of the margin and one closest to the hedgerow (Figure 3.1). This was done to ensure the different plant communities associated with different areas of the field margin were surveyed. Plant communities were surveyed at a random place in the length of the margin, with the location coordinates recorded via GPS to allow the margin characteristic survey to be made at the same point and spatial distance between plant communities to be calculated. Where margins were less than 3 m wide, the maximum number of quadrats were surveyed across the width (e.g. a 2 m margin was surveyed with two 1 m x 1 m quadrats, a 1 m margin was surveyed with one 1 m x 1 m quadrat) (Figure 3.1). The total number of plant communities analysed per farm is given in Table 3.1.



Figure 3.1 (This diagram is reproduced from Figure 2.3, Chapter 2 of this thesis). The quadrat placement to sample plant communities from across the width of the field margin. A) Shows the quadrat placement for wide margins of more than 3 m. B) Shows the quadrat placement for margins between 2 and 3 m wide. C) Shows the quadrat placement for margins less than 2 m wide.

Farm	**Field margins surveyed**	**Plant communities (quadrats) surveyed**
A	12	34
B	11	24
C	12	30
D	12	32
Total	47	120

Table 3.1 The number of field margins and plant communities (quadrats) surveyed at each farm.

The position of the quadrat within the field margin was recorded for each plant survey. All flowering plant species in a quadrat were recorded, and relative abundance estimated using the DOMIN scale (Rodwell 2006). Estimated abundances from the 10-point DOMIN scale, could later be converted into an estimate of percentage cover (mid-point conversions are listed Chapter 2, Table 2.2.). Plant species were identified using Rose and O'Reilly (2006). Where species could not be identified, specimens were taken for identification by an expert.

3.3.5 Margin characteristic surveying

For each plant community surveyed, 12 margin characteristics were recorded. These margin characteristics are outlined in Table 3.2, with the range of values associated with each characteristic at each of the four farms listed. Margin characteristics were surveyed over a 30 m section of the field margin. The midpoint of the margin characteristic survey was where the plant diversity survey was undertaken in the field margin. Margin characteristics were surveyed according to the standards described in The Hedgerow Survey Handbook (Defra, 2007).

Variable	Variable type	Levels	Range Farm A	Range Farm B	Range Farm C	Range Farm D	Survey method
Adjacent Land use	Environmental variable; categorical	Crop-crop, crop-road, grass-crop, grass-road (as defined in Defra 2007)	All types	All types	All types	All types	Field observation
Aspect	Environmental variable; categorical	N = north, S = south, E = east, W = west	All aspects	All aspects	All aspects	All aspects	Determined on a map
Bank Height	Manageable variable; continuous	a = side a (margin in which quadrats surveyed), b = side b (margin on other side of hedgerow); to nearest 25 cm	0 – 175 cm	0 – 300 cm	0 cm	0 cm	Measured bank height at point of margin vegetation survey
Farm	Categorical	A, B, C, D	A	B	C	D	
Fence	Manageable variable; categorical	Present, absent	0 / 1	0 / 1	0 / 1	0	Field observation
Hedge Characteristics	Manageable variable; categorical or continuous	h = height to nearest 50 cm w = width to nearest 50 cm g = % gaps g5 = gaps of >5 m hb = height to base of hedgerow to nearest 25 cm	h = 175 – 500 cm w = 125 – 275 cm g = 0 – 20% g5 = 0 hb = 0 – 50 cm	h = 200 – 500 cm w = 200 – 500 cm g = 0 – 30% g5 = 0 / 1 hb = 0 – 75 cm	h = 175 – 400 cm w = 175 – 600 cm g = 0% g5 = 0 hb = 0 – 50 cm	h = 150 – 500 cm w = 150 - 350 cm g = 0 – 5% g5 = 0 hb = 0 – 75 cm	Hedge height: field observation, average height of hedgerow estimated, for 30 m section, excluding banks and hedgerow trees Hedge width: field observation, average hedgerow width estimated, for 30 m section % gaps: field observation, % gaps in hedgerow estimated for 30 m section Gaps of >5 m: field observation, any gaps of more than 5 m recorded Height to base of hedgerow: average height to base of hedgerow estimated to nearest 25 cm, for 30 m section

Continued on next page.

Variable	Variable type	Levels	Range Farm A	Range Farm B	Range Farm C	Range Farm D	Survey method
Hedgerow Shape	Manageable variable; categorical	a = trimmed and dense, b = intensively managed, c = untrimmed, d = tall and leggy, e = untrimmed, with outgrowth (described in Defra 2007, shown in Supplementary Figure 9.1)	Shapes A, C, D	Shapes A, C, E	Shape A	Shapes A, C	Field observation
Hedgerow Type	Manageable variable; categorical	A: shrubby hedgerow, B: line of trees, C: shrubby with line of trees (described in Defra 2007, shown in Supplementary Figure 9.2)	All types	All types	Types A, C	Types A, C	Field observation
Herbaceous Vegetation Height	Manageable variable; continuous	Mean height to the nearest 5 cm	10 – 50 cm	25 – 125 cm	35 – 150 cm	15 – 100 cm	Measured mean height of herbaceous vegetation in the margin at point of margin vegetation survey
Indicator Species	Manageable variable; percentage	n = nettles, d = docks, c = cleavers (%)	n = 4 – 40% c = 0 – 10% d = 0 – 4%	n = 0 – 80% c = 0% c = 0 – 40%	n = 0 – 90% c = 0 – 30% d = 0 – 30%	n = 0 – 80% c = 0 – 40% d = 0 – 10%	Field observation, estimating percentage of indicator species (docks, nettles and cleavers) in within 1 m of hedgerow base, for a 30 m section of the field margin
Margin Width	Manageable variable; continuous	a= side A (margin in which quadrats surveyed), b = side B (margin on other side of hedgerow); to nearest 25 cm.	100 – 900 cm	100 – 650 cm	100 – 650 cm	100 – 950 cm	Measured at point of margin vegetation survey
Quadrat Position	Categorical	Hedge, middle, edge (Figure 3.1)	All	All	All	All	

Table 3.2. The 12 margin characteristics surveyed, associated with each plant community sampled.

3.3.6 Analysis

All analyses were conducted using the vegan package in R statistical software (Oksanen *et al.*, 2017) and in Microsoft Excel.

3.3.6.1 Plant species richness

Margin plant species richness was compared over the four farms, at a margin-level, via a one-way ANOVA. Margin plant species richness was calculated across all quadrats within a field margin, and given as a mean value per field margin (plant species richness per m^2). To see if different farms had different field margin species richness, a one-way ANOVA was conducted, with 'Farm' as a factor with four levels.

3.3.6.2 Community analysis

Analysis of plant community composition was conducted at a quadrat level, to ensure plant communities were not conflated. Each quadrat was used to sample a different sub-component of the field margin (edge, middle and hedge) and so was expected to be associated with different plant communities.

3.3.6.2.1 Non-metric multidimensional scaling

Non-metric multidimensional scaling (NMDS) was used to identify any groups of similarity in plant community composition, across the four farms. NMDS was used as a way of visualising the level of similarity in plant community composition between samples. NMDS visually represents similarities between communities in a small number of dimensions. It was used here to visually see if there were groups in the plant communities surveyed, according to the farm from which the plant community was sampled.

3.3.6.2.2 ANOSIM

Analysis of similarity (ANOSIM) was performed to identify if there was a difference in plant community composition at each farm. This grouping, defined *a priori,* compared plant community dissimilarity (via the Bray-Curtis dissimilarity index) from each farm (A, B, C and D).

The Bray-Curtis dissimilarity index quantifies the compositional dissimilarity between two communities, based on species abundance data. Communities which are identical have a Bray-Curtis dissimilarity score of 0, whilst communities which are entirely different have a score of 1.

3.3.6.2.3 Mantel test

A Mantel test was conducted to see if geographic distance between the locations of each plant community surveyed was correlated with plant community dissimilarity (spatial autocorrelation). If spatial autocorrelation was present, communities which are spatially closer together would be more compositionally similar. Where communities which are closer together are more similar, this may be due to different environmental conditions in different areas, and can indicate that environmental factors not tested may affect plant community composition. Geographic distance was measured as the distance between quadrats surveyed, in kilometres. Plant community dissimilarity was quantified using the Bray-Curtis dissimilarity index. Mantel tests were run using Pearson's product-moment correlation, and 999 permutations.

Mantel tests were performed for all the data across the four farms, and for each of the four farms individually.

3.3.6.3 Plant community composition and margin characteristics

Canonical correspondence analysis (CCA) (Ter Braak, 1986) was used to provide a graphical summary of the relationship between plant community composition and the 12 margin characteristics recorded.

Two CCAs were run: a full CCA and a simplified CCA. A full CCA, which included all 12 explanatory variables (listed in Table 3.2), was conducted. The variance inflation factor, a measure of multicollinearity between variables in the CCA, was calculated for each margin characteristic. As some margin characteristics, such as those controlled by management, differed between farms, high levels of collinearity between 'Farm' and other margin characteristics were expected. A simplified CCA ordination therefore was also run, which did not include 'Farm' as a variable. This simplified CCA included the other 11 margin characteristics as explanatory variables. Variance inflation factors were also calculated for the simplified CCA.

For both CCAs, ANOVA-like permutation tests (999 permutations) were used to test the significance of: the overall CCA; each CCA axis; each of the margin characteristics contributing to the model.

3.4 Results

A total of 104 plant species were recorded across the four farms, with 815 plant records in total. The most common plant species over the four farms were cock's-foot *Dactylis glomerata* L., hogweed *Heracleum sphondylium* L. and stinging nettle *Urtica dioica* L., all found in 54 of the 120 quadrats surveyed, and cleavers *Galium aparine* L., found in 49 of the 120 quadrats surveyed. 35 of the 104 species were only found in one of the 120 quadrats surveyed: 19 species at Farm D, 14 at Farm A, 2 at Farm B and none at Farm C.

Species richness in each quadrat surveyed over the four farms ranged from 1 to 14 species per m^2. No Red List endangered plant species were found (listed in Cheffings and Farrell 2006). A complete list of the plant species found at each farm is given in Appendix 5.

3.4.1 Variation in field margin plant species richness over four farms

A one-way ANOVA showed that at least one farm had a significantly different field margin plant species richness per m^2 ($F_{3, 43} = 7.58$, $p = 0.000355$, Figure 3.2). Farm D had the highest plant species richness per m^2 per margin of 8.61 ±1.97 species (mean ±SD). Farm A had an intermediate plant species richness of 6.64 ±1.45 species. Farm B and Farm C had the lowest plant species richness per margin, with 5.92 ±1.88 species and 5.68 ±1.28 species respectively.

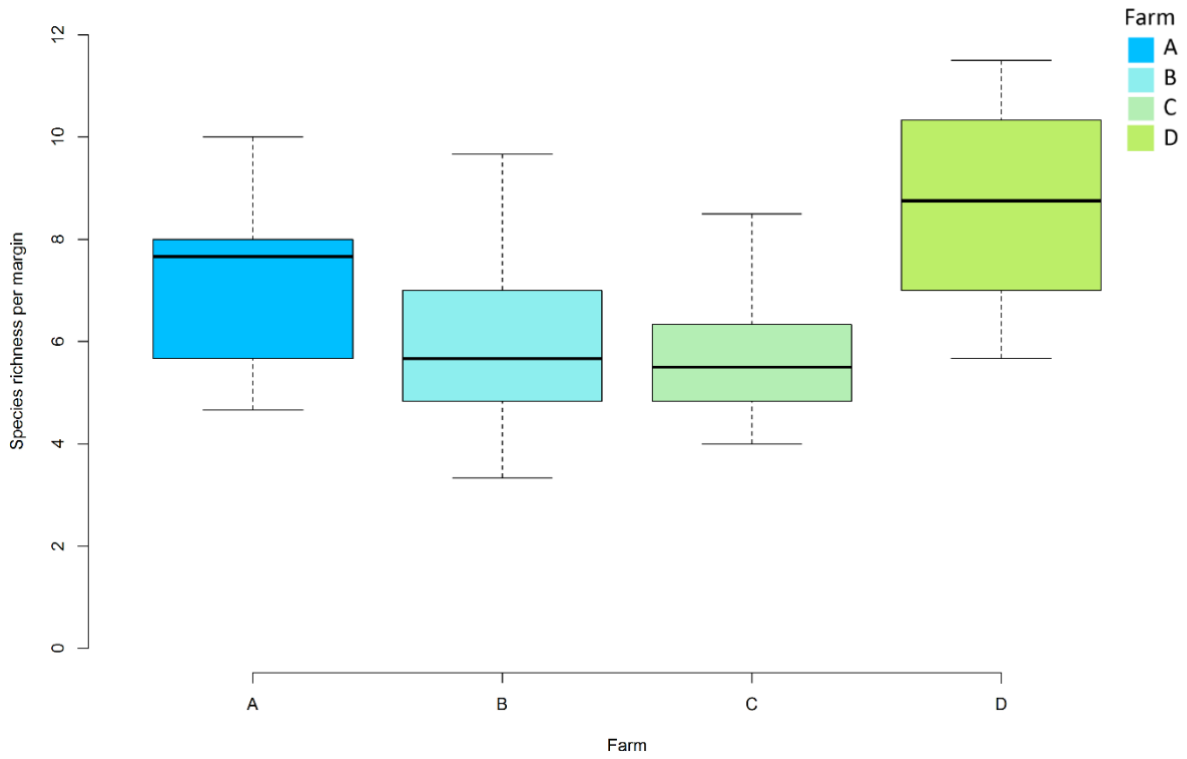


Figure 3.2 The plant species richness in field margins over four different farms (A, B, C, D). The median, upper and lower quartiles, and range are plotted. Farm A, n = 12; Farm B, n = 11; Farm C, n = 12; Farm D, n = 12.

The NMDS analysis showed no evidence of plant community divisions between farms, as the plot showed no clear clustering of plots in two-dimensional space (Bray-Curtis dissimilarity index, stress value = 0.22, Figure 3.3). The stress value associated with this NMDS was relatively high, and so interpretation of the plot should be done cautiously.

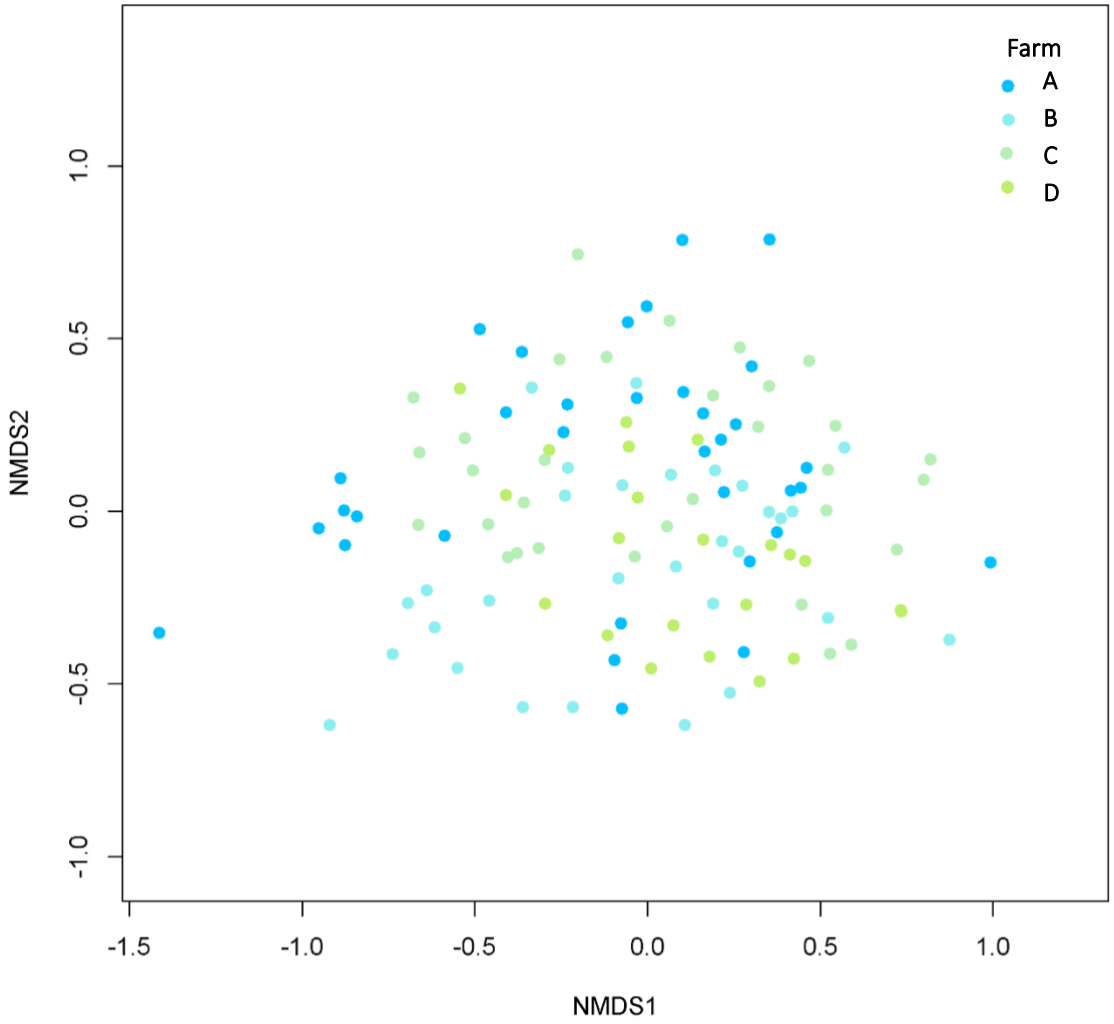


Figure 3.3 Non-metric dimensional scaling (two dimensions) of plant communities across four farms, with Bray-Curtis dissimilarity index. NMDS stress value = 0.22, n = 120.

ANOSIM was performed to establish if each farm had different plant community compositions, which were not visually identified in the NMDS plot. The ANOSIM indicated small but significant differences in plant community composition in quadrats between farms ($R = 0.0945$, $p = 0.001$, $n = 120$). Whilst the results are statistically significant at $p < 0.05$, the test static, R, is very close to 0. This suggests that both high and low community similarities are seen both between farms and within farms. These results support the lack of groupings of plant communities by farm observed in the NMDS.

The result of the Mantel test for spatial autocorrelation between plant community composition (Bray-Curtis dissimilarity index) and geographic distance (kilometres) between quadrat locations over all four farms showed a significant but very weak positive correlation between geographical distance and community dissimilarity ($r = 0.0662$, $p = 0.004$, $n = 120$).

Within farm Mantel correlation tests for each of the four farms independently showed no consistent correlation between geographic distance between samples (quadrats) and plant community composition (Table 3.3). A significant positive correlation was observed between community dissimilarity and geographic distance at Farm A and Farm D. No correlation was observed at farms B and C.

Farm	Mantel statistic r	p-value
A, n = 34	**0.43**	**0.001**
B, n = 24	0.069	0.225
C, n = 30	0.029	0.278
D, n = 32	**0.27**	**0.001**

Table 3.3 The results of four Mantel correlation tests, between plant community dissimilarity (Bray-Curtis dissimilarity index) and geographic distance (km) between sample sites within each farm. Significant differences (p <0.05) are shown in bold.

3.4.2 Margin characteristics and plant community composition

Full CCA

In the full CCA, based on all 12 explanatory varaibles, the total variation in plant community composition explained was 44% (Table 3.4). The explained variation in plant community composition was significant (ANOVA-like permutation test, (999 permutations): $F_{29, 58} = 1.57$, p = 0.001). ANOVA-like permutation tests showed that 11 of the 12 margin characteristics significantly affected plant community composition (p <0.05, Supplementary Table 9.1 and Figure 9.3). Presence of a fence did not significantly affect plant community composition at p <0.05 ($F_{1, 58} = 0.895$, p = 0.484). 56% of variation in plant community composition was unexplained by the 12 margin characteristics.

The variance inflation factor, a measure of collinearity between variables, was very high (more than 20) for some variables. Variance inflation factors were calculated for each level of the 12 margin characteristics, for 29 variable levels in total. 11 of the 29 variable levels included in the CCA had a variance inflation factor of more than 20 (variance inflation factors are given in Supplementary Table 10.2). This means that the percentage variation explained in plant community composition by
this full CCA is inflated, as multiple variables explain the same variation.

	Overall model	CCA axis 1	CCA axis 2	CCA axis 3
Variation explained	44%	4.8%	4.1%	4.0%
Permutation test	$F_{29, 58} = 1.57$ **p = 0.001**	$F_{1, 58} = 4.99$ **p = 0.017**	$F_{1, 58} = 4.22$ **p = 0.034**	$F_{1, 58} = 4.10$ **p = 0.034**

Table 3.4 The contribution of the first three CCA axes to the full CCA. Significant differences (ANOVA-like permutation test, 999 permutations) at p <0.05 are shown in bold. n = 120.

Simplified CCA

In the simplified CCA, where 'Farm' was not included as a factor, 40% of the variation in plant community composition was explained. In this simplified model, four of the 26 variable levels had a variance inflation factor of more than 20, indicating some collinearity in the model (exact variance inflation factors are listed in Supplementary Table 9.2). The four variables with high variance inflation factors were: herbaceous vegetation height, hedge shape C, hedge height and hedgerow gaps of greater than 5 m.

The simplified CCA was significant (ANOVA-like permutation test (999 permutations): $F_{26, 61} = 1.57$, p = 0.001). ANOVA-like permutation tests showed 10 of the 11 margin characteristics significantly affected plant community composition (Supplementary Table 9.3). Presence of a fence ($F_{1, 61} = 1.22$, p = 0.157) did not significantly affect plant community composition (p >0.05).

The percentage variation explained by each CCA axis is shown in Table 3.5. ANOVA-like permutation test (999 permutations) showed that the first three axis of the CCA significantly accounted for variation in plant community composition ($p < 0.05$).

The CCA ordination diagram (Figure 3.4) shows that axis 1 represents characteristics descriptive of adjacent features and plant structural diversity. Indicator species (cleavers) and adjacent land use (grass-road) is positioned at one end of the axis, and hedge height to base, hedge width and herbaceous vegetation height at the other end. Factors at opposite ends of axis are associated with different plant communities. Axis 2 represents margin state, with margin width at one end of the axis and presence of nettles as an indicator species at the other end. Hedge shapes D (tall and leggy) and E (untrimmed with outgrowth) are also positioned at the end of axis 2.

	Overall model	**CCA axis 1**	**CCA axis 2**	**CCA axis 3**
Variation explained	40%	4.6%	4.1%	3.7%
Permutation test	$F_{26, 61}$= 1.57 **p = 0.001**	$F_{1, 61}$ =4.71 **p = 0.031**	$F_{1, 61}$ = 4.14 **p = 0.032**	$F_{1, 61}$ = 3.72 **p = 0.039**

Table 3.5 The contribution of the first three CCA axes to the simplified CCA. Variations explained by axis significant (ANOVA-like permutation test, 999 permutations) at the p <0.05 level are in bold. n = 120.

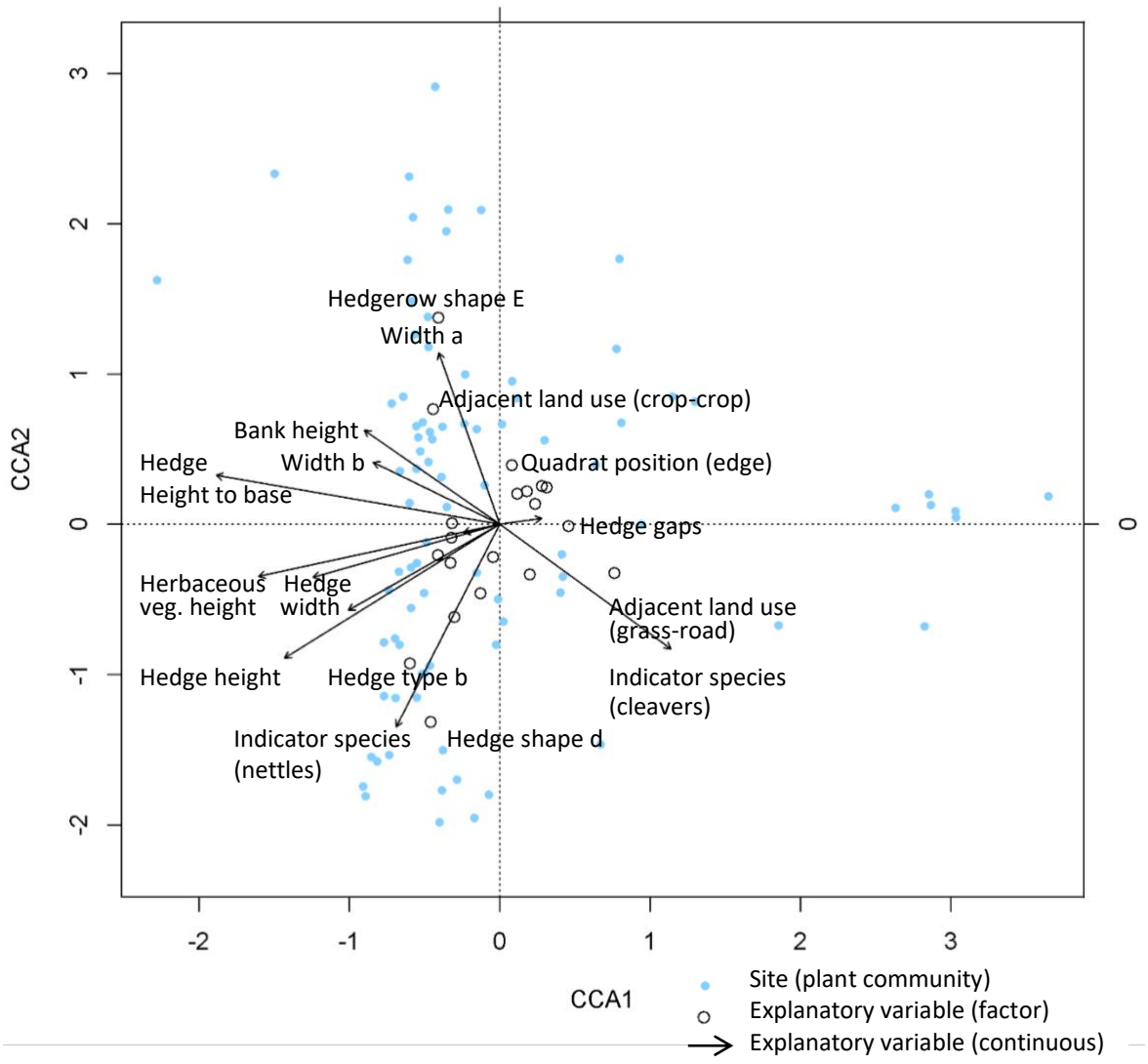


Figure 3.4 A CCA ordination diagram (axis 1 and 2) from the simplified CCA, containing 11 margin characteristics. 40% of variability in plant community composition is explained for by the 11 explanatory variables in this CCA. n = 120. Not all explanatory variable labels are shown, labels were prioritised based on the relative importance of each variable.

3.5 Discussion

Similar groups of plant species were found across the four farms, with no species of conservation concern identified in any field margin. These results do not support the hypothesis that geographic distance between farms and difference in plant community composition are correlated, at the scale investigated here. 11 margin characteristics significantly contributed to explaining 44% of the variation in plant community composition, including farm identity. This supports the hypothesis that both field margin characteristics and farm identity affect plant community composition in field margins.

These results suggest that plant community composition in field margins may not be driven by environmental factors which vary on a spatial gradient between farms up to 50 km apart. This data adds to our understanding of the factors which affect plant community composition in field margins across different farms. This is important when considering the management of field margins for conservation. The results show that different farms within the same region may have different field margin plant species richness.

3.5.1 Field margin plant diversity over four farms

3.5.1.1 Plant species richness

Plant species richness varied between the four farms studied, which were in the same region. Even though the four farms surveyed are all committed to Higher-Level agri-environmental schemes, and appear to be similar in terms of geology, climate and cropping, one farm had 2 – 3 species per m^2 more than the other farms. With species richness in field margins being relatively low, ranging from 1 - 14 species per m^2 over the four farms, this increase in 2 – 3 species per m^2 is relatively large. These differences in species richness between field margins at different farms supports a previous study, which found different mean levels of species richness in field margins in different farms (Moonen and Marshall, 2001). Moonen and Marshall (2001) found a difference of 2.8 species per field margin (surveyed in 25 m long plots), when comparing two different farms.

Differences in species richness may be driven by differences in both management, environment and land-use history. Notably, Farm D, the farm with the highest species richness, is an organic farm, whilst the other farms are not. Biodiversity on organic farms has been shown to be higher than on non-organic farms (Tuck *et al.*, 2014). Whilst the field margins across all four farms are managed as part of Higher-Level agri-environmental schemes (and so subject to similar field-margin management), different management on adjacent land, as an organic farm, may affect plant species richness. It has been suggested the finding of higher biodiversity levels on organic farms is due to restricted herbicide use (Rundlöf, Edlund and Smith, 2010).

Whilst higher species richness per margin was observed at Farm D, similar species within plant communities sampled were found across all farms. In a study across two farms, Moonen and Marshall (2001) report that the species pools in field margins across two farms were essentially identical. At the scale investigated in this study, field margins contain similar plant species across different farms.

3.5.1.2 Spatial correlations between plant communities

A very weak correlation between geographic distance and plant community similarity was observed across all four farms. The strength of this correlation was very low (r = 0.0662) and therefore difficult to interpret. There are at least three hypotheses which may explain the lack of strong spatial autocorrelation observed between plant communities over the four farms in this study. This could be explained by patchy environmental variables, which do not vary on a gradient with distance (Diniz-Filho, Bini and Hawkins, 2003). If this were the case, farms which are closer together are no more likely to have similar plant communities than those far apart, and so there would be no clear, ecological benefit to agri-environmental schemes in field margins targeted at a local level. Alternatively, the lack of strong spatial autocorrelation may be controlled by factors which vary stochastically, which are very difficult to predict (Haydon and Steen, 1997). This would mean that practically speaking, agri-environmental schemes can only predictably affect a limited amount of variation in plant communities. Finally, the lack of strong spatial autocorrelation at this scale may be explained by management variables, which vary between farms, but are not spatially correlated. If this were the case, grouping of plant communities by farm (but not distance) would be expected, however this was not shown.

At a smaller, within-farm scale, two farms showed a medium positive correlation between geographic distance between plant communities and plant community composition dissimilarity. At these two farms (A and D), communities surveyed from margins which were geographically further apart had less similar plant community composition. This suggests that despite similar plant species communities being observed over all four farms, at a smaller farm-scale, there may be some effect of spatial autocorrelation. Whilst spatial synchrony is expected for climate (such as rainfall and temperature) (Koenig, 1999), other environmental factors (such as soil nutrients, soil type) may be patchy within the landscape. Where only small distance autocorrelation is observed (here, stronger within farm correlations are detected than between farms) spatial variation may be structured in patches (Diniz-Filho, Bini and Hawkins, 2003).

The presence of spatial autocorrelation within some farms observed here suggests that field margin plant communities may be affected by variables which vary on a spatial gradient within farms, but not between farms. Spatial autocorrelation was not investigated in similar studies. This merits further investigation, across a large sample size, to elucidate: if spatial autocorrelation occurs between plant communities in field margins; the scale over which spatial autocorrelation is observed (if at all); what causes spatial autocorrelation (if observed). Answering these questions will have practical implications for the design of conservation schemes.

3.5.2 Margin characteristics and plant community composition

Results of CCA reveal that margin-level characteristics can be used to explain 40% of the variation in plant community composition. This suggests that the management of the entire boundary strip (hedgerow and field margin) and the adjacent land is important for managing plant communities in field margins. The percentage variation explained in this study is greater than that which has been reported in previous studies, where approximately 20% variation is explained (Le Coeur, Baudry and Burel, 1997; Moonen and Marshall, 2001; Deckers, Hermy and Muys, 2004). This may be due to collinearity between explanatory variables. Variables which account for the same variation in plant community composition in the CCA are collinear. Collinearity is frequent in ecological studies, where data is taken from a single region or time (Dormann *et al.*, 2013). Variables may be collinear if they have the same ecological effect: for example, north facing field margins and margins with tall hedgerows may both increase the shading in a field margin. This may result in an increase in shade-tolerant plant communities in both field margins which are north facing, and field margins with tall hedgerows. If there are high levels of collinearity in a CCA, the overall amount of variation in plant community composition explained will be inflated. Pre-analysis variable selection was undertaken to reduce the impact of collinearity.

The margin characteristics which were here shown to significantly explain variation in plant community composition were: adjacent land use, aspect, bank height, hedge characteristics, hedgerow shape, hedgerow type, herbaceous vegetation height, presence of indicator species, margin width, and quadrat position.

The largest amount of variation in plant community composition was explained by variation in plant structural diversity (height to base of hedgerow, hedgerow width and herbaceous vegetation height in the field margin). Plant structural diversity is easily manageable, and has been shown to affect plant community composition in field margins in previous studies (Le Coeur, Baudry and Burel, 1997; Moonen and Marshall, 2001).

Hedgerow shape and hedgerow type are shown to have a smaller, but still significant effect, on plant community composition in field margins. Plant structural diversity of hedgerows is likely to affect plant communities due to the creation of different ecological niches, due to shading. Hedgerow structure, including width, has been shown to be associated with a different plant community composition in adjacent field margins (Le Coeur, Baudry and Burel, 1997; Moonen and Marshall, 2001)

Variation in field margin herbaceous vegetation height was associated with differences in plant communities. This may be explained for by the Intermediate Disturbance Hypothesis (Grime, 1973; Connell, 1978). In field margins, herbaceous vegetation height is controlled actively through cutting, which increases the number of niches in field margins, and prevents domination by any single species. This mechanism may be responsible for the differences in plant communities associated with different herbaceous vegetation height in field margins. Herbaceous vegetation height in field margins can be indicative of mowing management (Defra, 2007) which has been shown to affect plant diversity in field margins (Hovd and Skogen, 2005; Jantunen *et al.*, 2007).

Other variation in plant community composition is explained by margin width and the presence of nettles and cleavers as an indicator of nutrient enrichment in field margins. Wider margins are expected to support higher species richness, predicted by the Theory of Island Biogeography (MacArthur and Wilson, 1967). Margin width is already managed as part of agri-environmental schemes, with wider margins gaining higher payments (Rural payments agency, 2017). Previous studies showed that margin width affect plant diversity in field margins (Moonen and Marshall, 2001; Hovd and Skogen, 2005). Nutrient levels in field margins may affect plant communities, as varying nutrient levels are likely to suit different species. The presence of nettles and cleaver as indicators is used to determine nutrient enrichment from fertilisers beyond the edge of the crop (Defra, 2007). Previous studies have not included this in multivariate ordination analysis.

Variation in field margin characteristics is expected to affect the plant community composition, due to altering the environment present within each field margin. Greater heterogeneity in margin characteristics is expected to result in a greater number of different niches between field margins, which is predicted to increase biodiversity (Benton, Vickery, and Wilson 2003; Kleijn *et al.* 2011). This will mean that a greater range of plant communities will be supported in field margins.

The factors which here are shown to significantly affect plant community composition are similar to those reported in single-farm or landscape level studies of field margins (Le Coeur, Baudry, and Burel 1997; Moonen and Marshall 2001; Deckers, Hermy, and Muys 2004; Hovd and Skogen 2005; Marshall, West, and Kleijn 2006). This suggests that some management prescriptions can be generalised for field margin management, at least at the county-level explored here. Many of the margin characteristics can be adjusted by management or through landscape planning, and so could be practically included in conservation management.

3.5.3 Farm identity and plant community composition

Including farm identity as an explanatory variable of plant community composition explained a further 4% of the variation. This increase in the variation in plant community composition explained is similar to that found by Moonen and Marshall (2001), who found an additional 5.4% variation in plant community composition was explained when including 'Farm' in a multivariate ordination analysis.

Excluding farm identity in analysis reduced the levels of collinearity between explanatory variables. High levels of collinearity associated with the variable 'Farm' suggests that farm identity represents (in part) a combination of margin characteristics associated with each farm. Collinearity between farm identity and explanatory variables was not expected as collinearity was not reported in a previous study (Le Coeur, Baudry and Burel, 1997). Le Coeur *et al.* found that over three sites, 'site' (similar to 'Farm' here) explained variation in plant community composition, however low variance inflation factors (of less than 3) were reported between 'site' and margin characteristics. The margin characteristics investigated by Le Coeur *et al.* were similar to the variables included in this study, and categorised into: hedge structure variables, adjacent land use and herb layer management factors. These contrasting results merit further investigation, but could be due to Le Coeur *et al.*'s study specifically covering three sites associated with different land cover patterns and field sizes at a landscape scale. In this study, farms were chosen for having similar land cover patterns and field sizes, in order to establish the extent to which margin-level characteristics may affect plant community composition in field margins.

A lack of spatial autocorrelation between farms and plant community composition make it difficult to narrow down what might be responsible for the variation in plant community composition which is not explained in the analysis presented here. Future work, focusing on the spatial variation in factors likely to affect plant communities, may elucidate the mechanisms responsible for farm identity explaining variation in field margin plant communities.

3.5.4 Conclusions

Over four farms in Oxfordshire, large differences were observed in plant species richness but only small differences in plant community composition. These results suggest that the plant communities in field margins do not vary greatly between farms in the same county.

Nine of the 11 margin characteristics investigated are shown to account for 40% of the variation in plant community composition. Whilst this figure is relatively large compared to other studies, this may be due, in part, to collinearity between margin characteristics. Nonetheless, 60% of variation in plant community composition is unaccounted for. Given the lack of strong spatial autocorrelation at the scale of this study, it is not clear if stochasticity, environmental factors or variables indicative of management not included in this analysis are responsible for this unexplained variation.

Farm identity also explains some variation in field margin plant community composition in this study. This is due, in part, to correlations between farm identity and margin characteristics. This suggests that some of the differences in plant communities between farms may be due to management of margin characteristics.

It is concerning that, over 47 field margins surveyed, at farms committed to Higher-Level agri-environmental schemes, no endangered plant species were observed. As no rare species were found in these field margins surveys, and communities do not vary greatly between farms, conservation in field margins could focus, in part, on the heterogeneity of plant communities in field margins. These results suggest that heterogeneity in field margin boundary structure and adjacent features is likely to increase the heterogeneity of the field margin plant communities across farms.

Chapter 4: The associations between field margin structure and butterfly diversity in field margins

Contributions

Data collection for this chapter was undertaken by the author, with a contribution of 140 of the 288 field margin butterfly surveys undertaken by Ellen Stickland. Field margin characteristic surveys and plant surveys were all undertaken by the author.

Supplementary materials

Supplementary tables for this chapter can be found in Appendix 3.

4.1 Chapter summary

To better understand the relationship between butterfly diversity and field margin structure, an observational study was conducted over 60 field margins at a farm in Oxfordshire. This chapter investigates if field margin structure affects butterfly diversity, due to differences in both plant species composition (e.g. food plant presence) and plant structural diversity (e.g. habitat structure). Understanding the factors which effect butterfly diversity in field margins is critical for effective land management for butterfly conservation, via agri-environmental schemes.

This observational study was conducted to describe the relationship between five characteristics, descriptive of the field margin structure, and butterfly diversity. These five characteristics (adjacent land use, margin aspect, margin vegetation height, margin width, and plant species richness) have previously been suggested to affect butterfly diversity, across different spatial scales and in different geographic areas. Plant species lists were also compared to butterfly species lists, to understand if food plant presence is required for butterfly presence, at a field margin scale. Butterfly diversity was surveyed across 60 margins, throughout June and July 2016, with at least four repeats per margin.

The five margin characteristics measured explained 16% of variation in butterfly community composition at each margin. Out of the five characteristics, butterfly species richness was significantly associated with higher field margin plant species richness and intermediate vegetation height.

Contingency analysis on the presence of adult and larval primary food plants and the presence of butterflies in the same field margin revealed significant positive associations for two of the five butterfly species investigated. Ringlet *Aphantopus hyperantus* L. butterflies were more likely to be found in margins with larval primary food plants present. Essex Skipper *Thymelicus lineola* Oschenheimer butterflies were more likely to be found in margins with at least one adult or larval primary food plant present. No positive correlations were identified for Small White *Pieris rapae* L., Large White *Pieris brassicae* L. or Meadow Brown *Maniola jurtina* L. butterfly presence and presence of their primary food plants, possibly due to the higher mobility of adult butterflies.

The results reported here show that butterfly species community composition is associated with elements of field margin boundary structure, and that higher butterfly species richness is associated with different field margin structure characteristics. The presence of some butterfly species is shown to be independent of primary food plant species presence in field margins. However, some species are observed to be significantly more likely to be found in field margins with adult or larval primary food plants present.

These results suggest that field margin structure may impact butterfly community composition and species richness at the margin scale. Field margin management for butterfly conservation with a focus on increasing plant species richness, particularly ensuring food plant presence at a field margin scale, and managing vegetation height, is likely to increase butterfly presence and affect the butterfly community composition in field margins.

4.2 Introduction

Across the UK, butterfly species are declining at both a national and regional scale (Thomas *et al.*, 2004). In farmland, this decline in butterfly populations has been attributed to a variety of causes, including the degradation or loss of hedgerows and field margins (Dover and Sparks 2000). With agricultural land covering 72% of the UK (Defra, 2018a), agricultural land provides a valuable opportunity for butterfly conservation. Understanding how farmland management of field margin structure affects butterfly populations is therefore critical for butterfly conservation in the UK.

Butterfly diversity is valued in farmland for a number of reasons. Butterfly diversity contributes to ecosystem functioning, through non-crop plant pollination (Kremen *et al.*, 2007, Oliver *et al*., 2015a) and sustaining farmland bird populations with larvae providing a food source (Vickery, Feber and Fuller, 2009). Due to the reliance of some plants and birds on butterfly species for pollination or food, decline in butterflies may be linked to declines in plant and bird species. Butterflies are also greatly valued as a flagship group for conservation (Fox *et al.*, 2015), as well as being charismatic species that benefit human well-being (Dallimer *et al.*, 2012).

Between 1976 and 2014, 76% of the UK's resident and regular migrant butterfly species have experienced declines in either abundance, occurrence, or both (Fox *et al.*, 2015). This decline in butterfly species is largely attributed to changes in management practices on farms over the past 100 years (Robinson and Sutherland, 2002), and may also be exacerbated by climate change (Oliver *et al.,* 2015b). Many butterfly species have highly specific habitat requirements (Thomas *et al.*, 2001), and so changes in the field margin habitat, mediated by changes in farmland management practices, may be responsible for changes in butterfly diversity. When modelled, increasing the quantity and quality of field margins (as encouraged by agri-environmental schemes) increased number of eggs laid and average lifespan of the butterfly *Maniola jurtina* L. (Evans *et al.,* 2019). Management changes resulting in alterations in vegetation structure, such as vegetation height, have been attributed to changes in butterfly abundance of certain species (Thomas *et al.*, 2001). The loss of herbaceous vegetation in margins due to close ploughing, and decline in hedgerow and field margin quality due to drift from fertilisers and herbicides, is blamed for loss of butterfly diversity in farmland (Dover and Sparks, 2000). Specifically, changes affecting food plant abundance in agricultural land are cited as negatively impacting butterfly populations (Smart *et al.*, 2000).

However, there is currently no consensus on what local factors, at a margin scale, affect butterfly diversity on farmland. Studies conducted at a landscape-scale have identified factors which impact butterfly diversity in Oxfordshire (Botham *et al.*, 2015), but no studies have focussed on the impacts of field margin structure (plant species diversity and structural diversity) on butterflies in Oxfordshire. It is likely that the management of field margins, shown to impact plant community composition in field margins (Moonen and Marshall, 2001; Deckers, Hermy and Muys, 2004; Hovd and Skogen, 2005), will also impact butterfly diversity. Establishing the role of primary food plant species in determining butterfly diversity at a margin scale, as well as understanding if the structure of field margins affect butterfly diversity, could greatly improve action taken for butterfly conservation.

Field margin structure can be broken down into both the physical structure of the plant communities (such as vegetation height) and the plant community composition (including species richness, species abundance and species identities). Five elements of field margin structure that

have been suggested in previous studies to impact butterfly diversity, to varying degrees, are explored in this study: adjacent land use, margin aspect, margin vegetation height, margin width, and plant species richness. All these factors can be controlled through management or, in the case of margin aspect, easily incorporated into conservation measures.

The management of land adjacent to margin boundaries has been shown to impact butterfly diversity. Adjacent land uses reported to increase butterfly diversity include woodlands (Sparks and Parish 1995; Dover and Sparks 2000) and grasslands (Rands and Sotherton, 1986). Butterfly abundance and species richness in field margins is reported to be negatively associated with adjacent tracks (Dover 1996; Dover and Sparks 2000).

Margin aspect, due to different levels of shading and shelter from hedgerows of different aspects, may affect butterfly community composition. Dover (1996) found there to be no impact of margin aspect on butterfly diversity. However, factors which may be a result of margin aspect are shown to affect butterfly distributions, such as shelter and insolation (the amount of solar radiation which reaches the soil) (Dover 1996).

Margin vegetation height, managed by margin mowing, has been shown to significantly affect butterfly diversity. Margin mowing is required in some agri-environmental schemes options (HGCA, 2005), and so understanding how this affects butterfly diversity is particularly important. Butterfly species richness has been shown to be greater in margins with taller vegetation (Öckinger and Smith, 2006; Milberg *et al.*, 2016) and with a reduction in margin mowing (Courtney and Duggan, 1983).

Increases in margin width are predicted to increase the levels of butterfly diversity by niche theory (Hutchinson, 1957) and Island Biogeography theory (MacArthur and Wilson, 1967). Wider margins are likely to contain greater heterogeneity, and therefore a greater number of niches. This is likely to support a greater diversity of butterfly species. At a population level, higher heterogeneity in wider field margins will result in greater butterfly population stability (Oliver *et al.*, 2010). Wider field margins have been shown to increase butterfly abundance in farmland for three common butterfly species (Dover 1996).

Levels of plant species richness and plant community composition in field margins are likely to affect butterfly diversity. Croxton *et al.* (2004) report a positive correlation between plant species richness and butterfly species richness. This may be due to greater availability and range of food plants. Changes in butterfly nectar sources have been shown to affect longevity and fecundity of butterflies (Watt, Hoch and Mills, 1974; Murphy, Launer and Ehrlich, 1983). It is suggested that adult nectar sources may be a limited resource in intensively managed farmland (Dover and Sparks 2000). The management of field margin flowering plants, as a source of nectar for adult butterflies, is therefore likely to affect butterfly diversity. Previous studies on the impact of food plant presence on butterfly abundance and distribution show varying degrees of reliance on food plants at a field margin scale. The level of reliance of butterflies on food plants ranges from correlated with plant species richness (Croxton *et al.*, 2004), to correlated with adult food plant sources (Öckinger and Smith 2006; Bergman *et al.* 2008; Krämer, Poniatowski, and Fartmann 2012), and correlated with larval food plant sources (Croxton *et al.*, 2004). However, some studies, such as Hanski (1999), have found no relationship between flower abundance (a measure of nectar abundance) and specific butterfly species presence (Hanski's study focussed on the Glanville Fritillary *Melitaea cinxia* in the Baltic).

In order to test the hypothesis that field margin structure will impact butterfly community composition and butterfly species richness in field margins, we surveyed butterfly species and their abundance over 60 field margins across a large farm in Oxfordshire, and surveyed five margin characteristics at each field margin. Butterfly community composition was the relative abundance and identity of butterfly species recorded in a field margin. Each field margin was described by five

margin characteristics, descriptive of field margin structure and adjacent structures. These characteristics were: adjacent land use, margin aspect, margin vegetation height, margin width, and plant species richness. Comparisons between the five field margin structure characteristics and butterfly community composition, species richness and species presence – absence, were used to identify associations between butterflies and local scale field margin characteristics.

I also hypothesised that butterfly species presence within a field margin will be positively associated with the presence of primary food plants within the field margin. To understand these interactions, a comparison between butterfly species presence and adult nectar or larval food source primary food plant presence was conducted.

4.3 Methods

4.3.1 Methods overview

To see if there was a link between field margin structure and butterfly diversity, an observational study was conducted in 2016. 60 field margins were surveyed at least four times throughout June and July 2016 for levels of butterfly diversity. Five field margin structure characteristics were surveyed: adjacent land use, margin aspect, margin vegetation height, margin width, and plant species richness. Plant species surveys were conducted using walking transects down the length of each margin. To understand the level of reliance of butterfly species on specific food plant species in field margins, butterfly species presence was compared to primary food plant species presence.

4.3.2 Study site

This research was conducted on a 1,600 ha mixed arable farm in West Oxfordshire. The farm has been managed as part of agri-environmental schemes since 1997, and is currently committed to Higher-Level schemes. As part of the Higher-Level scheme agreement, hedgerows and margins are maintained on the farm, including EF4 Nectar Flower Mix planted margins (containing nectar food plant species for butterflies). The farm is described in detail as ‘Farm A’ in Chapter 1 (Section 1.6.1. Study sites).

4.3.3 Margin selection

In 2015, a full inventory of all field margins across the farm was completed by visiting each field boundary. All field margins were adjacent to either a woodland, crop or road on one side, and a crop on the other side. All field margins were numbered, and adjacent land use and margin aspect was noted for each field margin. Longer margins of over 200 m were split into 100 m sections for surveying. For margins which were between 100 m and 200 m in length, a 100 m section was chosen using random number generation. Some field boundaries had two margins which could be surveyed, one on either side of a hedgerow. These were treated as independent sampling units.

From this a stratified survey design was adopted, balanced for adjacent land use and margin aspect. Margins were randomly selected in each category, using random number generation. A total of 60 margins were surveyed. Due to limitations in the number of field margins associated with each adjacent land use and aspect on this site, 17 crop-road field margins, 20 crop-woodland field margins and 23 crop-crop field margins were surveyed (Figure 4.1). Table 4.1 shows the number of field margins of each aspect and adjacent land uses surveyed.

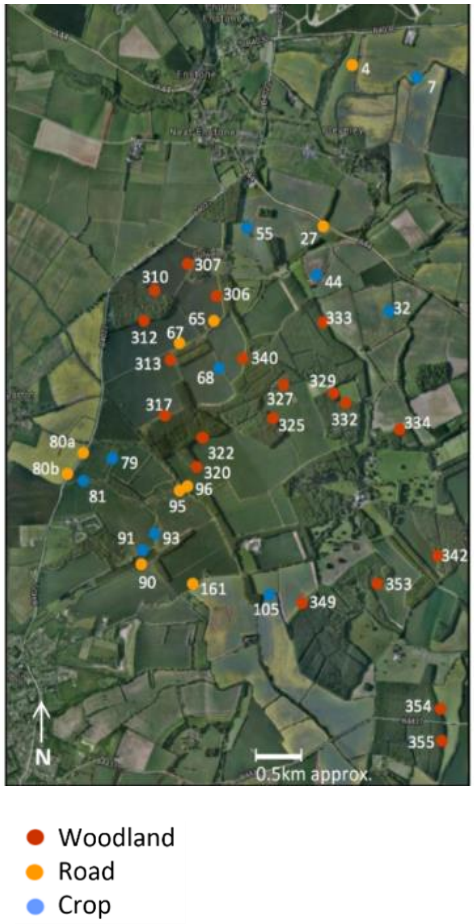


Figure 4.1 A satellite image showing surveyed field boundaries, across the 1,600 ha mixed arable farm in West Oxfordshire, England (made in Google Earth Pro (2015) by Stickland, 2017).

Adjacent land use	**Margin Aspect**				Total field margins
	North-facing margins	South-facing margins	East-facing margins	West-facing margins	
Crop-Road	3	4	5	5	17
Crop-Woodland	5	5	5	5	20
Crop-Crop	6	6	5	6	23
Total field margins	14	15	15	16	60

Table 4.1 The number of field margins surveyed, associated with each adjacent land use and margin aspect. A total of 60 field margins were surveyed.

4.3.4 Margin structure surveys

To record the field margin characteristics associated with each margin, surveys were undertaken once per margin in either 2015 or 2016. Field margins were assessed over the entire 100 m (Figure 4.2). Four characteristics were recorded relating to each margin surveyed: adjacent land use (either crop-crop, crop-road, or crop-woodland); margin aspect; margin herbaceous vegetation height (to the nearest 0.25 m); margin width (to the nearest 0.5 m). The fifth margin characteristic, plant species richness, was calculated from vegetation surveys. The survey methods used to measure each characteristic are listed in Table 4.2. Factors were recorded according to the Hedgerow Survey Standard Procedure (Defra, 2007).

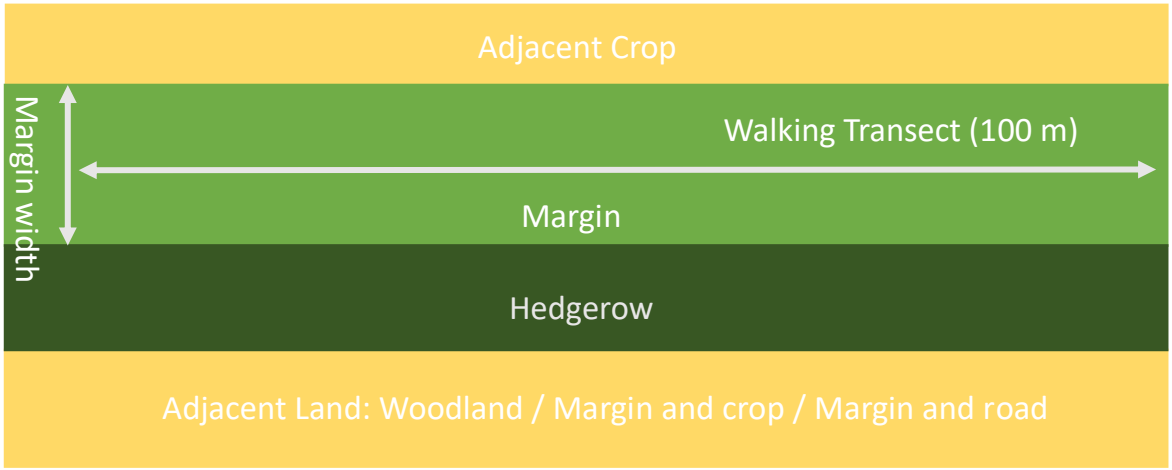


Figure 4.2 The field margin survey set up. Walking transects were used to survey butterflies and plants.

Variable	Levels / range	Survey method
Adjacent Land Use	1. Crop-crop: surveyed margins were adjacent to a crop on one side and to a hedgerow with a field margin and crop on the other side of the hedgerow. 2. Crop-road: surveyed margins were adjacent to a crop on one side and to a hedgerow with a margin and road on the other side of the hedgerow. Roads here included any tarmacked or paved lane which was used by motorised vehicles. The amount of traffic on each road varied from very low on private roads to heavier on B and A roads. 3. Crop-woodland: surveyed margins were directly adjacent to a crop on one side and a woodland on the other side.	Field observation
Margin Aspect	N = north facing, S = south facing, E = east facing, W = west facing.	Determined on a map
Margin herbaceous vegetation height	Mean margin herbaceous vegetation height estimated to nearest 25 cm, estimated over 100 m field margin section. The height of the main herbaceous mass was measured using a tape measure, excluding herbs which extended beyond the tops of the main sward such as spikes of grass. Where vegetation height varied across the margin, the vegetation height covering the greatest area was used. Range: 0.25 – 1.25 m.	Field observation
Margin Width	Mean margin width estimated to nearest 0.5 m, estimated over 100 m field margin section. Range: 0.5 m – 10 m.	Field observation
Plant species richness	Plant species richness per field margin. Plant species were surveyed over a 100 m walking transect.	Field observation

Table 4.2 The recorded field margin structure characteristics with details of survey method.

4.3.5 Vegetation surveys

Plant surveys were conducted once per field margin, between June and August 2016. To survey plant species richness (the fifth margin structure characteristic in this analysis) and the plant species present in each margin, a 100 m walking transect of each margin was conducted. Observations were made across the width of the entire margin, for the 100 m transect (the same distance covered in the butterfly surveys). The vegetation survey followed a random zig-zag pattern across the width of the field margin, determined by the surveyor, who was able to ensure visually heterogeneous areas of the margin were surveyed (similar to the plant survey method described in Rapid Botanical Surveys (Hawthorne and Marshall, 2016)). For each walking transect, the presence and identities of all species were recorded according to Rose and O'Reilly (2006). Where species could not be identified, specimens were taken to be identified by an expert.

4.3.6 Butterfly surveys

Butterfly surveys were conducted fortnightly from June–July 2016 by two individuals, with a minimum of four visits to each margin over this period. Each surveyor undertook approximately half of the butterfly surveys each. Some margins were surveyed five times within this period, with a total of 288 margin surveys completed. Surveys were conducted according to UKBMS butterfly surveying protocol (UKBMS, 2018), so were limited by weather conditions (either above 13° C and 60% sun, or above 17° C and not raining; wind below 5 on the Beaufort scale) and time of day (10.45 am – 15.45 am).

The Pollard Walk, a transect line method, was used to survey butterflies (Pollard, 1977). Each margin was walked 100 m in one direction, with all butterflies within 5 m corridor of the walking transect recorded. Butterflies were recorded to species level, and counts of abundance of each species at each margin were recorded.

4.3.7 Analysis

There were two parts to this analysis: establishing if any of the five field margin characteristics affected butterfly community composition or species richness, and establishing if there was an association between food plant species presence and butterfly species presence at a margin-level. All analyses were performed in Microsoft Excel and *R* statistical software, using the *vegan* package (Oksanen *et al.*, 2017).

4.3.7.1 Butterfly community composition

To establish if any of the five field margin characteristics were associated with differences in butterfly community composition, canonical correspondence analysis (CCA) (Ter Braak, 1986) was used. CCA is a method of constrained ordination, used to provide a graphical summary of the main structure of the community data. The significance of the overall CCA, each CCA axis, and of each explanatory variable in the CCA was tested using an ANOVA-like permutation test (999 permutations). Variance inflation factors, a measure of collinearity between explanatory variables, were calculated.

4.3.7.2 Butterfly species richness

Butterfly species richness was calculated as the mean species richness per margin per visit. To establish if any of the five margin characteristics were correlated with butterfly species richness, a linear model was used. Four margin structure characteristics were included in the initial model as explanatory variables. One explanatory variable (herbaceous vegetation height) was excluded due to violating the assumption of a linear relationship with butterfly species richness. The linear model

was used to see if adjacent land use, aspect, margin width and plant species richness was correlated with butterfly species richness.

When plotted, herbaceous vegetation height and butterfly species richness followed a quadratic relationship, rather than a linear relationship. The association between herbaceous vegetation height and butterfly species richness was then investigated using a quadratic model, where butterfly species richness was predicted by herbaceous vegetation height and the square of herbaceous vegetation height.

Margin characteristics which were shown to correlate with butterfly species richness were plotted independently, in scatter plots (numerical factors) or box plots (categorical factors).

4.3.7.3 Butterfly species and food plant species presence-absence

Presence-absence data for primary food plant species and butterfly species in each margin was compared. Contingency tables were made for each butterfly species with more than 30 individuals observed across the 288 margin-visits against each primary food plant species associated with the larval and adult stages of that butterfly species. 30 observations were chosen as the lower limit of observations with which to conduct this analysis, as many butterfly species had few observations across the two-month survey period, increasing the chance of Type 2 error.

Each butterfly species had between three and six associated primary food plant sources (food plants for each species are listed in Supplementary Table 10.1 and Table 10.2, compiled from Porter 1992, Porter *et al.,* 1992 and Asher *et al.,* 2001). Three lists were compiled for each butterfly species: larval primary food plants; adult primary food plants; and combined lists of both larval and adult primary food plants. Secondary food plants were not included in this analysis, as they are not the first-choice food plant for butterflies, and provide an extensive list of plant species which are likely to be found in all field margins regardless of management, so could not be used to provide targeted management suggestions for field margins.

For each butterfly species, each field margin was assessed according to the three species lists, and noted as having: at least one larval primary food plant present; at least one adult primary food plant present; at least one larval or adult primary food plant present. Butterflies could either be present in a margin with or without a primary food plant present, or they could be absent in a field margin with or without a primary food plant present. This was used to create three contingency tables per butterfly species, one based on larval primary food plant presence, one based on adult primary food plant presence, and one based on at least one adult or larval primary food plant present.

Chi-squared tests were performed to see if there was a significant association between the presence of primary food plants, and the presence of butterfly species, in any margin. Where expected values were too small to conduct a Chi-squared test, Fishers Exact test was conducted.

4.4 Results

Over the two-month survey period, 288 butterfly 100 m transects were walked. A total of 1,949 individuals of 21 species of butterfly were observed. In nine of the 20 woodland margins surveyed at least one Silver-Washed Fritillary *Argynnis paphia* L. was found; a species of conservation concern in the UK due to declines in the past 200 years (Fox *et al.*, 2015). Over half of the butterflies surveyed were one of two species: Ringlet *Aphantopus hyperantus* (575 individuals) and Meadow Brown *Maniola jurtina* (474 individuals). Species surveyed and their mean abundance, over the surveys, grouped according to adjacent land use, are shown in

Species		Mean abundance per margin		
Scientific	Common	Woodland	Crop	Road
Aglais io L.	Peacock	0.02	0.01	0.00
Aglais urticae L.	Small Tortoiseshell	0.03	0.10	0.14
Anthocharis cardamines L.	Orange tip	0.07	0.01	0.01
Aphantopus hyperantus L.	Ringlet	2.58	2.26	1.07
Argynnis paphia L.	Silver-washed Fritillary	0.11	0.00	0.00
Aricia agestis Denis & Schiffermüller	Brown Argus	0.00	0.01	0.00
Celastrina argiolus L.	Holly Blue	0.01	0.00	0.00
Gonepteryx rhamni L.	Brimstone	0.00	0.01	0.01
Maniola jurtina L.	Meadow Brown	2.08	1.61	1.20
Melanargia galathea L.	Marbled White	0.49	0.61	0.12
Ochlodes Sylvanus Esper	Large Skipper	0.55	0.23	0.16
Pararge aegeria L.	Speckled Wood	0.31	0.01	0.03
Pieris brassicae L.	Large White	0.25	0.24	0.38
Pieris napi L.	Green-veined White	0.24	0.06	0.10
Pieris rapae L.	Small White	0.46	0.49	0.48
Polyommatus icarus Rottemburg	Common Blue	0.00	0.00	0.04
Pyronia tithonus L.	Gatekeeper	0.55	0.36	0.16
Thymelicus lineola Ochsenheimer	Essex Skipper	0.66	0.67	0.42
Thymelicus sylvestris Poda	Small Skipper	0.06	0.20	0.19
Vanessa atalanta L.	Red Admiral	0.04	0.04	0.06
Vanessa cardui L.	Painted Lady	0.03	0.00	0.04
Mean species richness ±SD		2.94 ±1.36	2.31 ±0.86	1.89 ±1.19
Mean abundance of species present per margin ±SD		0.81 ±0.56	0.78 ±0.43	0.93 ±0.45

Table 4.3.

Species		Mean abundance per margin		
Scientific	Common	Woodland	Crop	Road
Aglais io L.	Peacock	0.02	0.01	0.00
Aglais urticae L.	Small Tortoiseshell	0.03	0.10	0.14
Anthocharis cardamines L.	Orange tip	0.07	0.01	0.01
Aphantopus hyperantus L.	Ringlet	2.58	2.26	1.07
Argynnis paphia L.	Silver-washed Fritillary	0.11	0.00	0.00
Aricia agestis Denis & Schiffermüller	Brown Argus	0.00	0.01	0.00
Celastrina argiolus L.	Holly Blue	0.01	0.00	0.00
Gonepteryx rhamni L.	Brimstone	0.00	0.01	0.01
Maniola jurtina L.	Meadow Brown	2.08	1.61	1.20
Melanargia galathea L.	Marbled White	0.49	0.61	0.12
Ochlodes Sylvanus Esper	Large Skipper	0.55	0.23	0.16
Pararge aegeria L.	Speckled Wood	0.31	0.01	0.03
Pieris brassicae L.	Large White	0.25	0.24	0.38
Pieris napi L.	Green-veined White	0.24	0.06	0.10
Pieris rapae L.	Small White	0.46	0.49	0.48
Polyommatus icarus Rottemburg	Common Blue	0.00	0.00	0.04
Pyronia tithonus L.	Gatekeeper	0.55	0.36	0.16
Thymelicus lineola Ochsenheimer	Essex Skipper	0.66	0.67	0.42
Thymelicus sylvestris Poda	Small Skipper	0.06	0.20	0.19
Vanessa atalanta L.	Red Admiral	0.04	0.04	0.06
Vanessa cardui L.	Painted Lady	0.03	0.00	0.04
Mean species richness ±SD		2.94 ±1.36	2.31 ±0.86	1.89 ±1.19
Mean abundance of species present per margin ±SD		0.81 ±0.56	0.78 ±0.43	0.93 ±0.45

Table 4.3 The mean abundance, species richness, and overall abundance of butterfly species observed, over three adjacent land use types in 288 field margin surveys. Surveys took place in field margins associated with three different adjacent land use types (woodland n = 17, crop n = 23, road n = 20).

4.4.1 Effects of margin characteristics on butterfly community composition

To investigate the relative importance of five margin characteristics on butterfly community composition in margins, a CCA model was run. Visual assessment of the CCA ordination diagram suggest that margin width, herbaceous vegetation height and plant species richness have the greatest relative impact on butterfly community composition (Figure 4.3 A). Adjacent land use and margin aspect had a smaller impact on butterfly community composition. An ANOVA-like permutation test showed the overall model is significant, but accounted for only 16.3% of the total variation in butterfly community composition across the 60 margins ($F_{8,51} = 1.244$, $p = 0.042$). When each variable in the model was tested using ANOVA-like permutation tests, no variable significantly impacted the model independently ($p > 0.05$, Supplementary Table 10.3).

CCA axis 1 accounts for the greatest variation, with 5.8% of variation in butterfly community composition explained by the five characters in this axis. CCA axis 2 accounts for the second greatest amount of variation, with the five factors included in the model explaining 4.6% of variation in butterfly community composition (Table 4.4). CCA axis 1 and 2 are plotted in Figure 4.3A.

Visual interpretation of the CCA plot showed some butterfly species were associated with one of the five margin structure characteristics (Figure 4.3B). The Brown Argus *Aricia agestis* is correlated

with field margins with higher plant species richness. Holly Blue *Celastrina argiolus* L. and Brimstone *Gonepteryx rhamni* L. butterflies presence are correlated with North-facing margins. Other butterfly species are clumped in the centre of the CCA plot, suggesting that they are not specifically correlated with changes in the value of any of the five margin structures included in this analysis. The spread of margin butterfly community composition in this CCA is large, with no specific groupings visible, suggesting that butterfly communities surveyed in these margins are not strongly divided by any of the five margin characteristics included in this analysis.

Variance inflation factors associated with each explanatory variable were less than 3, suggesting no effect of collinearity between explanatory variables (Supplementary Table 10.4).

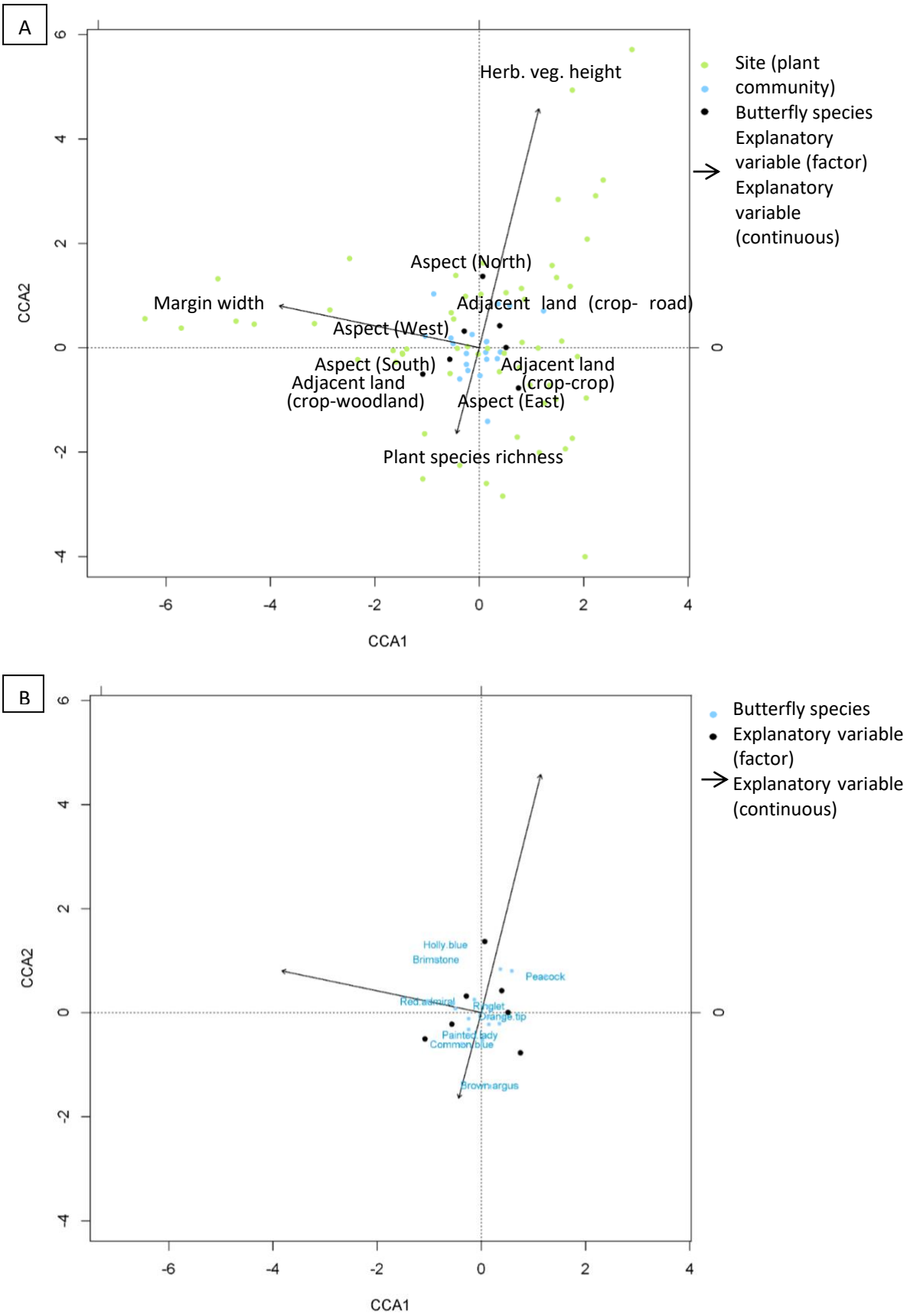


Figure 4.3 A) A CCA ordination diagram (axis 1 and 2) of butterfly communities recorded in 60 margins and five field margin structure characteristics. 16.3% of variation in butterfly community composition is explained for in the CCA model. B) A CCA ordination diagram (axis 1 and 2) of butterfly species (labelled) in relation to five field margin characteristics (labelled in Figure 4.3 A). Not all butterfly species labels are shown.

	Overall CCA	CCA axis 1	CCA axis 2	CCA axis 3
Variation explained	16.3%	5.8%	4.6%	1.9%
Permutation test	$F_{8,51}$ = 1.24, **p = 0.042**	$F_{1,51}$ = 3.51, **p = 0.017**	$F_{1,51}$ = 2.79, p = 0.113	$F_{1,51}$ = 1.15, p = 0.998

Table 4.4 The contribution of the first three CCA axes to explaining variation in butterfly community composition. Significant differences (ANOVA-like permutation test, 999 permutations) at p <0.05 are shown in bold. n = 60.

4.4.2 Effects of margin characteristics on butterfly species richness

A linear model was run to see if the five margin structure characteristics measured were correlated with butterfly species richness. The assumptions of the linear model were met for four of the five characteristics. Herbaceous vegetation height was excluded from the model for violating the assumption of linearity. In the initial model, which included four characteristics (adjacent land use, margin aspect, margin width and plant species richness), only plant species richness significantly contributed to the model. The overall model was significant (Adjusted R^2 = 0.239, $F_{7,52}$ = 3.65, p = 0.00282, Table 4.5).

Variable	Estimate	Standard Error	t – value	p – value
Intercept	0.367	0.642	0.572	0.570
Aspect North	-0.403	0.387	-1.04	0.303
Aspect South	0.156	0.393	0.398	0.692
Aspect West	-0.000519	0.373	-0.001	0.999
Margin Width	0.132	0.0671	1.97	0.0537
Adjacent land use Road	-0.140	0.361	-0.389	0.699
Adjacent land use Woodland	0.480	0.327	1.47	0.148
Plant species richness	**0.0732**	**0.0245**	**2.99**	**0.00423**
Overall model	Adjusted R^2 = 0.239, $F_{7,52}$ = 3.651, p = 0.00282			

Table 4.5 A linear model to show the correlations between five margin structure characteristics and butterfly species richness. The margin characteristics were: aspect, margin width, adjacent land use, margin vegetation height, and plant species richness. Plant species richness significantly correlated with butterfly species richness in this model (significant p value of <0.05 is shown in bold).

Whilst not statistically significant, margins with woodlands as their adjacent land use were observed to have a higher butterfly species richness, with a mean of 2.9 species per margin visit (SD = 1.4), (Figure 4.4). Margins adjacent to roads had the lowest species richness with a mean of 1.9 species per margin visit (SD = 1.2). Margins adjacent to crops had intermediate levels of butterfly species richness with a mean of 2.3 species per margin visit (SD = 0.9).

Whilst the linear model did not show that wider margins were significantly linearly correlated with butterfly species richness, wider margins were associated with higher butterfly species richness. Margins of 2 m or narrower had a mean species richness of 1.48 butterflies (SD = 1.24), whilst margins of 6 m or wider had a mean species richness of 2.83 butterflies (SD = 0.795).

A linear model including the only significant margin structure characteristic (plant species richness) was run. This model showed plant species richness was significantly correlated with butterfly species richness, but had a lot of spread in the data (adjusted R^2 = 0.143, $F_{1, 58}$ = 10.83, p = 0.00170, Figure 4.5).

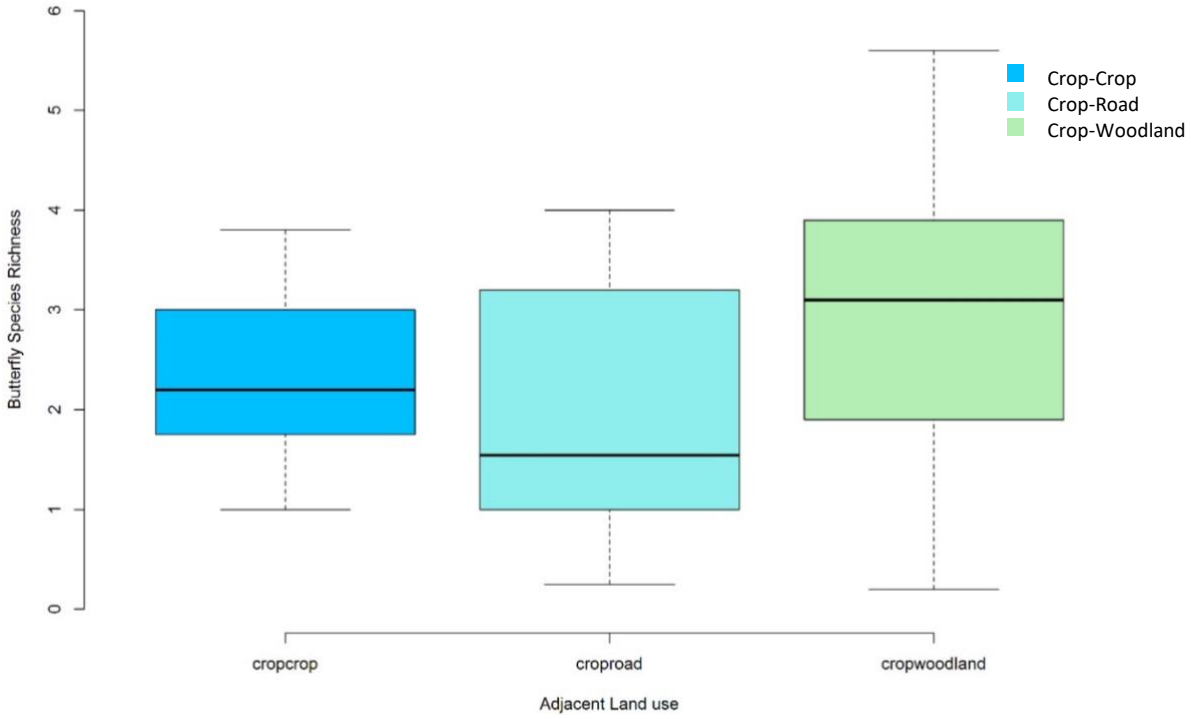


Figure 4.4 The butterfly species richness surveyed in field margins with three different adjacent land uses. The median, 1st and 3rd quartile and ranges are plotted. Crop-crop n =23, crop-road n =17, crop-woodland n =20.

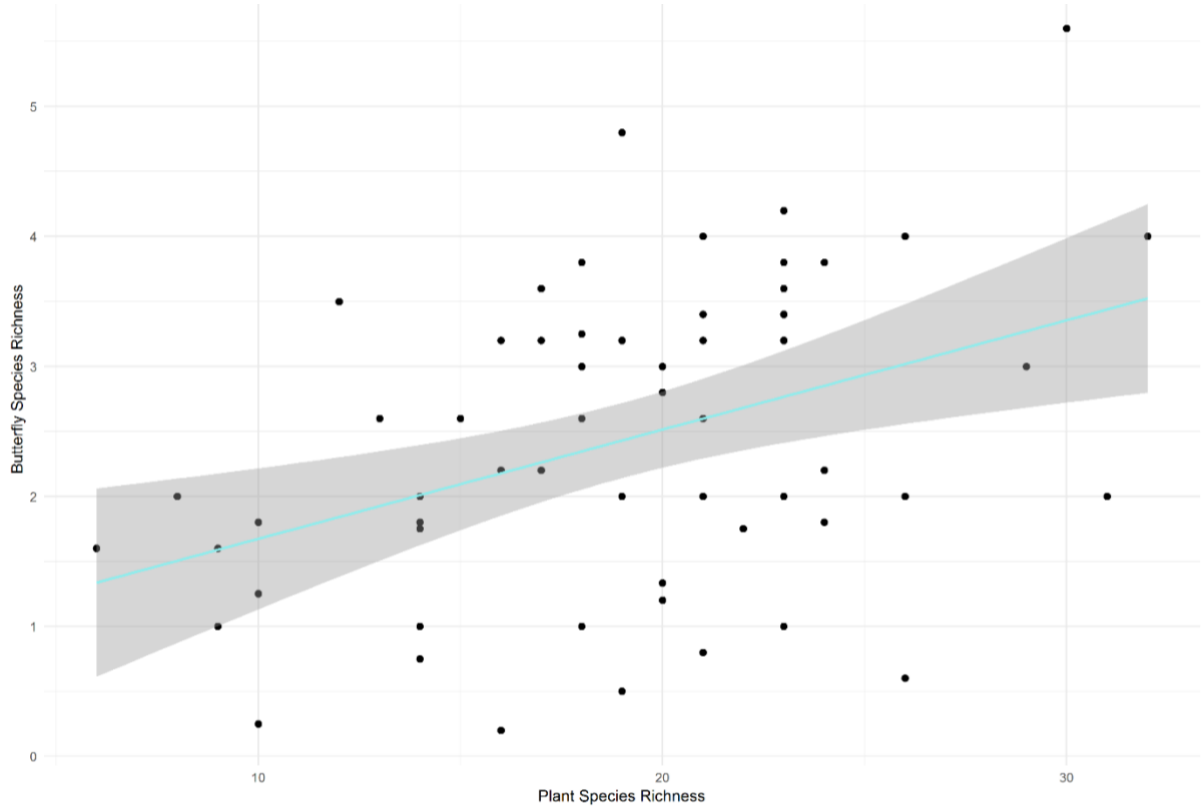


Figure 4.5 The linear relationship between plant species richness and mean butterfly species richness observed in field margins. Field margins with higher plant species richness are associated with higher butterfly species richness. The grey area shows the 95% confidence interval around the linear regression line. 60 field margins were surveyed.

As the relationship between herbaceous vegetation height and butterfly species richness did not follow a linear relationship, a quadratic model was run instead. The relationship is shown in Figure 4.6. The quadratic model included vegetation height, and vegetation height squared, to predict butterfly species richness. This model was significant (at $p < 0.05$), showing a significant association between herbaceous vegetation height and butterfly species richness (adjusted $R^2 = 0.233$, $F_{2, 57} = 9.98$, $p = 0.000192$, Table 4.6).

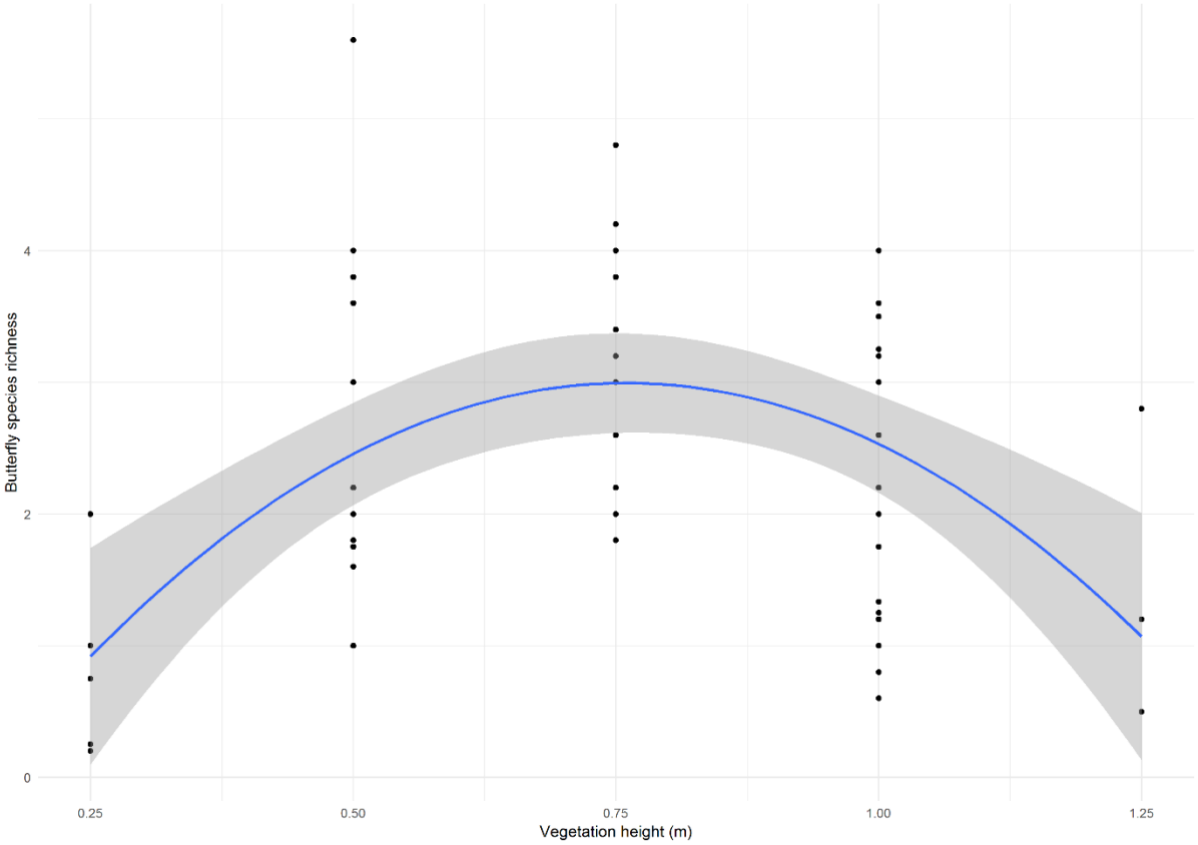


Figure 4.6 A scatterplot to show the relationship between margin vegetation height and butterfly species richness. A line representing a quadratic model based on vegetation height is plotted. The grey area shows the 95% confidence interval around the quadratic model line.

	Estimate	**Standard Error**	**t-value**	**p-value**
Intercept	-1.62	0.936	-1.73	0.0892
Vegetation Height	12.2	2.72	4.47	**3.83×10^{-5}**
Vegetation Height Squared	-8.00	1.84	-4.36	**5.59×10^{-5}**
	Overall model: adjusted $R^2 = 0.233$, $F_{2, 57} = 9.98$, $p = 0.000192$			

Table 4.6 A quadratic model to describe the relationship between butterfly species richness and herbaceous vegetation height. Plant species richness significantly correlated with butterfly species richness in this model (significant p value of <0.05 is shown in bold).

4.4.3 The presence of food plants and associated butterfly species

Five butterfly species had more than 30 individual observations over the 288 field margin surveys. These five butterfly species were analysed via contingency analysis to see if there was an association between butterfly species present in a field margin, and the presence of primary food plants. Three contingency tables were made for each of the five species investigated: one for

presence of butterfly and larval primary food plants in the same margin; one for presence of butterfly and adult primary food plants in the same margin; one for the presence of butterfly and at least one larval or adult primary food plant in the same margin.

Significant associations between butterfly presence and primary food plant presence were found for three of the five species investigated (Table 4.7). No significant association was detected for Meadow Brown *Maniola jurtina* or Large White *Pieris brassicae.*

The Ringlet *Aphantopus hyperantus* showed a positive association between larval food plant presence and butterfly presence in a field margin (Table 4.8 A). Field margins with larval food plants present were more likely to contain adult butterflies. As the Ringlet *Aphantopus hyperantus* had no primary food plants as an adult, when considering margins with at least one adult or larval food plant present, the same positive association was found.

The Essex Skipper *Thymelicus lineola* showed a positive association between at least one adult or larval food plant presence and butterfly presence in a margin (Table 4.8 B). Field margins with at least one adult or larval food plant present were more likely to contain adult butterflies.

The Small White *Pieris rapae* showed an association between larval food plant absence, and butterfly presence (Table 4.8 C). Field margins with larval food plants present were less likely to contain adult butterflies.

No butterfly species showed a correlation between adult primary food plant presence and butterfly presence in a field margin.

Butterfly species		**Larval food plant**	**Adult food plant**	**At least one adult or larval food plant**
Latin	Common			
Pieris rapae	**Small White**	**X^2 (1, N = 60) = 8.65 p = 0.0032**	X^2 (1, N = 60) = 0.889 p = 0.346	X^2 (1, N = 60) = p = 0.796
Pieris brassicae	**Large White**	X^2 (1, N = 60) = 2.37 p = 0.124	X^2 (1, N = 60) = 1.07 p = 0.301	X^2 (1, N = 60) = p = 0.796
Maniola jurtina	**Meadow Brown**	95% CI = 0.368 – 90.1 odds ratio = 5.73 p = 0.126	No primary adult food plants	95% CI = 0.368 – 90.1 odds ratio = 5.73 p = 0.126
Aphantopus hyperantus	**Ringlet**	**95 % CI = 2.72 – 2760 odds ratio = 43.8 p = 0.0022**	No primary adult food plants	**95% CI = 2.72 – 2760 odds ratio = 43.8 p = 0.0022**
Thymelicus lineola	**Essex Skipper**	X^2 (1, N = 60) = 0.25 p = 0.617	X^2 (1, N = 60) = 0.222 p = 0.637	**95% CI = 0.974 – 484 odds ratio = 9.62 p = 0.0268**

Table 4.7 The significance of associations observed between presence of butterfly species and presence of larval or adult food plant species. Contingency tables were analysed for each food plant species and butterfly species, via Chi-squared tests or where the assumptions of this test were violated, Fisher's exact test. The results from these tests are shown in this table. Significant associations (p <0.05) are in bold. Meadow Brown and Ringlet butterflies do not have any primary adult food plants, and so could not be analysed.

A		Ringlet butterfly *Aphantopus hyperantus*	
		Present	Absent
Larval primary food plant	Present	53	3
	Absent	1	3

B		Essex Skipper butterfly *Thymelicus lineola*	
		Present	Absent
Adult and larval primary food plant	Present	36	18
	Absent	1	5

C		Small White butterfly *Pieris rapae*	
		Present	Absent
Larval primary food plant	Present	8	1
	Absent	36	15

Table 4.8 Contingency tables showing the frequency of field margins with primary food plant species presence or absence, and butterfly species presence or absence. Table A shows Ringlet butterflies. Table B shows Essex Skipper butterflies. Table C shows Small White butterflies.

4.5 Discussion

These results show, at a local level, field margin structure is associated with 16% of the variation in butterfly community composition observed in this study. These results support the hypothesis that elements of field margin structure are associated with butterfly species richness and butterfly community composition. Whilst many previous studies have found landscape level factors to be of great importance in affecting butterfly diversity (Debinski, Ray and Saveraid, 2001; Thomas *et al.*, 2001; Soga *et al.*, 2015), these results suggest that local level field margin characteristics should not be overlooked. It is possible that local level management of field margins and hedgerows can result in an increase in butterfly species richness and changes in community composition. Of the five field margin structure characteristics investigated, two characteristics were significantly associated with butterfly species richness: plant species richness and margin vegetation height.

The species-level presence-absence data supported the hypothesis that butterfly species presence is positively associated with primary food plant presence, in some butterfly species. The results presented here indicate that certain butterfly species were positively associated with the presence of larval primary food plants in field margins.

4.5.1 Field margin structure and butterfly community composition

With five field margin structure characteristics explaining 16% of variation in butterfly community composition, there is a small impact of field margin structure on butterfly community composition. Each factor in the CCA did not contribute independently to the butterfly community composition. Together, these margin characteristics explain a low amount of variation and show no significant effect of any single margin characteristic.

The relatively small amount of variation in butterfly community composition explained for by the five margin structure characteristics investigated may be due to other factors, at a larger spatial scale, being of greater importance. Environmental factors measured over a larger spatial scale than a field margin, such as connectivity within a landscape, have been shown to significantly impact

butterfly community composition (Debinski, Ray and Saveraid, 2001), but were not investigated here. The results presented here support Bergman *et al.,* (2004) who found that changes in butterfly community composition associated with differences in herbaceous species richness and margin vegetation height were not detectable at a local scale (500 m radius), a similar spatial scale to this study. However, Bergman *et al.* (2004) found that differences in butterfly community composition associated with differences at a landscape scale (5000 m radius) were detectable. It is therefore likely that landscape-level factors may be responsible for some of the unexplained variation in butterfly community composition in this study.

4.5.2 Field margin structure and butterfly species richness

This observational study suggests that two of the five margin structure characteristics investigated have a significant impact on butterfly species richness. Of the four factors investigated by linear models, only plant species richness was shown to significantly correlate with butterfly species richness. Adjacent land use and margin width are observed to show non-significant correlations with butterfly species richness. It is not surprising that some of the factors included in the analysis do not significantly correlate with butterfly species richness as effects may be masked by other factors, not included in the analysis, accounting for much greater variation, such as landscape factors (Weibull, Bengtsson, and Nohlgren 2000; Debinski, Ray, and Saveraid 2001; Thomas *et al.* 2001; Bergman *et al.* 2004; Soga *et al.* 2015).

The field margin surveys conducted here show a significant positive correlation between plant species richness and butterfly species richness. Previous studies, in which surveys were conducted over a similar spatial scale, have also reported that higher plant species richness correlated with higher butterfly species richness (Croxton *et al.*, 2004). Kramer *et al.* (2012) found in grasslands, higher butterfly diversity and density was found in sites with higher levels of plant host species. In terms of conservation, it is positive that plant species richness is correlated with butterfly species richness, as the same conservation practices can be used to increase species richness in both plants and butterflies in field margins.

Whilst adjacent land use showed limited correlations with butterfly community composition, different adjacent land uses showed non-significant correlations with butterfly species richness. Crop margins adjacent to woodlands resulted in the greatest butterfly species richness, with a mean of 2.9 species per margin (SD = 1.4), compared to 2.3 species (SD = 0.86) in margins with crops on both sides, and 1.9 species (SD = 1.2) in margins with crop and road on either side. This may be due, in part, to the greater structural diversity in the immediate landscape in margins adjacent to woodlands, compared with crop margins adjacent to other crops, or roads. This finding supports a previous study by Dover (1996) which found higher butterfly densities in hedges and woodland edges, compared to farm tracks or grass banks. The lower butterfly species richness in roadside margins may be due, in part, to direct mortality for adult butterflies from road vehicles (Munguira and Thomas, 1992).

The widest margins of 6 m or more supported nearly double the number of butterfly species as the narrowest margins of 2 m or less. Whilst this relationship was not statistically significant, this trend supports previous studies. This increase in butterfly species richness is in line with previous studies which report an increase in margin width (or uncropped land) increased butterfly density (Dover 1996). This is likely to be due to both an increase in the number of niches due to heterogeneity in the margin, and larger population sizes in the field margin, due to the increase in area (Hutchinson, 1957; MacArthur and Wilson, 1967). Furthermore, wider margins are likely to reduce the impact of farming practices further into the margin (cited as the main reason for reduction in butterfly diversity on farmland (Fox *et al.,* 2015)), such as the effects of pesticide and fertiliser run-off (Dover and Sparks 2000). As increased margin width is already incentivised as part of agri-environmental schemes, further research is merited into the impact of margin width on butterfly species richness.

The lack of association between butterfly species richness and margin aspect reported here is unsurprising. Dover (1996) found no effect of margin aspect on butterfly species richness, as also found here. Factors which aspect affect likely to impact butterfly diversity, such as shelter, are affected by other factors too. This means that aspect alone cannot be considered as the only proxy for these factors.

Butterfly species richness and margin vegetation height showed a quadratic relationship, with highest butterfly species richness observed in margins with vegetation height around 75 cm, associated with a butterfly species richness of 3 species per margin visit. Lack of a linear association between margin herbaceous vegetation height and butterfly species richness is surprising. Higher structural complexity from taller margin vegetation is expected to benefit butterflies (Dennis, Young, and Gordon 1998). Previous studies have used vegetation height as a measure of grassland habitat quality (Öckinger and Smith, 2006; Milberg *et al.*, 2016) and field margin habitat quality (Ouin *et al.*, 2004). Differences in butterfly species richness found in this study did not support the use of vegetation height as a linear measure of habitat quality. The relationship observed here may be explained by the finding that different butterfly species prefer different vegetation heights (Thomas *et al.*, 2001). This may explain why the greatest butterfly species richness is observed at an intermediate vegetation height, which may not be optimal for any single species but may overlap with the greatest number of species requirements. A future experimental study, in which vegetation height is manipulated in field margins, will be able to elucidate how vegetation height in field margins affects butterfly diversity.

4.5.3 Primary food plant presence and butterfly species identities

Understanding the relationship between specific butterfly species presence and primary food plant species presence may explain the positive correlation between plant species richness and butterfly species richness, at a field margin scale.

Out of the five butterfly species analysed here, two were significantly more likely to be found in field margins with their primary food plants for either adults or larvae present (Essex Skipper *Thymelicus lineola* and Ringlet *Aphantopus hyperantus*). One species (Small White *Pieris rapae*) was more likely to be found in a margin where larval food plant species were absent. Two species (Large White *Pieris brassicae* and Meadow Brown *Maniola jurtina*) showed no associations with primary food plant presence. These relationships may be explained by the relative mobility of the adult butterflies. Both Small White *Pieris rapae* and Large White *Pieris brassicae* are highly mobile butterflies (Cowley *et al.*, 2001) and these species do not show a positive correlation between primary food plant presence and butterfly presence. Meadow Brown *Maniola jurtina* is also considered a relatively mobile species (Warren, 1992; Cowley *et al.*, 2001). The Essex Skipper *Thymelicus lineola* and Ringlet *Aphantopus hyperantus* are two butterfly species considered to be immobile (Warren, 1992; Cowley *et al.*, 2001) and so this may explain the positive correlation between primary food plant presence and butterfly species presence. This may suggest that mobile butterflies do not rely on primary food plant presence at a field margin scale, whilst less mobile species may rely more on food plant presence at a field margin scale.

Croxton *et al.* (2004) in a single-year study found a significant association between higher larval food plant presence and higher butterfly species richness, however Smart *et al.* (2000) found no clear relationship between butterfly population trends and larval food plant trends over a 12-year period, at a larger spatial scale than reported here. The range of relationships in this study compared to that reported in previous studies may be due to methods adopted in this analysis. Croxton *et al.* (2004) recorded the level of butterfly species richness and any larval food plants (not just species associated with the butterfly species reported in the same margins). Smart *et al.* (2000) studied trends over 1 km x 1 km squares. The analysis here was conducted at species level, in which only the primary food plants for the specific butterfly species found in each field margin were

analysed. The more targeted, species specific analysis presented here shows the relationship between butterfly presence and adult and larval food plant species presence is not consistent at the margin-scale investigated. Future studies, with higher numbers of species observations could investigate this over a wider range of butterfly species than the five explored here, to establish how relevant the margin-scale is for butterfly feeding on primary food plants.

4.5.4 Conclusions

This work finds that butterfly diversity in field margins is positively associated with some elements of field margin structure. Differences in field margin structure (which can be controlled through management) have been shown here to correlate with increases in butterfly species richness and changes in butterfly community composition. Higher butterfly species richness was associated with higher plant species richness and intermediate vegetation height in field margins. In practice, management with a focus on increasing plant species richness and managing vegetation height is likely to be associated with an increase in butterfly species richness.

A focus on the conservation or planting of the larval primary food plants of butterfly species may increase species presence in field margins, especially for less mobile butterfly species. However, the relationship between primary food plant presence and the presence of butterflies at a margin scale merits further investigation, across more butterfly species.

These results contribute to our understanding of the relationship between butterflies and field margin structure, from previous butterfly studies conducted across farms in different regions of the UK. Whilst many previous studies have focussed on landscape level factors to improve butterfly conservation, the local management of field margins is likely to play a role in affecting butterfly diversity. Associations between plant diversity and butterfly diversity suggest that conservation measures for plants will also benefit butterflies. With field margins already managed under agri-environmental schemes, this is encouraging as these results support the idea that we are able to guide field margin management for butterfly conservation.

Chapter 5: Differences in the plant records of field margins surveyed via different methods

Contributions

Data collection for this chapter was primarily undertaken by the author (surveyor A, 168 field margin surveys, over 48 field margins), with a contribution of 15 field margin surveys over five field margins by Stephen Harris (surveyor F), and six field margin surveys over two field margins by each of four student volunteers (surveyor's B, C, D, E).

Supplementary materials

Supplementary information and tables for this chapter can be found in Appendix 4. The plant species found are listed in Appendix 5.

5.1 Chapter summary

Accurate and repeatable methods for surveying plant diversity in field margins are important for conservation, to assess trends in changes of plant diversity over time. This chapter investigates if variation occurs in plant lists produced by different survey methods for the same field margins. Understanding the impacts of survey methods on plant species records is particularly important when designing plant monitoring schemes and interpreting time-series data for conservation.

Four farms were examined during 2016 and 2017, with the plant species in 51 field margins recorded via three different survey methods. Two walking transects (30 m and 100 m length, and of variable width) and one quadrat survey method (the mean of up to three 1 m x 1 m quadrats, across the margin width) were compared. To establish if the differences in plant species lists produced are likely to be consistent across different surveyors, four volunteers each surveyed two field margins, via the same three survey methods.

The time taken for surveyors to survey a field margin via quadrat and transect survey methods was, surprisingly, not significantly different. Comparisons of quadrats and transects represents two survey methods which required similar effort in terms of time. Transect survey methods recorded a significantly higher species richness per margin than quadrat survey methods (as expected by species-area relationships, as total area surveyed in transects is greater than quadrats). These differences were consistent across surveyors, and farms.

The species lists recorded using quadrats and transects differed. There was systematic bias in plant species lists produced, with species from the Asteraceae and Fabaceae more likely to be recorded in transect surveys, and species from the Lamiaceae more likely to be recorded in quadrat surveys. This may be explained by the differences in morphology in plant species from different families. Visually cryptic species were less likely to be detected via transects, and spatially aggregated species were less likely to be detected via quadrats. When species lists were analysed in terms of plant traits, no biases were observed in the Grime's CSR strategy of the plant species recorded by either method. These results have implications for the interpretation of plant surveys from field margins, for long term trends used for plant species conservation and when interpreting the scientific literature.

5.2 Introduction

Plants, as the primary producers in terrestrial ecosystems, provide habitat and food for the survival of many species. Conservation on agricultural land is therefore largely dependent on plant diversity. Compiling representative plant species lists is needed to better understand overall levels of biodiversity in an ecosystem (Duelli and Obrist, 1998). The ability to compile representative and accurate plant species lists is critical to monitor changes in plant diversity. With 72% of land cover in the UK committed to agriculture (Defra 2018a), conservation in agricultural land is essential for the UK's wildlife (Lawton *et al.*, 2010). Arable field margins are a UK Biodiversity Action Plan Priority habitat, and the maintenance of arable field margins is incentivised through agri-environmental schemes (JNCC, 2019c). However, the impact of agri-environmental schemes on plant diversity in field margins has not been reported in recent years (Defra, 2018d). To monitor these changes in diversity, the design of long-term studies is important in the resulting trends detected (Yoccoz, Nichols and Boulinier, 2001).

Plant data reported by the UK government is dated at 2007, when the last Countryside Survey was conducted (Carey *et al.,* 2007) and whilst larger-scale national plant quadrat data is widely available (BSBI 2017), the 2 km x 2km grain size is not appropriate to monitor plant diversity in field margins. The Countryside Survey was conducted between 1978 and 2007 at discrete intervals, to monitor changes in the UK countryside (CEH, no date b). The aim of the Countryside Survey was to assess natural resources in the UK, using scientifically rigorous and repeatable methods, to allow comparisons to be drawn between years (CEH, no date b). In 2007, field surveys over 591 1 km squares across the UK, representing all habitat types, included mapping of habitat types, assessing streams and ponds, taking soil samples, geo-referenced photos and recording vegetation plots of different types. Within linear boundaries, vegetation plots were surveyed for species presence and relative abundance (CEH, no date a). A large range of plot types were surveyed in linear boundaries: B plots (10m x 1m plots adjacent to field boundaries), A plots (100m x 1m plots, in the arable field edges centred on each B plot) H plots (10m x 1m plots, alongside hedgerows), D plots (30m x 1m plots, to measure hedgerow diversity) and M plots (2m x 2m plots in field margins) (Maskell *et al.,*2008). The lack of Countryside Survey vegetation data since 2007 has resulted in no plant diversity data being reported by the government, as part of the UK biodiversity indicators (Defra, 2018d).

The lack of currently available plant data contrasts with data that have been regularly reported for countryside birds, bats and butterflies. The development and implementation of robust and efficient survey methods for plant diversity surveys on UK agricultural land is essential for monitoring the impacts of agri-environmental schemes, and ensuring environmental quality of farmland into the future. The identification of survey methods which offer a quick, effective and repeatable way to survey plants in field margins, despite limited resources and expertise, offers a challenge for policy makers.

Beyond national monitoring schemes, the scientific literature does not consistently employ any single survey method for plant surveys on agricultural land. When surveying using quadrat or transect methods, there is no consensus on survey protocol in scientific studies. Quadrat size in the scientific literature on temperate agricultural land ranges from 0.25 m^2 (Marshall, 1989) to 50 m^2 (Sutcliffe and Kay, 2000). Transect length can also vary greatly, with the transect length adopted varying from 10 m (Schneider *et al.*, 2014) to 50 m (Fahrig *et al.*, 2015).

Changes in plant diversity over time are often quantified for conservation in terms of changes in species richness or species diversity (May 1988; Buckland *et al.* 2005). Changes in specific species identities, such as species with a functional role for other species survival, or plants that fill a specific niche is also often of interest (Hillebrand *et al.*, 2018). When reporting changes in species from the same area over time, the turnover of species is often calculated to establish trends in

species changes over time. However, reported changes in plant diversity may be due to sampling bias, in which apparent changes in plant species are reported, rather than due to actual changes in plant diversity. The term sampling bias is used interchangeably with 'pseudoturnover', 'spurious turnover' and 'sampling error' in the literature (Klimeš *et al.*, 2001).

When developing survey methods to record changes in plant species diversity over time, there are numerous factors which should be considered, which may result in recording bias in plant surveys (Table 5.1). Notably, factors which have been shown to affect plant species lists, which can be controlled in survey design include: surveying effort (time), survey method (e.g. transects, quadrats, survey area), surveyor and seasons. Factors which have been shown to impact the plant species lists produced, but which cannot be controlled in survey design include: plant morphology, species rarity and species abundance.

Factors affecting plant records	Impact	Studies
Effort	Often measured in terms of time spent surveying, greater effort is correlated with detection of more species.	Nilsson and Nilsson, 1985; Archaux *et al.*, 2006; Kéry *et al.*, 2006; Chen *et al.*, 2013; Iknayan *et al.*, 2014
Survey method	Survey method likely to affect species detection. Surveys covering greater areas likely to detect more species due to ecological species-area relationships. Impact of plot area is likely to affect plant species lists, but mixed results have been reported in previous studies.	Peterken, 1981; Rich and Woodruff, 1992; Klimeš *et al.*, 2001; Yoccoz, Nichols and Boulinier, 2001; Buckland *et al.*, 2005, 2007; Chen *et al.*, 2009; Iknayan *et al.*, 2014; Ratnieks *et al.*, 2016
Surveyor	Inter-surveyor differences are present between most surveyors but are greater between surveyors with different levels of experience and ability.	Kirby *et al.*, 1986; Vittoz and Guisan, 2007; Milberg *et al.*, 2008; Prosser and Wallace, 2008; Vittoz *et al.*, 2010; Iknayan *et al.*, 2014
Season	Affects the life-state of species. Species have lower detectability when not in flower, and when in smaller life-states (e.g. seedlings). Weather also varies seasonally, affecting surveyor effort.	Kirby *et al.*, 1986; Rich and Woodruff, 1992; Chen *et al.*, 2013; Iknayan *et al.*, 2014
Plant morphology (e.g. life form, minimum / average size, flowering period)	Level of detectability of a species is affected by plant morphology. Smaller plants, plants with smaller life-states (e.g. seedlings) or those not in flower are less likely to be detected in field surveys.	Klimeš *et al.*, 2001; Kéry and Gregg, 2003; Buckland *et al.*, 2007; Chen *et al.*, 2009, 2013; Burg *et al.*, 2015
Species rarity	Species which are rarer are more likely to be overlooked in plant surveys.	Iknayan *et al.*, 2014
Species abundance	Species with low local abundance are more likely to be overlooked in plant surveys.	Klimeš *et al.*, 2001; Vittoz and Guisan, 2007; Milberg *et al.*, 2008; Burg *et al.*, 2015
Relocation of study plots in multi-year studies	Inaccurate relocation of study plots has previously been a problem, resulting in pseudoturnover. However, in recent years accurate, handheld GPS technology has become more widely available, reducing this problem.	Wiens, 1989; Dodd, 2011

Table 5.1 The factors reported to affect plant species records.

The survey method adopted for any taxonomic survey will result in bias in the species recorded and so should be considered in survey design (Rich and Woodruff, 1992; Klimeš *et al.*, 2001; Yoccoz, Nichols and Boulinier, 2001; Chen *et al.*, 2009; Iknayan *et al.*, 2014). Different survey methods lend themselves to monitoring certain taxa, over defined temporal and spatial scale (Rich and Woodruff, 1992). Increasing the sample size in surveys which are subject to systematic bias in plant records due to survey methods will not reduce the bias in the records.

Understanding how different survey methods may introduce systematic bias into plant records is important, especially where differences in species richness are associated with repeated under-sampling of specific groups of plant species. For example the impact of line transect methods on plant surveys have been investigated, showing that transects do not record species with a strongly aggregated distribution or visually cryptic species very well (Buckland *et al.* 2007).

Many groupings of plant species reflect differences in plant morphology. If different survey methods systematically bias surveying of plants associated specific morphological traits, then this will have implications for the results reported in scientific studies.

Classifying plants at a family level is a common way of grouping species, reflecting the taxonomic diversity within an area. Burg *et al.* (2015) in a study of bias in botanical surveys in high alpine summits, noted that some taxonomic plant groups were often overlooked, which they attributed to differences in morphological traits and abundance between families. In their study, they found that Orchidaceae, Liliaceae and Scrophulariaceae (which they describe as often found in low abundance and small in stature) were frequently overlooked. Difficulties in identifying Asteraceae and grass species (such as Poaceae) were also reported. Similarly, other studies have reported that plants of small stature, or those difficult to differentiate (such as grasses) are more likely to be overlooked in surveys (Klimeš *et al.* 2001; Kéry and Gregg 2003; Chen *et al.* 2009, 2013; Buckland *et al.* 2007). Family classifications can therefore been used to broadly assess the visual properties of species within the group, which may result in the systematic biases in plant families surveyed which have been reported.

Another common grouping of plant species in plant records for analysis is grouping according to trait-based classification, such as Grime's Competitor-Stress tolerator-Ruderal (CSR) plant strategy (Grime, 1977). CSR plant strategy is often used to interpret the results of monitoring studies and ecological experiments (e.g. Hunt *et al.*, 2004). Plant species with a similar CSR plant strategy indicates a similarity in plant traits. The CSR plant strategy of each species in the British flora has been determined based on a combination of plant morphology, life history and physiology (Grime, Hodgson and Hunt, 1988). The life history and morphological traits used to establish CSR strategy include frequency of flowering, life form, morphology of the shoot, leaf form and canopy. These traits may affect the detectability of plant species in the field. If, as suggested by Buckland *et al.* (2007), line transects are less likely to detect visually cryptic species in field margins, different survey methods may result in systematic biases in the CSR strategies of the plant species identified in field margins, with potential implications for the ecological interpretation of results.

A variety of factors relating to survey design have been shown to impact plant records, including the time spent surveying and the area surveyed. In woodlands, the impact of survey method on plant records has been highlighted, with a random walk compared to randomly placed quadrats. The number of species recorded was significantly affected by the survey method used (Kirby *et al.*, 1986). It has been shown in previous studies that an increase in time spent surveying (a measure of survey effort) shows a similar increase in species richness as increases in area surveyed (Peterken, 1981). Kirby *et al.* (1986) suggest that in the case of walking transect surveys, time spent walking correlates with distance covered, and so an increase in transect length is expected to correlate with more species found, as predicted by species-area relationships (MacArthur and Wilson, 1967; Connor and McCoy, 1979).

Further variation can be introduced into plant records when different surveyors conduct surveys, which may compound differences in species lists associated with differences in survey methods. Inter-surveyor differences are known to impact the species records in woodlands (Goodfellow and Peterken, 1981; Kirby *et al.*, 1986; Milberg *et al.*, 2008), alpine habitats (Vittoz and Guisan, 2007; Vittoz *et al.*, 2010) and nationwide surveys (Rich and Woodruff, 1992; Prosser and Wallace, 2008). Less experienced surveyors are reported to take longer to survey the same area, as well as finding fewer species than a more experienced surveyor (Prosser and Wallace, 2008). If using volunteers for surveys, it may be the case that effects of systematic bias due to the survey method employed may be even greater.

With predominantly small, herbaceous vegetation, the impacts of survey method on plant records from field margins may be more pronounced than in other habitats. In field margins, many of the plant species found are characterised by morphological characteristics making species more likely to be overlooked in surveys. Understanding how survey methods and inter-surveyor differences bias plant data sets is critical to allow the analysis of data sets for conservation, agri-environmental schemes and scientific studies.

To explore if survey method will impact the plant records from field margin surveys, field margins were surveyed via three different methods. The three survey methods were: two walking transect methods (30 m and 100 m) and one quadrat survey method. Two hypotheses are tested here. Firstly, I hypothesise that transect survey methods will record higher species richness than quadrat survey methods. This is because the sample area surveyed via transect methods is larger, and the number of species recorded should increase with area sampled (Peterken, 1981). Secondly, I expect the species composition to vary based on survey method: transect survey methods should identify more spatially aggregated species, and quadrat survey methods should identify more visually cryptic species. To test this, plant species lists were compared, grouped by family and Grime's CSR strategy.

5.3 Methods

5.3.1 Methods overview

To compare the impact of different survey methods on plant species lists and plant species richness, an observational study was conducted in 2016 and 2017. In 2016, 42 field margins at Farm A, a large mixed arable farm in Oxfordshire, were each surveyed by three different survey methods. The three survey methods were a quadrat method (up to three 1 m x 1 m quadrat) and two transect methods (a 30 m walking transect and a 100 m walking transect, covering the entire margin width). For each survey method, all plant species present were recorded.

In 2017, to see if the impacts of survey methods on plant records were consistent across different farms, the same three survey methods were used to survey three margins at three additional farms in Oxfordshire. 10 margins were also resurveyed at Farm A, via the three different survey methods.

To establish if differences in plants records observed by the main surveyor are likely to be consistent for different surveyors, four undergraduate student volunteers each surveyed two margins at Farm A, using the same three survey methods. Time taken to survey was recorded in the 2017 surveys.

A summary of the factors accounted for in the design of this study, which are likely to affect plant species records (including survey method) is given in Table 5.2.

Factor affecting plant records	Impact in this study
Survey method	Three survey methods are compared (three 1 m x 1 m quadrats, 30 m walking transect, 100 m walking transect)
Effort	Time taken to survey is not limited in these surveys, but is recorded for each survey method.
Plant morphology	Plant species lists are analysed in terms of their taxonomic family, and Grime's CSR plant strategy, to establish if morphology can explain differences in plant species lists.
Surveyor	Most of the surveys in this study were undertaken by one individual. Five additional surveyors surveyed a small number of field margins, to establish if trends reported here are representative of the wider population.
Season	Each field margin was surveyed by the three survey methods consecutively within the same day.

Table 5.2 A summary of how factors commonly reported to affect plant records were accounted for or included in the design of this study, investigating the impact of survey method on plant records in field margins.

5.3.2 Study sites

Research was conducted across four farms in Oxfordshire, England. Farms were chosen for being mixed arable farms, with cattle and sheep grazing, committed to Higher-Level schemes, with field margins managed as part of these schemes. Farms are described in Chapter 1, Section 1.6.1 Study sites. Fieldwork was conducted in May, June and July 2016 at Farm A, and May and June 2017 at farms A, B, C and D.

5.3.3 Margin identification

The field margins surveyed were all at least 100 m in length, and at least 1 m wide. Margins which were more than 100 m long were split into 100 m sections for surveying.

The 42 field margins surveyed in 2016 were randomly selected, using random number generation, from full inventory of 113 field margins made from on-site visits to Farm A in 2015. In 2017, a random subset of 10 field margins at Farm A were resurveyed. Three field margins, of the 10 resurveyed in 2017, were also surveyed by volunteers in 2017 (Table 5.3). At each of Farms B, C and D, three field margins were surveyed by an experienced surveyor in 2017. Field margins were randomly chosen to survey from a full inventory of field margins, identified via satellite images (Google Earth Pro, 2015). If an on-site visit excluded a field margin from being surveyed (for example, due to not being wide enough, if less than 1 m), the next field margin in the list was surveyed.

Year	Farm	Number of field margins surveyed	Surveyor workforce (surveyor)
2016	A	42	Experienced surveyor (surveyor A).
2017	A	10	Experienced surveyors (8 margins surveyed by surveyor A, 2 margins surveyed by surveyor F); four volunteers with limited experience (surveyors B, C, D, E) each surveyed 2 field margins, from a choice of 3 field margins.
2017	B	3	Experienced surveyor (surveyor A).
2017	C	3	Experienced surveyor (surveyor A).
2017	D	3	Experienced surveyor (surveyor F).

Table 5.3 A summary of the field margin surveys undertaken.

5.3.4 Survey methods

For each margin, three survey methods were employed: up to three 1 m x 1 m quadrats; 30 m walking transect; 100 m walking transect. All margins were surveyed via three survey methods, with the three surveys for each margin undertaken on the same day. This was to ensure that differences in plant species lists observed were not due differences associated with surveys undertaken at a different time, such as seasonal changes in plant species, or differences in weather conditions.

For each field margin, a list was made of the plant species found, by each of the three survey methods. Plant species were recorded using Rose and O'Reilly (2006). Where species could not be identified, samples were taken for identification by an expert.

For the 2017 surveys, the time (to the closest minute) to complete each survey in each margin was recorded.

The exact survey area was calculated for each survey. For the quadrat surveys, this was either 1 m^2, 2 m^2 or 3 m^2. For the transect surveys, this was calculated as transect length (either 30 m or 100 m) multiplied by the margin width (to the closest 0.25 m). A summary of the three survey methods is given in Table 5.4.

Survey Method	Description	Area covered
Quadrat	Up to three 1 m x 1 m quadrats surveyed at the middle point in the 100 m field margin section. Quadrats were placed with equal spacing across the margin width. Where field margins were less than 3 m wide, fewer quadrats were surveyed.	Between one and three 1 m x 1 m quadrats per margin (1 - 3 m^2). Over the 51 different field margins surveyed: four margins were less than 2 m wide, one margin was between 2 m and 3 m wide, and 46 margins were 3 m or greater.
30 m transect	A 30 m walking transect, in which the surveyor walks the 30 m length, and is encouraged to survey plant species across the entire margin width, and to explore areas which are visually heterogeneous.	30 m x Margin Width Range: 30 – 300 m^2
100 m transect	A 100 m walking transect, in which the surveyor walks the 100 m length, and is encouraged to survey plant species across the entire margin width, and to explore areas which are visually heterogeneous.	100 m x Margin Width Range: 100 – 1000 m^2

Table 5.4 A summary of the three survey methods used in this study to survey field margin plant diversity (quadrats, 30 m walking transect, 100 m walking transect).

5.3.4.1 Transect surveys

30 m transects were surveyed in the mid-point of the length of the field margin. 100 m transects covered the entire length of the margin section surveyed (Figure 5.1).

Transects were either 30 m or 100 m. These lengths were compared as UK Hedgerow Survey protocol (Defra, 2007) requires 30 m sections of hedgerows to be surveyed, representative of an 100 m margin section of interest.

For all field margins, both 30 m- and 100 m-walking transects were conducted to sample plant diversity. The length of each transect was walked, with surveyors making observations across the entire width of each margin. The width of the field margins surveyed was variable, so the total area surveyed via these methods varied. Surveyors were encouraged to survey over the entire width of

the field margin, and to be guided by areas which were visually heterogeneous, as in 'Rapid Botanical Survey' methods (Hawthorne and Marshall, 2016).

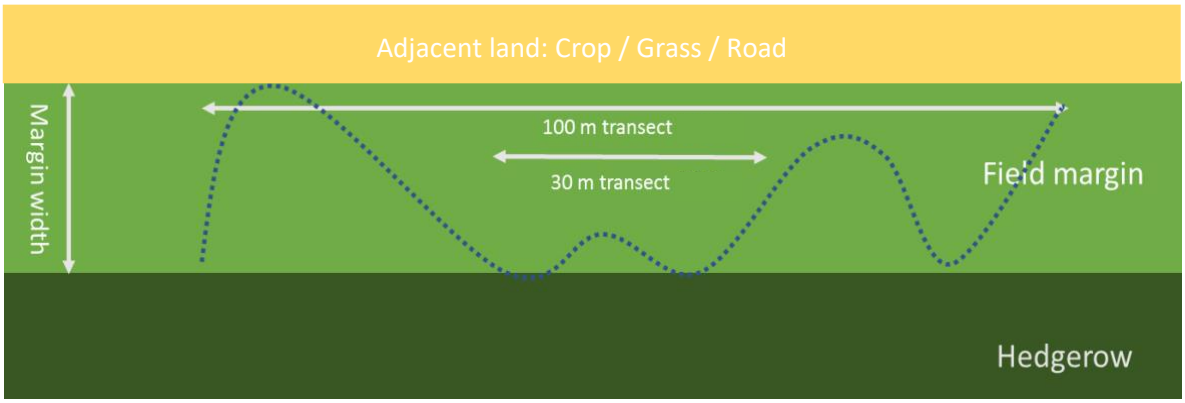


Figure 5.1 The field margin survey set up, with 100 m walking transects or 30 m walking transects. Surveyors are encouraged to survey over the entire width of the field margin, and not to restrict themselves to a linear walk. Plant species across the entire width of the margin are recorded.

5.3.4.2 Quadrat surveys

In each margin, a random point was chosen within the 100 m margin section to survey quadrats, using random number generation. Up to three 1 m x 1 m quadrats were placed across the width of each margin, one quadrat at either edge, and one in the middle (Figure 5.2). Margin width varied between 1 m and 8 m, so in some margins the width limited the maximum number of quadrats which could be surveyed. Margins less than 2 m wide were limited to one 1 m x 1 m quadrat. Margins between 2 and 3 m wide were limited to two 1 m x 1 m quadrats. All margins of 3 m or more had three 1 m x 1 m quadrats surveyed.

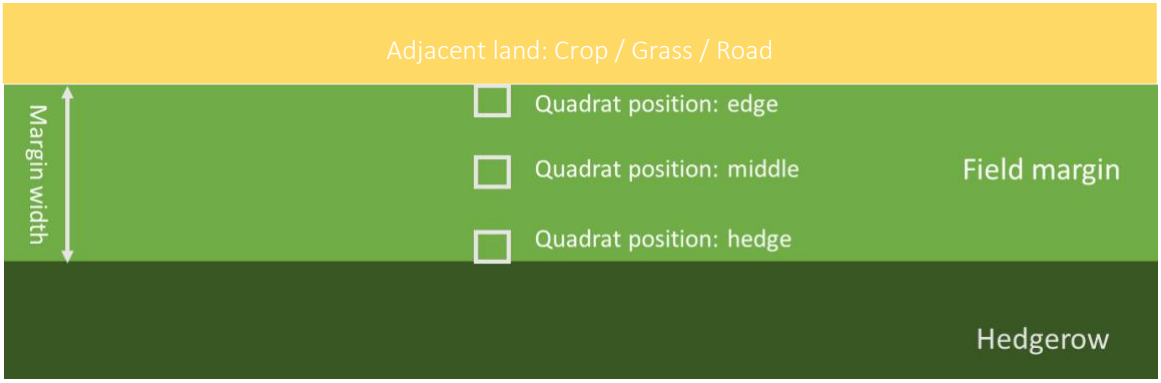


Figure 5.2 The quadrat positions in quadrat surveys. Plant species within the 1 m x 1 m quadrats are recorded.

5.3.4.3 Surveyors

Six surveyors contributed to the data collected. Surveys were predominantly completed by one surveyor (surveyor A) with two field seasons of experience undertaking botanical surveys in field margins over these farms. Surveyor F, an experienced surveyor with more than 30 years surveying experience with British lowland agricultural flora, undertook a small number of surveys.

To assess if differences observed between the three survey methods by one surveyor (surveyor A) may be similar across different surveyors, surveys of two margins at Farm A were undertaken by four volunteers using the same methods. Two margins were each surveyed by five different surveyors in 2017: one experienced field botanist (surveyor A) and four volunteer undergraduate biologists (surveyors B, C, D and E). Each surveyor worked independently, without discussing their

results. Each surveyor surveyed two out of three field margins (chosen randomly) on the same day (13th June 2017). This was to ensure that differences in survey records were not due to differences in location of the field margin, or differences associated with performing surveys on different days.

The undergraduate volunteers all had at least one week's training in fieldwork and plant identification in the UK as part of their degree course, and were in their second year of undergraduate study in Biological Sciences. The volunteer undergraduates were therefore expected to be well informed in plant identification skills, but with limited field experience. Whilst not representative of the wider volunteer population, using this workforce provided an insight into inter-surveyor differences, in a group of individuals who have similar levels of experience in plant surveying.

All surveyors were instructed to survey two field margins using the three methods described above. Each surveyor therefore performed six surveys in total. For each method surveyors were required to record all the species found, according to Rose and O'Reilly (2006). If plants could not be identified to the species level, volunteers were instructed to take a sample and assign it a unique name and the sample was later identified by an experienced surveyor. For each survey method, time taken to survey each margin was recorded. Volunteers were given verbal as well as written instructions (given in Supplementary methods).

5.3.5 Analysis

A plant species database was created in BRAHMS, and analyses were conducted using the *vegan* package (Oksanen *et al.*, 2017) in *R* statistical software, and in Microsoft Excel.

5.3.5.1 Survey time

Time taken to survey a margin via transect and quadrat methods was compared, as a measure of surveying effort for each margin (and often the limiting factor when undertaking surveys). To compare the time taken to survey three 1 m x 1 m quadrats, and a 100 m-walking transect, a paired t-test was used on data collected by four surveyors over 18 margin surveys in 2017 at Farm A.

5.3.5.2 Species-area relationship

To see if the different survey methods resulted in different recorded levels of plant species richness, a repeated measures one-way ANOVA was conducted on the 2016 survey records (over 42 field margins), with survey method as a factor with three levels. Total species recorded via each of the three different survey methods were compared.

To visually see if the expected ecological species-area relationship held when sampling the same margins over different areas a species-area graph was plotted for the 2016 data. Log species richness and log survey area for each survey method, per margin, were plotted. Survey areas were calculated exactly, with three areas plotted: either log 1 m^2, 2 m^2 or 3 m^2 for quadrats, and two areas for transect survey areas, calculated as log 30 m x width m and log 100 m x width m.

To see if any differences observed extended to surveys undertaken by different surveyors, the mean levels of plant species richness recorded via the three different survey methods, across five surveyors in 2017 was tabulated. A log species-area graph was plotted, to visually compare the species richness found by different surveyors over surveys covering different areas, at Farm A.

To see if differences observed were likely to reflect widespread biases for survey methods across field margins, survey records from farms A, B, C and D in 2017 were compared. The mean species richness found via each survey method over the four farms was compared, and a log species-area graph plotted.

5.3.5.3 Differences in plant species lists

Comparisons of differences in the plant species lists recorded using the quadrat and 30 m transect survey methods were conducted using Excel pivot tables. The comparison was conducted between the 30 m transect survey species list and the quadrat survey species list per field margin, as the species-area plot suggested little increase in the number of species richness of an 100 m walking transect compared to a 30 m walking transect.

For each field margin, the plant species lists were compared. Across the surveys undertaken at Farm A, plant species recorded a greater number of times via quadrats (but not transects) or transects (but not quadrats) per field margin were noted. Species were then grouped according to their taxonomic family, and these results were tabulated. Species were also compared based on their Grime's CSR values. Grime's CSR values for each species found more frequently by either method were plotted in ternary plots, from Grime *et al.* (1988), to show the CSR strategy of plant species more likely to be found by either 30 m transects or quadrat surveys.

5.4 Results

5.4.1 Survey time

Time taken to survey field margins via the different survey methods was recorded by four surveyors, across three farms (Figure 5.3). Data from a fifth surveyor was not included in the analysis, as they took over twice as long to survey margins as all other surveyors, and so was considered an outlier. 18 margin records were compared. A paired t-test showed there was no significant difference in the time taken to survey a margin using three 1 m x 1 m quadrats or an 100 m walking transect, ($t = 1.399$, $p = 0.1798$, $n = 18$). Sampling effort, in terms of time, does not significantly differ between 100 m transect and quadrat survey methods.

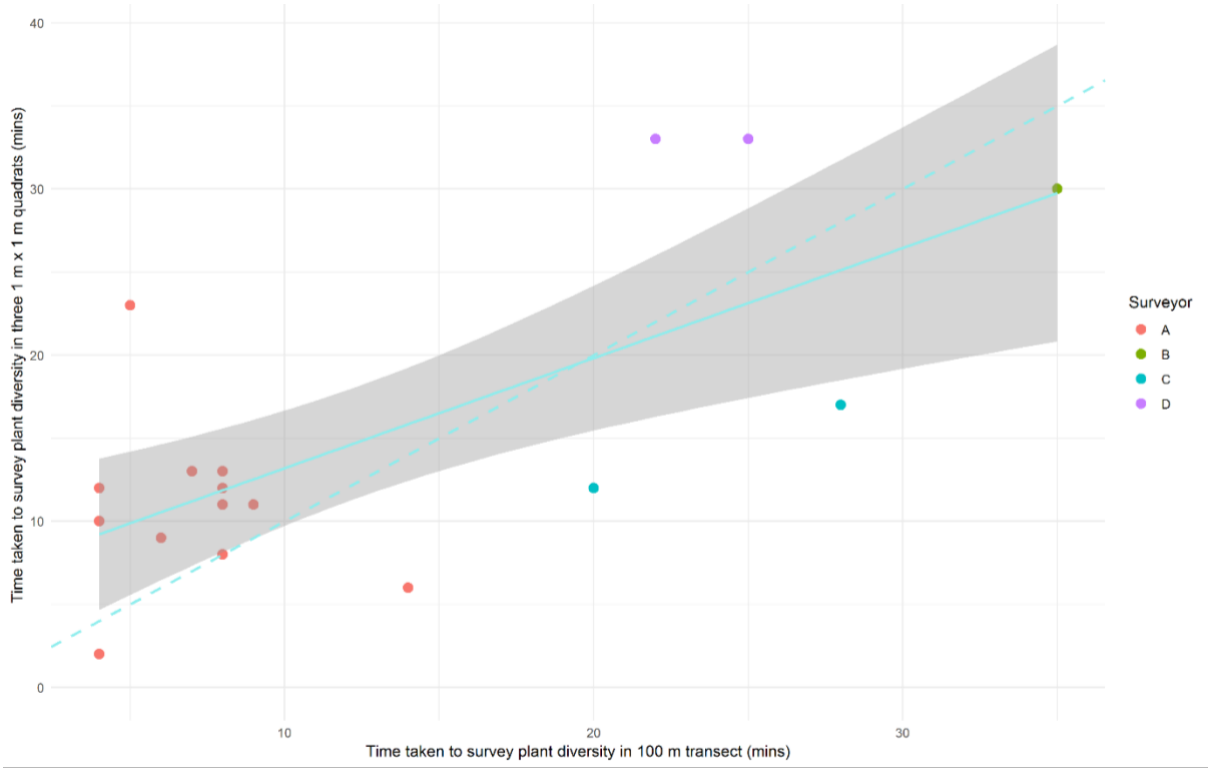


Figure 5.3 The time taken to survey three 1 m x 1 m quadrats and one 100 m transect in the same margin, by four different surveyors. Each point is one margin surveyed by one surveyor. Surveyor A is an experienced surveyor, and B, C and D are inexperienced surveyors. 18 comparisons between three quadrat and a 100 m transect surveying times are made (n=18, across 16 different margins and four surveyors). The dashed line shows where points would lie if all quadrats and transects took the same time to survey. The solid line is the actual linear regression of the results. The grey area shows the 95% confidence interval around the regression line.

5.4.2 Species richness

At Farm A, a total of 1,766 plant records were recorded across 42 margins, using three different survey methods in 2016. The species richness recorded was higher using transects compared with quadrats (Table 5.5). A repeated-measures ANOVA showed a signficant difference between plant species richness observed in each field margin via the three survey methods ($F_{2,82} = 227$, $p = 2x10^{-16}$). The differences in species richness per field margin surveyed in 2016, based on the exact area surveyed, is shown in Figure 5.4.

Year and farm	Number of field margins	Mean plant species richness ±standard deviation		
		Quadrat Mean	30 m Transect	100 m Transect
2016, Farm A	42	6.19 ±1.97	16.5 ±4.91	19.4 ±5.31
2017, Farm A	10	7.53 ±1.31	18.9 ±5.43	24.9 ±5.15
2017, Farms B, C, D	9	7.11 ±2.72	19.0 ±6.25	24.4 ±8.71

Table 5.5 The mean plant species richness per field margin recorded with three different survey methods. The highest surveyed plant species richness was found via 100 m transect surveys. All surveys were undertaken by an experienced surveyor (surveyor A or surveyor F).

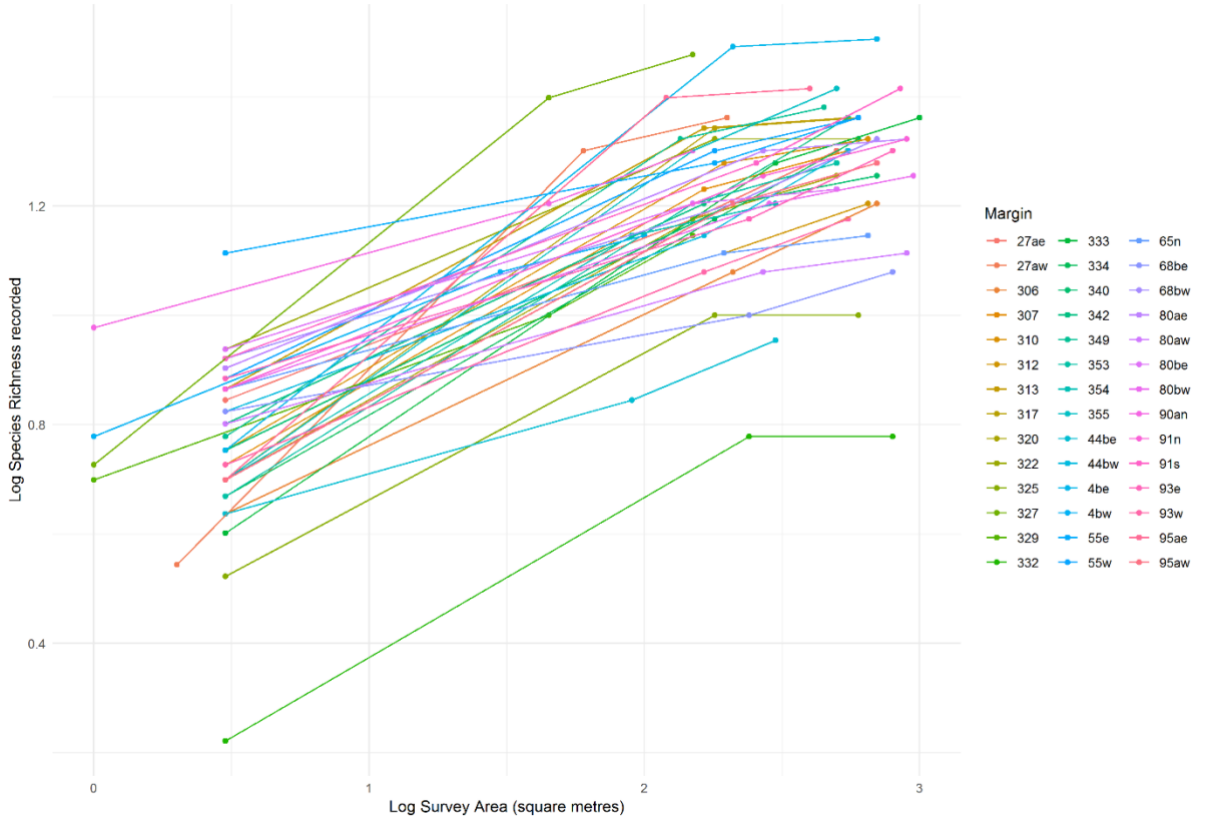


Figure 5.4 The log survey area-log species richness relationship for each of the three survey methods, over 42 field margins surveyed in 2016. On the log survey area axis, the first point (with the smallest survey area) is the quadrat survey; the next point is the 30 m transect survey (of variable width); the largest survey area is the 100 m transect survey (of variable width). The location of the field margins surveyed are shown in satellite photos of the farm (margins 27 – 95 in Chapter 2, Figure 2.1 and margins 306 – 355 in Chapter 4, Figure 4.1).

A similar pattern in increases of plant species richness reported for survey methods which covered a greater area was observed across five different observers (Table 5.6, Figure 5.5). Highest species richness was recorded via 100 m transects, and lowest recorded using quadrats.

Year and farm	Surveyors	Number of field margins surveyed	Mean plant species richness ±standard deviation		
			Quadrat Mean	30 m Transect	100 m Transect
2017, Farm A	4 volunteer surveyors	8	5.42 ±1.82	14.0 ±4.63	17.8 ±5.75
2017, Farm A	1 experienced surveyor	3	7.11 ±1.26	18.7 ±8.15	27.7 ±3.21

Table 5.6 The mean number of species identified by volunteer surveyors and an experienced surveyor, via three survey methods, across the same three field margins. Surveys occurred over the same three field margins at Farm A in 2017, via three different survey methods.

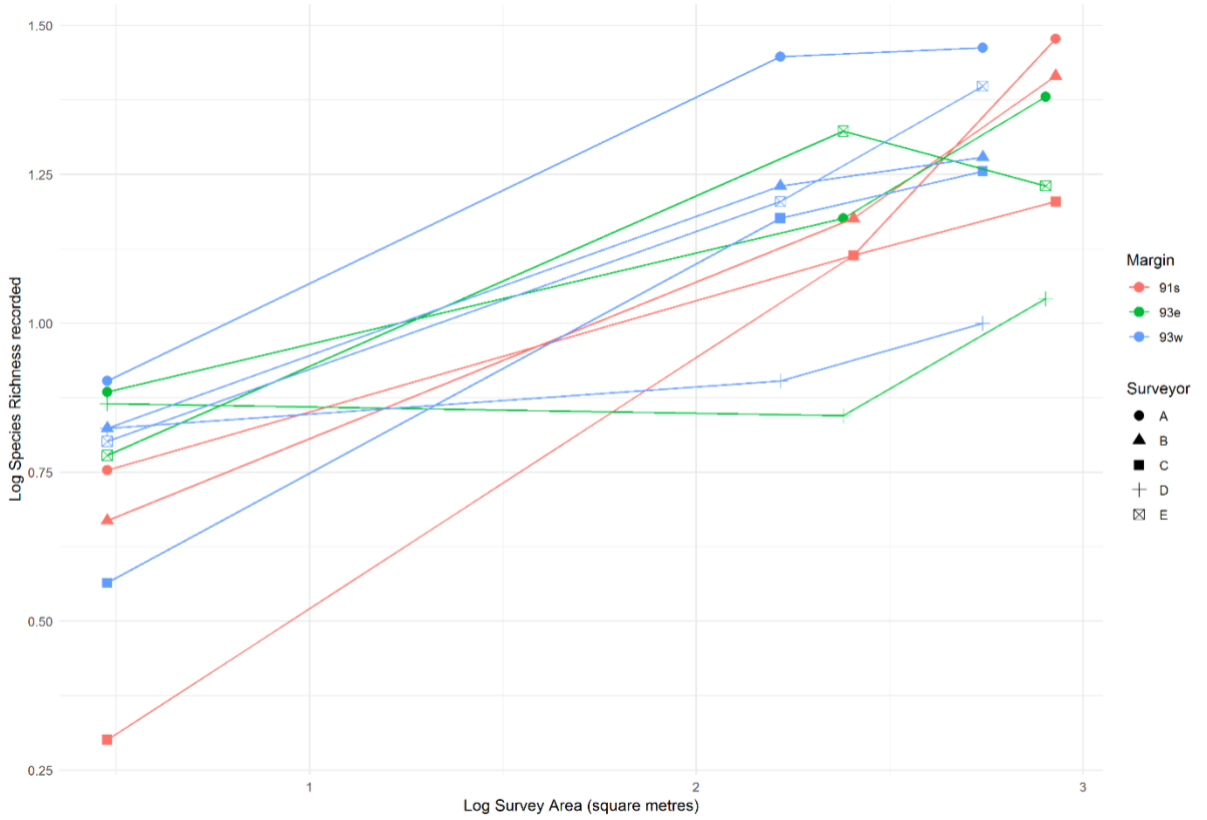


Figure 5.5 The log survey area-log species richness relationship for each of three survey methods, over three field margins, undertaken by five surveyors in 2017. On the log survey area axis the first point (with the smallest survey area) is the quadrat survey; the next point is the 30 m transect survey (of variable width); the largest survey area is the 100 m transect survey (of variable width).

Repeat visits to 10 of the margins at Farm A in 2017 by an experienced surveyor gave a total of 558 taxon observations, using three different survey methods. Across farms B, C and D, a total of 455 taxon observations were recorded across nine margins, using the three different survey methods.

Similar trends in plant species richness recorded via the three different survey methods were observed in 2017, across four farms. As in the other data sets, higher plant species richness was recorded via transects than quadrat survey methods (Table 5.5, Figure 5.6).

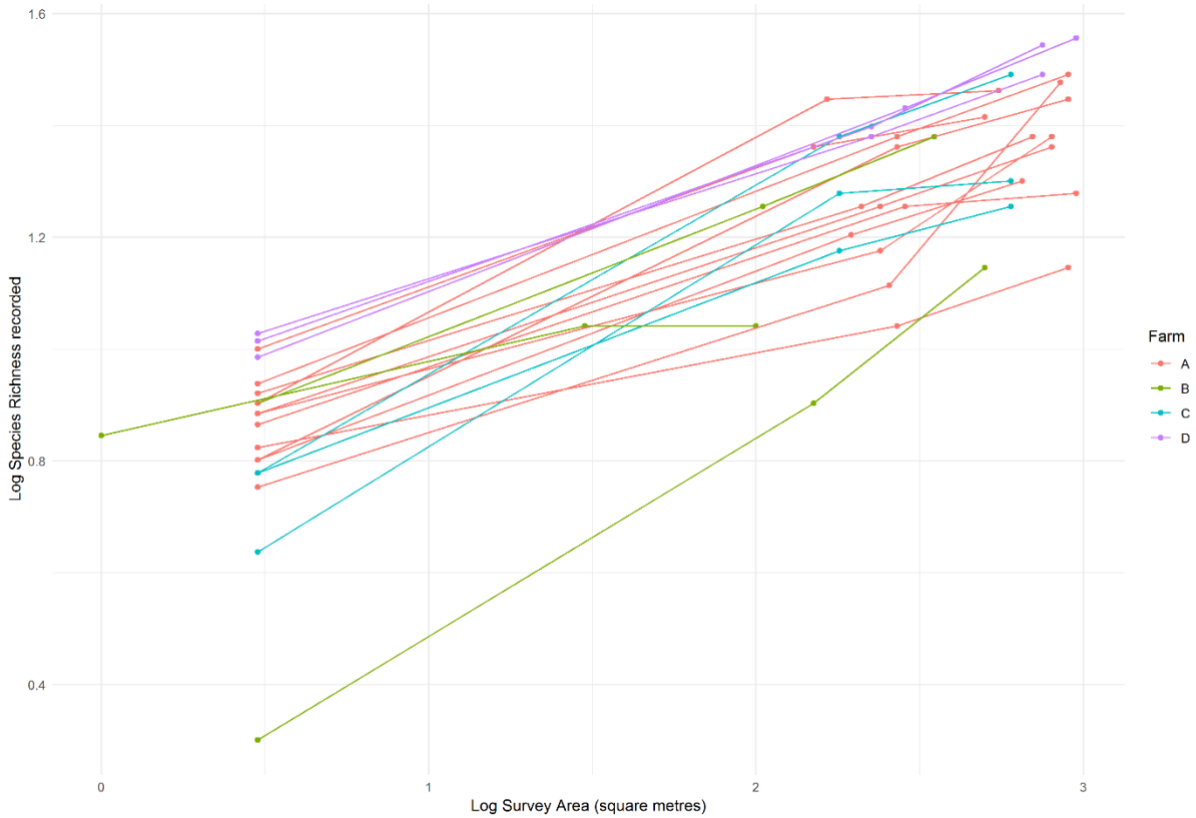


Figure 5.6 The log survey area-log species richness relationship for each of three survey methods, over 19 field margins, over four farms (A, B, C, D) in 2017. On the log survey area axis, the first point (with the smallest survey area) is the quadrat survey; the next point is the 30 m transect survey (of variable width); the largest survey area is the 100 m transect survey (of variable width).

5.4.3 Plant families

Differences in plant families detected more frequently via 30 m-walking transects or via quadrat survey methods are shown in Table 5.7. The main difference, which may account for the greater number of species found via transect surveys compared to quadrat surveys, is the greater number of Asteraceae and Fabaceae detected by transect sampling. Rosaceae and Lamiaceae were more likely to be detected via quadrats. A greater number of spatially aggregated species, such as species which are likely to be found in clumps or as large, single individuals are more likely to be found in transect surveys than quadrat surveys.

	Plant species more frequently found in:		
Family	**Quadrat survey**	**30 m transect survey**	**Both***
Apiaceae	*+ Anthriscus sylvestris* *+ Torilis japonica*	*+ Daucus carota* *+ Heracleum sphondylium*	
Araliaceae	*Hedera helix*		
Asteraceae	*Cirsium arvense* *Tripleurospermum inodorum*	*+ Achillea millefolium* *+ Artemisia vulgaris* *+ Centaurea nigra* *+ Cirsium acaule* *+ Cirsium vulgare* *+ Crepis sp.* *+ Hieracium agg.* *Lapsana communis* *+ Leucanthemum vulgare* *Sonchus asper* *Taraxacum agg.*	*Artemisia matricarioides*
Boraginaceae	*Myosotis arvensis*	*Myosotis scorpioides*	
Brassicaceae	*Lepidium*	*Hirschfeldia incana*	*Brassica napus*
Caprifoliaceae		*+ Lonicera periclymenum*	
Caryophyllaceae	*Cerastium fontanum* *+ Silene latifolia*		
Convolvulaceae		*+ Convolvulus arvensis*	
Euphorbiaceae	*Euphorbia helioscopia* *Mercurialis perennis*		
Fabaceae		*Lathyrus pratensis* *Lotus corniculatus* *Medicago lupulina* *Trifolium pratense* *Trifolium repens*	*Vicia sativa*
Fagaceae	*Quercus robur*		
Geraniaceae	*Geranium pyrenaicum* *Geranium robertianum*	*+ Geranium dissectum* *+ Geranium molle* *+ Geranium pratense*	
Lamiaceae	*Clinopodium vulgare* *Glechoma hederacea* *+ Stachys sylvatica*		*Prunella vulgaris*
Oleaceae	*Fraxinus excelsior*		
Onagraceae	*+ Circaea lutetiana*		
Orobanchaceae		*+ Odontites vernus*	
Papaveraceae		*+ Papaver rhoeas*	
Plantaginaceae	*Veronica filiformis* *Veronica officinalis*	*+ Plantago lanceolate* *+ Plantago major* *Veronica persica* *Antirrhinum spurium*	
Poaceae	*Agrostis sp.* *Alopecurus myosuroides* *Anisantha sterilis* *Elymus caninus* *Cynosurus cristatus* *+ Holcus lanatus* *Triticum sp.*	*+ Arrhenatherum elatius* *+ Dactylis glomerata* *Danthonia decumbens* *Elymus repens* *Holcus mollis* *Lolium perenne* *+ Poa trivialis*	
Polygonaceae		*Rumex sp.*	*Polygonum persicaria*
Primulaceae		*Anagallis arvensis*	
Ranunculaceae		*Ranunculus repens*	
Rosaceae	*Crataegus monogyna* *+ Geum urbanum* *Prunus spinosa* *+ Rubus fruticosus agg.*	*+ Agrimonia eupatoria*	
Rubiaceae	*Galium aparine* *+ Cruciata laevipes*	*+ Galium mollugo* *+ Galium verum*	
Sapindaceae	*Acer campestre* *Acer pseudoplatanus*		
Urticaceae		*+ Urtica dioica*	

+ indicates species which are usually spatially aggregated into clumps, or found as large, single individuals, according to expert opinion.
* Both refers to species found equal amounts of times via each survey method.

Table 5.7 Plant species more likely to be identified by quadrats or 30 m transect surveys per field margin, grouped by family. Woody species identified were all small saplings and so were not considered to be visually outstanding.

5.4.4 CSR plant strategy

To understand if there was a trend in the plant CSR strategies (Grime, Hodgson and Hunt, 1988) found in species recorded using different survey methods, species records from quadrat surveys and 30 m transect surveys were compared for each margin. Differences in species CSR strategy between quadrat surveys and 30 m transect surveys are shown in Figure 5.7.

The mean species strategy of plants recorded via 30 m transects and quadrat surveys are very similar. Both survey methods are shown to detect species across a similar range of CSR strategies. No highly stress tolerant plant species were found in field margins via either survey method.

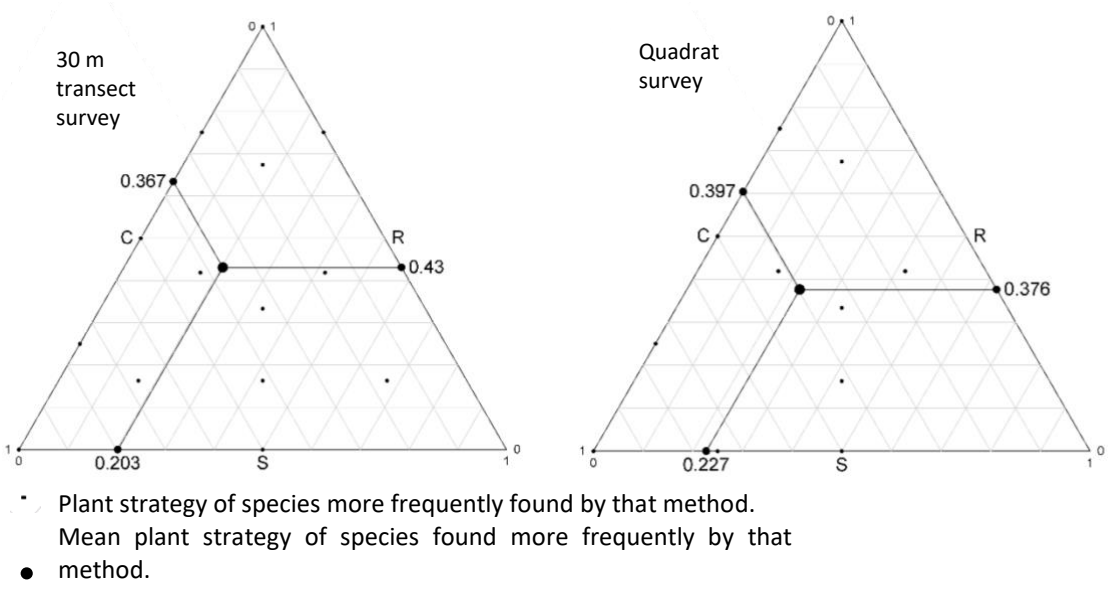


Figure 5.7 Ternary plots to show the Grime's CSR plant strategy of species more likely to be found by either transect or quadrat survey method. The mean plant strategy for each survey method is plotted, calculated based on abundance of species of each strategy. CSR is plotted on a scale of 0 – 1, where 1 is pure competitor, stress-tolerator or ruderal strategy and 0 is the most unlike that strategy.

5.5 Discussion

Field margin surveys were conducted using three methods to examine the effects of survey method on plant species records. These results support the hypothesis that transect survey methods record higher species richness than quadrat survey methods. Different survey methods resulted in biases in plant species records in field margins. The species lists produced by transect and quadrat surveys supported the hypothesis that transect survey methods were more likely to record spatially aggregated species, and quadrat survey methods were more likely to record visually cryptic species.

The results presented here support previous studies showing biases in plant species records compiled from different survey methods (Peterken, 1981; Kirby *et al.*, 1986; Rich and Woodruff, 1992; Klimeš *et al.*, 2001; Yoccoz, Nichols and Boulinier, 2001; Buckland *et al.*, 2005, 2007; Chen *et al.*, 2009; Ratnieks *et al.*, 2016). Results across different farms, and from different surveyors, followed similar trends, indicating the systematic bias from survey methods observed here is likely to be widespread. These results have implications for the design of plant surveys for scientific studies, and plant monitoring schemes.

5.5.1 Survey effort

In the surveys conducted, there was no significant difference in the time taken to survey a margin using 100 m walking transect or three 1 m x 1 m quadrats, across four different surveyors. The quadrat methods, despite covering a smaller area, took the same amount of time to survey as the larger transects. This may be due to more attention being paid when surveying the smaller area of quadrats. Other studies have reported surveyor effort to be inconsistent. Surveyor search effort increased where species richness was unusually low (Lepš and Hadincová, 1992) or where there are many species (Wilson, 1995). The suggestion that greater attention is paid in quadrat surveys is supported by the species identities reported, with visually cryptic species more likely to be found in quadrats than walking transects. As both transect and quadrat methods take a similar amount of time to survey, there is no temporal benefit to surveying margins using either survey method. The time taken to survey via transect and quadrat methods, suggests equal surveying effort.

Differences in plant species richness between survey methods are therefore not due to increased sampling effort, as found in previous studies (Goodfellow and Peterken, 1981; Kirby *et al.*, 1986; Rich and Woodruff, 1996; Zhang *et al.*, 2014).

5.5.2 Differences in species richness

Higher plant species richness was recorded in the same margins via transect surveys than quadrat surveys. For surveys conducted across 42 margins in 2016, mean species richness per margin surveyed was more than three times larger when surveyed using a 100 m transect than when surveyed using quadrats (19.4 ±5.31 species vs 6.19 ±1.97 species (mean ±SD)). The longer 100 m transects resulted in marginal increase of a mean of three species more per margin, compared to the 30 m transects (19.4 ±5.31 species vs 16.5 ±4.91 species (mean ±SD)).

The scale of this relationship, of a three times greater recorded species richness in margins when surveyed with 100 m transects compared to quadrat surveys, is consistent for margins surveyed in 2017, at different farms and with different surveyors.

This is most likely explained by the greater area surveyed, resulting in more species found, following the species-area relationship predicted by ecological theory (MacArthur and Wilson, 1967; Connor and McCoy, 1979). When exact survey area was plotted, an increase in survey area resulted in higher species richness, with the rate of increase in species richness increase decreasing over time.

In this study, species richness per field margin also differed with both surveyor and survey method, when considering the impact of surveying method with five different surveyors. The experienced plant surveyor identified a greater number of species per margin than inexperienced undergraduate volunteers over the same field margins. Inexperienced surveyors also took around twice as long to complete each margin survey. These results are similar to previous studies, which report significant inter-surveyor differences (Goodfellow and Peterken, 1981; Kirby *et al.*, 1986; Rich and Woodruff, 1992; Prosser and Wallace, 2008). Whilst the relatively small sample size of surveys by multiple surveyors limits the conclusions which can be drawn from this study, these results indicate that future work, involving a greater number of surveyors, should be conducted to establish if the patterns described here can be more widely generalised. This research is especially important in the context of citizen science plant monitoring schemes, to ensure comparable data is collected.

5.5.3 Differences in species identities

The differences observed in plant species richness, between quadrat and transect surveys, were further investigated in terms of plant families and CSR plant strategy.

Different plant families are more likely to be observed via different survey methods. In the surveys conducted, transect surveys were more likely to detect species from the Asteraceae and Fabaceae, whilst quadrat surveys were more likely to detect species from the Lamiaceae. This may be accounted for by Asteraceae and Fabaceae having bright, eye-catching flowers, whilst Lamiaceae are often smaller individuals with less eye-catching colours. These results provide empirical support for the work of Buckland *et al.* (2007, 2005) which suggests that transects are more likely to overlook visually cryptic species. The walking transect surveys were more likely to find a greater number of spatially aggregated species or large individuals, whilst quadrat surveys were more likely to find small, visually cryptic species. In the surveys conducted, volunteers chose to get down on their hands and knees to closely examine plant species in quadrat surveys, but did not do this for transect surveys.

These results break the assumption of random sampling in biodiversity records, which assumes individual samples recorded are a random sample of the overall population (Magurran and McGill, 2014). To minimise the effects of detectability bias in surveying, field margin surveys would have to incorporate both quadrat and transect methods. The National Plant Monitoring Scheme, recommends surveying two 1m x 25m linear plots (for surveying linear features, such as field margins) and three 5m x 5m square plots per 1km square surveyed (National Plant Monitoring Scheme, 2015) is therefore likely to overcome some of the limitations for survey methods, and reduce bias in surveying plants from different families.

The impact of detectability on plant species lists may be even greater than reported here, if multiple surveyors are used. Even amongst more charismatic species, such as birds in the North American Breeding Bird Survey, inter-surveyor variation in bird detectability is reported (Sauer, Peterjohn and Link, 1994; Kendall, Peterjohn and Sauer, 1996; Link and Sauer, 1998). Inter-surveyor variation may be greater in plant surveys than bird surveys due to additional complexity in identification from the larger number of species, younger plants being visually very different to adult plants, and seasonal variation in plant morphology (Chen *et al.*, 2013). Here, lower species richness was reported in volunteer surveys across the same field margins, which may compound the impacts of survey method bias on species lists. To counteract this potential problem, the National Plant Monitoring Scheme requires volunteers to assess vegetation plots according to one of three possible levels of difficulty: 'Wildflower Level' which involves recording the fewest species; 'Indicator Level' which involves recording a larger number of species as indicators of different aspects of the habitats; 'Inventory Level' which involves recording all vascular plant species in the plot) (National Plant Monitoring Scheme, 2015). This allows volunteers to self-assess their own level of plant identification skills, to reduce the impact of inter-surveyor difference due to different levels of knowledge.

Both transect and quadrat survey methods recorded plants across a similar range of CSR strategies, with a similar mean CSR strategy. Within this study, commonly found plant species included cleavers *Galium aparine* and stinging nettles *Urtica dioica*. These species are commonly found in field margin surveys (Critchley *et al*., 2008) and are indicative of nutrient enrichment in the field margins (Defra, 2007). Invasive species are often successful due to competitive and ruderal characteristics. Within field margins, invasive species such as Common Field Speedwell *Veronia persica* have been shown in Countryside Survey plots to be increasingly common (Carey *et al.,* 2008). No stress tolerant plant species were found, which is expected as field margins are not a high stress habitat.

Neither survey method introduces a systematic bias, compared to the other method, in the CSR strategy of plant species recorded. This finding may be of practical importance as the classification of the plants in field margins according to functional group provides a valuable way of assessing the state of vegetation for conservation (Critchley *et al.,* 2013). Critchley *et al.* (2013) assessed Countryside Survey field margin vegetation plots according to the species attributes: habitat,

Ellenberg values, CSR strategy, grazing indicator status and life history. Whilst species habitat preference explained the most variation in field margin vegetation, Ellenberg values, life histories and ruderal and stress CSR strategy also identified important environmental gradients.

5.5.4 Conclusions

The results reported here using three survey methods, across four farms and five surveyors indicate that significant differences in both plant species richness and plant identities are found in surveys conducted by different methods. Quadrat and transect methods, frequently used to monitor plant diversity in agricultural land, may add bias to plant records.

Year-on-year trends are considered important in plant conservation, and so representative species lists are essential for conservation (Yoccoz, Nichols and Boulinier, 2001). Suggestions for future surveys can be made based on these results. Ideally, both transect and quadrat methods should be used, as transect and quadrat methods have a different likelihood of detecting species from different families. Surveys using both transects and quadrats will increase the likelihood of recording both spatially aggregated and visually cryptic species. Based on these results, where time restrains the ability to survey using both quadrat and transect methods, transects should be used preferentially due to higher levels of plant species richness being recorded. The shorter, 30 m transects are shown to be adequate to survey plant species richness in field margins.

In this study, these differences in species richness recorded by different methods are consistent across localities, surveyors and years. Depending on the questions being asked, in scientific studies on agricultural land, a shift away from a default of using quadrats for surveys should be considered, to encourage more representative surveys of agricultural land. Sampling bias may be reduced if records from both quadrats and transects are combined.

Chapter 6: General discussion

6.1 Overview

In the UK, species extinctions have been recorded at a high rate (Walker, 2003; Thomas *et al.*, 2004; Hayhow *et al.*, 2016; Hooftman, Edwards and Bullock, 2016). The Aichi Biodiversity targets and Global Strategy for Plant Conservation targets are the UK's main conservation goals (Defra, 2011b; JNCC, 2019a), addressed in part by agri-environmental schemes. Conservation in agricultural land is particularly important, as 72% of land in the UK is committed to agriculture (DEFRA, 2018a). To date, limited progress has been reported towards any of these targets (Plantlife, 2014b; JNCC, 2019a). Furthermore, the data available to monitor progress is limited, with no plant diversity trends on farmland reported since 2007 (Defra, 2018d). Understanding the ecological reasons behind the lack of progress towards stemming biodiversity loss in UK farmland will help to inform future agri-environmental schemes.

Field margins are semi-natural habitats within farmland with significant cultural and conservation value (Baudry, Bunce, and Burel 2000; Smart, Bunce, and Stuart 2001; Barr *et al.* 2005; Hackett and Lawrence 2014). Within arable farmland, field margins offer an opportunity for conservation within a productive landscape. Understanding the factors which can affect plant diversity within field margins is important not only for plant species conservation, but also for those species that rely on plant diversity for food and habitat (Verboom and Huitema 1997; Marshall, West, and Kleijn 2006; Vickery, Feber, and Fuller 2009).

Using observational data, collected over four farms in Oxfordshire, I have furthered our understanding of the margin-level factors which affect plant diversity, and the relationship between plant diversity and butterfly diversity in field margins. Firstly, I compared plant diversity surveyed over two years, to determine whether the same margin characteristics affect plant diversity year-to-year. I then compared plant diversity in field margins over four farms, in relation to margin-level characteristics, to determine whether plant diversity differed spatially between farms in the same region. This was addressed to see if the results from my first study were applicable across a wider spatial scale, and to see if differences in plant diversity were spatially correlated. Thirdly I looked into the relationship between butterfly species diversity and both plant structural diversity and plant species diversity. This was addressed to establish how the management of plant diversity may affect other species in field margins, which rely on plants for survival. Finally, I investigated whether plant species lists, produced in surveys undertaken by quadrats or by transects, resulted in biases in plant records. This was addressed to establish how monitoring of plant diversity, important for both conservation in field margins and future scientific studies, may be affected by survey design.

In this chapter I first summarise the main results presented in this thesis thematically and outline outstanding questions. I then explore how emerging technology may be used to answer some of these outstanding questions. Finally, I report the general conclusions of this thesis.

6.1.1 Factors affecting plant diversity in field margins

Observational data, collected over two years on one farm, were used to infer the extent to which manageable variables (such as margin width) and environmental variables (such as margin aspect) are associated with differences in plant communities. In 2015, 18% of the variation in plant community composition was accounted for by 10 of the 12 margin characteristics investigated. Partial repeats conducted in 2016 showed that the relative importance of these margin characteristics varied year-to-year. The remaining variation in plant community composition was not explained by the explanatory variables in this study, and it remains to be shown if this can be

explained deterministically by variation in management or environmental factors (creating heterogeneity and different niches in field margins), or if it is due to stochasticity. These results support previous studies which have found approximately 18% of the variation in plant community composition in field margins can be accounted for by a similar suite of margin-level characteristics (Moonen and Marshall, 2001; Deckers, Hermy and Muys, 2004). Together these results highlight the importance of regular monitoring of plant diversity in field margins, since annual changes in the importance of the factors affecting plant community composition were recorded, even where no management changes have been made. Future studies over a longer time span than the two years investigated, may be used to provide further evidence on the year-to-year variation observed in this study.

Observational data, collected in 2017 over four farms in Oxfordshire, was used to infer spatial correlations in plant diversity in field margins. A similar range of plant species was found across field margins surveyed in four farms in Oxfordshire. Including 'Farm' in a multivariate analysis of the factors that affect plant community composition in field margins (alongside margin characteristics) explained more variation than when 'Farm' was excluded. However, collinearity between 'Farm' and several of the margin characteristics suggests 'Farm' explains some of the same variation as some of the manageable and environmental margin characteristics already included in the analysis. At the scale investigated, there was limited evidence that spatially-closer plant communities had greater similarity in plant community composition, than those that were further apart.

Throughout the surveys conducted over the four farms committed to Higher-Level agri-environmental schemes in Oxfordshire, no rare arable flowers or Red List species were found. The plant communities were largely composed of different combinations of the same species over the four farms. With limited effects of Farm identity on plant community composition, a one-size-fits-all approach to field margin management for agri-environmental schemes may be ecologically effective. Management of field margin characteristics is likely to be associated with some variation in the plant communities in field margins, with heterogeneity in margin characteristics resulting in heterogeneity in plant communities.

Looking forward, questions remain about the extent to which margin-level management will affect the plant communities in field margins. To establish what might be responsible for the unexplained variation in field margin plant communities in this study, a study conducted over multiple farms which measures both margin-level characteristics and landscape-level characteristics should be conducted. To establish if variation in plant communities in field margins is due to factors which can be controlled as part of agri-environmental schemes, or if variation is due to stochasticity, an experimental study could be conducted. Conducting an experimental study in which margin characteristics are manipulated would eliminate confounding variables, especially those which may be spatially autocorrelated. This would provide additional evidence, to complement observational studies undertaken on working farms.

6.1.2 Field margin structure and butterfly diversity

Observational data was used to investigate the relationship between butterfly diversity and plant diversity in field margins. Local management at the scale of a field margin may be associated with higher butterfly diversity. Higher plant species richness and intermediate vegetation height were found to be associated with higher butterfly species richness in this study.

Primary larval food-plant presence in a field margin was associated with increased presence of two butterfly species, Ringlet *Aphantopus hyperantus* and Essex Skipper *Thymelicus lineola*. However, across five species investigated, there was no clear pattern of relationship between primary food plants and butterfly species presence at a margin scale. This may be explained by different levels of mobility of the butterfly species. A future observational study, with analysis across more

butterfly species, would help to elucidate the relationship between food-plant presence, butterfly-species presence and butterfly mobility at a field margin level.

Whilst higher butterfly species richness is positively correlated with plant species richness, the associations between butterfly species presence and specific plant species presence are not clear from this study. This reinforces the need to survey both butterflies and plants in the monitoring of field margin biodiversity.

6.1.3 Monitoring plant diversity in field margins

Comparisons of plant lists, produced from three types of field margin survey (three 1 m x 1 m quadrats, a 30 m walking transect and a 100 m walking transect), were used to establish the biases introduced by different methods. As expected, more plant species were recorded via walking transects than quadrats, since greater areas were sampled using transects. However, the time taken (a measure of effort) to conduct quadrat and 100 m walking transect surveys did not differ, despite the greater area surveyed.

In terms of the specific species found, quadrat surveys were more likely to record visually cryptic species, whilst transect surveys were more likely to record spatially-aggregated species, in the same field margin. Consequently, in surveys where species identities are important, both quadrat and transect methods could be used. It should be noted that the survey methods compared are similar to those used in the National Plant Monitoring Scheme (a nationwide citizen-science survey, with both quadrats and transects, launched in 2015) and the Countryside Survey (conducted by experienced surveyors with both quadrats and linear-plots, between 1978 and 2007), and so similar biases in plant species lists are likely in these surveys.

Data were primarily collected by one surveyor, but a limited analysis of four additional surveyors showed the importance in future research of examining the effects of inter-observer differences in plant diversity surveys, across groups of observers with different levels of surveying experience.

Assessing progress towards the Global Strategy for Plant Conservation targets and the Aichi Biodiversity targets requires plant diversity data from agricultural land to be collected. Survey methods are likely to impact the type of species found in field margins, and reported levels of plant species richness. Consequently, comparisons of temporal trends require an evaluation of the survey methods employed. These results suggest that future plant monitoring schemes should utilise both walking transects and quadrats to reduce systematic bias in plant species records.

6.1.4 Emerging technologies

Emerging technologies, such as mobile phone apps, portable DNA sequencing, and satellite data, may be useful for tackling some of the outstanding questions in this thesis. These technologies may be used to identify plant species in surveys, to survey the structure of the woody hedgerows associated with field margins, and to implement future agri-environmental schemes.

One of the most pressing issues is to ensure regular, accurate monitoring of field margin plant diversity. An important, but disheartening, finding from the thesis' fieldwork was the lack of any rare arable plants or Red List plant species over the field margins surveyed, across four large farms. Understanding the distribution of rare plant species in field margins will require more extensive surveys.

Traditional tools for plant identification are being augmented by mobile phone applications (apps), such as Leafsnap, PlantSnap, iNaturalist, Pl@ntNet and the Rare Arable Flowers app. Apps can identify plant specimens, using either automated computer vision systems (e.g. Leafsnap (Kumar *et al.*, 2012) and Plantsnap (PlantSnap, 2019b)), identification by nature enthusiasts (e.g. iNaturalist (iNaturalist, 2019)) or confirmation of identification by an expert (e.g. the Rare Arable Flower app

(CEH, 2016)). They can also be used with geospatial markers to collect data for species distribution mapping.

These mobile apps are widely available and can be very popular. Pl@ntNet has been downloaded over five million times (Pl@ntNet, 2019), and PlantSnap has been downloaded over 10 million times (PlantSnap, 2019a). Whilst these apps may be able to identify plant species successfully, social mobilization is required to attract people to collect data (Palumbo *et al.*, 2012). The Rare Arable Flowers app, developed by the Centre for Ecology and Hydrology, is used to determine the distribution and numbers of 121 rare arable plant species. Launched in 2016, the app has only 62 records of rare arable flowers (iRecord, 2019) and has been downloaded around 500 times (CEH, 2019).

Another development in species identification is the use of DNA barcoding (de Vere *et al.,* 2012; Hollingsworth *et al.*, 2016; Parker *et al.*, 2017; Kersey, 2019). Portable, real-time, nanopore sequencing may be used to distinguish between visually similar species and may be very accurate in plant identification (Parker *et al.,* 2017). However, this technology requires a trained scientist to use the equipment, and requires a database of reference DNA sequences to compare samples to (Parker *et al*., 2017). Wales was the first country to have a national DNA barcode of all native flowering plants and conifers (de Vere *et al.,* 2012), with the rest of the UK flora barcode database being built (de Vere, no date). We are therefore making progress towards the use of DNA barcoding for plant species identification in the UK. To capitalise on these new technologies in field-margin research, engaging surveyors with new technologies and ensuring that they are affordable is import.

Despite technological advances for both plant identification apps and portable DNA sequencing, some problems in plant species monitoring will still remain. One major problem in field margin plant surveys, highlighted in this thesis, is the recognition of visually cryptic plant species. The two technologies discussed above will not aid in the recognition of visually cryptic species by a surveyor.

As it stands, no data on plant diversity trends in the UK Biodiversity Indicator report has been reported since 2007 (Defra, 2018d), and so it is important that accurate plant diversity data is collected soon. In the longer term, we may be able to turn towards new technologies to monitor changes in plant diversity. However, challenges remain in ensuring the accuracy of plant identification apps in the identification of small, herbaceous plants, especially when not in flower (Wäldchen *et al.*, 2018), as are commonly found in field margins. In the short term, collecting sufficient data to report plant diversity trends will rely on improving people's identification skills. Plant identification skills were reported to have declined in the most recent Countryside Survey compared to earlier surveys (Prosser and Wallace, 2008) and plant identification skills were found to be poor among UK school students (Balmford *et al.*, 2002; Bebbington, 2005). Educating plant surveyors (both at the student level and for more experienced surveyors) is the first and most obvious step towards reliable plant surveys. The National Plant Monitoring Scheme is using citizen science to report national plant diversity trends, and uses experts to improve the quality of volunteer-collected data (Pescott *et al.* 2015). In order to improve plant identification skills, the use of mobile phone apps may be effective (Teacher *et al.*, 2013; Hartman, Lydon and Rasmussen, 2019) and smart-phone-based video training may offer a cost-effective method of teaching as effectively as in-person training (Starr *et al.*, 2014). Whilst plant identification skills may improve with training and practice, technology may be used to improve the training offered.

The results of the surveys undertaken in this thesis suggest that many different margin-level characteristics are associated with changes in field margin plant community composition, but also that a large amount of variation in plant community composition remains unexplained. To address this gap in our understanding, further surveys of plant species diversity and plant structural diversity (such as field margin herbaceous vegetation height and hedgerow height) in field margins

may be required. Remote sensing radar and lidar can be used to examine three-dimensional woody vegetation structure (Hall *et al.*, 2011; Bargiel, 2013; Betbeder *et al.*, 2014; Froidevaux *et al.*, 2016). This could be used to record hedgerow structural diversity, such as hedgerow width and hedgerow height, which has been shown in this thesis to impact plant community composition in field margins. However, other aspects of plant structural diversity, such as herbaceous vegetation height in the field margins, cannot currently be surveyed using radar or lidar.

Emerging technologies may also be of use when implementing future agri-environmental schemes. In 2016, Defra Digital announced that Defra's strategy would be 'data driven' (Newman, 2016). The Common Agricultural Policy team, alongside the Rural Payments Agency, were reported to be exploring how Earth Observation data (NASA's open-access geographical data) could be used to reduce the number of farm inspections (Newman, 2016). This promise of fewer on-site inspections was reinforced in 2018, by Michael Gove (Secretary of State for Environment, Food and Rural Affairs) for post-EU agricultural policy (Gove and Defra, 2018). Both geographic information systems data and species records from mobile phone apps could be used to roll out farm-specific or outcome-based agri-environmental schemes in the future. Indeed, a farmer survey in 2014 found that 54% of British farmers in the survey would be willing to participate in smartphone app-based farmland wildlife recording either weekly or monthly (Dehnen-Schmutz *et al.*, 2016). Delivering new, ecologically effective agri-environmental schemes may therefore be facilitated by emerging technologies.

6.2 General conclusions

This thesis furthers our understanding of the factors which affect plant diversity in field margins, as well as our understanding of the factors which affect butterfly diversity in field margins, and the impacts of different monitoring methods on plant species lists. The ecological results reported here may be particularly important given the uncertain future of agri-environmental schemes.

With field margins in English lowland farms providing a variety of ecosystem services, including the provision of habitat for biodiversity, the monitoring and management of plant diversity in field margins is important. The results reported here support the idea that field margin plant diversity is important for the survival of other species. Butterfly species richness was observed to be higher in field margins with intermediate vegetation height and higher plant species richness.

The costs of subsidies associated with maintaining hedgerows and field margins in farmland as part of agri-environmental schemes in England have exceeded £200 million over the past 20 years (Natural England, 2019). In 2009, it was estimated that the value of public goods associated with the environmental improvements from agri-environmental schemes showed a net benefit of £25 million per £1 million spent (Natural England, 2009). This adds a financial incentive to ensure that future agri-environmental schemes are ecologically effective, to continue to provide these valuable benefits. The results reported here suggest variation in margin characteristics, achieved in part through management, only affects 18-40% of the variation in field-margin plant communities. Field margins surveyed in this study showed little variation in plant community composition across farms in the same county. Future agri-environmental schemes should therefore consider margin management only as part of the solution towards effective conservation of plant communities in field margins.

Reports on the progress of conservation nationally are not positive (Plantlife, 2014b; JNCC, 2019a). The results presented here may be used to update our understanding of the plant diversity in field margins, with no government data reported since 2007 (Defra, 2018d), and few ecological studies in field margins undertaken since 2010. Results from this study suggest that field margin surveys undertaken using both transect and quadrat methods are likely to reduce bias in the plant species lists produced by either method individually. These results therefore support the new National

Plant Monitoring Scheme, which in terms of the survey methods employed in using both quadrats and transects, may be able to address this lack of data.

The plants surveyed here give a worrying perspective: throughout surveys over four large farms committed to Higher-Level schemes in Oxfordshire, no rare arable flowers or Red List species were found. This suggests that, at least on the farms surveyed, conservation measures as part of Higher-Level agri-environmental schemes could be more ecologically effective. To improve conservation, questions remain on: how plant communities in field margins vary over larger spatial scales than investigated here; how plant communities react to differences in margin characteristics over several years; what the relationship between field margin plant species presence and butterfly species presence is. Looking forward, plant ecologists should continue to monitor and study field margins, in order to gather up-to-date and reliable data, to address these questions for the conservation of biodiversity.

Bibliography

Aavik, T. & Liira, J., 2009. Agrotolerant and high nature-value species-plant biodiversity indicator groups in agroecosystems. *Ecological Indicators*, 9(5), pp. 892–901.

Andreasen, C., Stryhn, H. & Streibig, J.C., 1996. Decline of the flora in Danish arable fields. *Journal of Applied Ecology*, 33(3), pp. 619–626.

Archaux, F., Gosselin, F., Bergès, L. & Chevalier, L., 2006. Effects of sampling time, species richness and observer on the exhaustiveness of plant censuses. *Journal of Vegetation Science*, 17(3), pp. 299–306.

Asher, J., Warren, M., Fox, R., Harding, P., Jeffcoate, G. & Jeffcoate, S., 2001. *The Millennium atlas of butterflies in Britain and Ireland.* Oxford: Oxford University Press.

Balmford, A., Clegg, L., Coulson, T. & Taylor, J., 2002. Why conservationists should heed Pokémon. *Science*, 295(5564), pp.2367-2367.

Bargiel, D., 2017. A new method for crop classification combining time series of radar images and crop phenology information. *Remote sensing of environment*, *198*, pp.369-383.

Barr, C. J. & Gillespie, M.K., 2000 Estimating hedgerow length and pattern characteristics in Great Britain using Countryside Survey data. *Journal of Environmental Management,* 60(1), pp. 23–32.

Barr, C.J., Britt, C.P., Sparks, T.H. & Churchward, J.M., 2005. *Hedgerow management and wildlife. A review of research on the effects of hedgerow management and adjacent land on biodiversity.* Available at: http://www.hedgelink.org.uk/cms/cms_content/files/65_hedgerow_management_and_wildlife.pdf (Accessed: 30 June 2019).

Batáry, P., Dicks, L.V., Kleijn, D. & Sutherland, W.J., 2015. The role of agri-environment schemes in conservation and environmental management. *Conservation Biology,* 29(4), pp. 1006–1016.

Baudry, J., Bunce, R. & Burel, F., 2000. Hedgerows: An international perspective on their origin, function and management. *Journal of Environmental Management,* 60(1), pp. 7–22.

Bebbington, A., 2005. The ability of A-level students to name plants. *Journal of Biological Education,* 39(2), pp. 63–67.

Benton, T.G., Vickery, J.A. & Wilson, J.D., 2003. Farmland biodiversity: Is habitat heterogeneity the key? *Trends in Ecology and Evolution,* 18(4), pp. 182–188.

Bergman, K.O., Askling, J., Ekberg, O., Ignell, H., Wahlman, H. & Milberg, P., 2004. Landscape effects on butterfly assemblages in an agricultural region. *Oikos,* 27(5), pp. 619–628.

Bergman, K.O., Ask, L., Askling, J., Ignell, H., Wahlman, H. & Milberg, P., 2008. Importance of boreal grasslands in Sweden for butterfly diversity and effects of local and landscape habitat factors. *Biodiversity and Conservation,* 17(1), pp. 139–153.

Betbeder, J., Nabucet, J., Pottier, E., Baudry, J., Corgne, S. & Hubert-Moy, L., 2014. Detection and characterization of hedgerows using TerraSAR-X imagery. *Remote Sensing*, *6*(5), pp.3752-3769.

Billeter, R., Liira, J., Bailey, D., Bugter, R., Arens, P., Augenstein, I., Aviron, S., Baudry, J., Bukacek, R., Burel, F., Cerny, M., De Blust, G., De Cock , R., Diekötter , T., Dietz, H., Dirksen, J., Dormann, C., Durka, W., Frenzel, M., Hamersky, R., Hendrickx F., Herzog, F., Klotz, S., Koolstra, B., Lausch, A., Le Coeur, D., Maelfait, J.P., Opdam, P., Roubalova, M., Schermann, A., Schermann, N., Schmidt, T.,

Schweiger, O., Smulders, M.J.M., Speelmans, M., Simova, P., Verboom, J., Van Wingerden, W.K.R.E., Zobel, M. & Edwards, P.J., 2008. Indicators for biodiversity in agricultural landscapes: a pan-European study. *Journal of Applied Ecology,* 45, pp. 141–150.

Biodiversity Reporting and Information Group to the UK Standing Committee (2007) *Report on the Species and Habitat Review*. Available at: http://jncc.defra.gov.uk/PDF/UKBAP_Species-HabitatsReview-2007.pdf (Accessed: 30 June 2019).

Boatman, N.D., Blake, K.A., Aebischer, N.J. & Sotherton, N.W., 1994. 'Factors affecting the herbaceous flora of hedgerows on arable farms and its value as wildlife habitat' in Watt, T.A. & Buckley G.P. (ed.) *Hedgerow management and nature conservation.*, Ashford: Wye College Press, pp. 33–46.

Borin, M., Passoni, M., Thiene, M. & Tempesta, T., 2010. Multiple functions of buffer strips in farming areas. *European Journal of Agronomy,* 32(1), pp. 103–111.

Botanical Society of Britain and Ireland (2017) *Maps and data distribution maps of plants*. Available at: http://bsbi.org/maps-and-data (Accessed: 12 September 2017).

Botham, M.S., Fernandez-Ploquin, E.C., Brereton, T., Harrower, C.A., Roy, D.B. & Heard, M.S., 2015. Lepidoptera communities across an agricultural gradient: how important are habitat area and habitat diversity in supporting high diversity? *Journal of Insect Conservation,* doi: 10.1007/s10841-015-9760-y.

Bradbury, R.B., Browne, S.J., Stevens, D.K. & Aebischer, N.J., 2004. Five-year evaluation of the impact of the Arable Stewardship Pilot Scheme on birds. *Ibis*, 146, pp. 171–180.

Broughton, R.K., Shore, R.F., Heard, M.S., Amy, S.R., Meek, W.R., Redhead, J.W., Turk, A. & Pywell, R.F., 2014. Agri-environment scheme enhances small mammal diversity and abundance at the farm-scale. *Agriculture, Ecosystems and Environment*. 192, pp. 122–129.

Büchs, W., 2003. Biotic indicators for biodiversity and sustainable agriculture - introduction and background. *Agriculture, Ecosystems and Environment,* 98(1–3), pp. 1–16.

Buckland, S.T., Borchers, D.L., Johnston, A., Henrys, P.A. & Marques, T.A., 2007. Line transect methods for plant surveys. *International Biometric Society,* 63(4), pp. 989–998.

Buckland, S.T., Magurran, A.E., Green, R.E. & Fewster, R.M., 2005. Monitoring change in biodiversity through composite indices. *Philosophical Transactions of the Royal Society,* 360(1454), pp. 243–254.

Bunce, R.G.H., Barr, C.J., Gillespie, M.K., Howard, D.C., Scott, W.A., Smart, S.M., Van de Poll, H.M. & Watkins, J.W., 1999. *Vegetation of the British countryside-the Countryside Vegetation System. ECOFACT Volume 1* (Vol. 1). DETR.

Burel, F. & Baudry, J., 1990. Structural dynamic of a hedgerow network landscape in Brittany, France. *Landscape Ecology,* 4(4), pp. 197–210.

Burg, S., Rixen, C., Stöckli, V. & Wipf, S., 2015. Observation bias and its causes in botanical surveys on high-alpine summits. *Journal of Vegetation Science,* 26(1), pp. 191–200.

Butler, S.J., Vickery, J.A. & Norris, K., 2007. Farmland biodiversity and the footprint of agriculture. *Science,* 315, pp. 381–384.

Carey, P.D., Barnett, C.L., Greenslade, P.D., Hulmes, S., Garbutt, R.A., Warman, E.A., Myhill, D., Scott, R.J., Smart, S.M., Manchester, S.J. & Robinson, J., 2002. A comparison of the ecological quality of land between an English agri-environment scheme and the countryside as a whole. *Biological Conservation*, *108*(2), pp.183-197.

Carey, P.D., Short, C., Morris, C., Hunt, J., Priscott, A., Davis, M., Finch, Curry, N., Little, W., Winter, M., Parkin, A. & Firbank, L.G., 2003. The multi-disciplinary evaluation of a national agri-environment scheme. *Journal of Environmental Management,* 69(1), pp. 71–91.

Carey, P. D., Wallis, S.M., Emmett, B., Maskell, L.C., Murphy, J., Norton, L.R., Simpson, I.C. & Smart, S.M., (2008) *Countryside Survey: UK Headline Messages from 2007*. Available at: http://nora.nerc.ac.uk/id/eprint/4986/1/N004986BK.pdf (Accessed: 30 June 2019).

Carvell, C., Meek, W.R., Pywell, R.F., Goulson, D. & Nowakowskii, M., 2006. Comparing the efficacy of agri-environment schemes to enhance bumble bee abundance and diversity on arable field margins. *Journal of Applied Ecology,* 44(1), pp. 29–40.

CBD (2016) *CBD List of Parties*. Available at: https://www.cbd.int/information/parties.shtml#tab=0 (Accessed: 21 January 2016).

CBD Secretariat (2010a) *Aichi Biodiversity Targets*. Available at: https://www.cbd.int/sp/targets/ (Accessed: 18 April 2019).

CBD Secretariat (2010b) *Global Strategy for Plant Conservation. The targets 2011-2020*. Available at: https://www.cbd.int/gspc/targets.shtml (Accessed: 18 April 2019).

CBD Secretariat (2011) *Global Strategy for Plant Conservation Mission Statement*. Available at: https://www.cbd.int/gspc/mission.shtml (Accessed: 17 May 2019).

CEH (2016) *Mobile technology helps save rare flowers*. Available at: https://www.ceh.ac.uk/news-and-media/news/mobile-technology-helps-save-rare-flowers (Accessed: 26 April 2019).

CEH (2019) *App store: Rare Arable Flower app*. Available at: https://play.google.com/store/apps/details?id=uk.ac.ceh.raf&hl=en_GB (Accessed: 6 June 2019).

CEH (no date a) *Countryside Survey Field Survey*. Available at: https://countrysidesurvey.org.uk/content/field-survey (Accessed: 17 May 2019).

CEH (no date b) *Countryside Survey – measuring change in our countryside*. Available at: https://countrysidesurvey.org.uk (Accessed: 17 December 2019).

Cheffings, C.M. & Farrell, L., (2006) *The vascular plant Red Data List for Great Britain*. Available at: http://jncc.defra.gov.uk/page-3354 (Accessed: 30 June 2019).

Chen, G., Kéry, M., Zhang, J. & Ma, K., 2009. Factors affecting detection probability in plant distribution studies. *Journal of Ecology,* 97(6), pp. 1383–1389.

Chen, G., Kéry, M., Plattner, M., Ma, K. & Gardner, B., 2013. Imperfect detection is the rule rather than the exception in plant distribution studies. *Journal of Ecology,* 101(1), pp. 183–191.

Connell, J.H., 1978. Diversity in tropical rain forests and coral reefs. *Science,* 199, pp. 1302–1310.

Connor, E.F. & McCoy, E.D., 1979. The statistics and biology of the species-area relationship. *The American Naturalist,* 113(6), pp. 791–833.

Courtney, S.P. & Duggan, A.E., 1983. The population biology of the Orange Tip butterfly. *Ecological Entomology,* 8, pp. 271–281.

Cowley, M.J.R., Thomas, C.D., Roy, D.B., Wilson, R.J., Leon-Cortes, J.L., Gutierrez, D., Bulman, C.R., Quinn, R.M., Moss, D. & Gaston, K.J., 2001. Density-distribution relationships in British butterflies. I. The effect of mobility and spatial scale. *Journal of Animal Ecology,* 70(3), pp. 410–425.

Critchley, C.N.R., Wilson, L.A., Mole, A.C., Norton, L.R. & Smart, S.M., 2013. A functional classification of herbaceous hedgerow vegetation for setting restoration objectives. *Biodiversity and conservation*, *22*(3), pp.701-717.

Croxton, P.J., Hann, J.P., Greatorex-Davies, J.N. & Sparks, T.H., 2004. Linear hotspots? The floral and butterfly diversity of green lanes. *Biological Conservation,* 121, pp. 579–584.

Dahl, E. & Hadac, E., 1941. Strandgesellschaften der Insel Ostøy im Oslofjord. Eine pflanzensoziologische studie. *Nytt Magasin for Naturvidenskapene*, 82, pp. 251–312.

Dallimer, M., Irvine, K.N., Skinner, A.M.J., Davies, Z.G., Rouquette, J.R., Maltby, L.L., Warren, P.H., Armsworth, P.R. & Gaston, K.J., 2012. Biodiversity and the feel-good factor: understanding associations between self-reported human well-being and species richness. *BioScience,* 62(1), pp. 47–55.

Debinski, D.M., Ray, C. & Saveraid, E.H., 2001. Species diversity and the scale of the landscape mosaic: do scales of movement and patch size affect diversity? *Biological Conservation,* 98(2), pp. 179–190.

Deckers, B., Hermy, M. & Muys, B., 2004. Factors affecting plant species composition of hedgerows: relative importance and hierarchy. *Acta Oecologica,* 26, pp. 23–37.

Defra (2007) *Hedgerow survey handbook. A standard procedure for local surveys in the UK*. Available at: https://www.gov.uk/government/publications/hedgerow-survey-handbook (Accessed: 15 October 2014).

Defra (2010) *Farming in the uplands*. Available at: https://publications.parliament.uk/pa/cm201011/cmselect/cmenvfru/writev/556/18.htm (Accessed: 30 March 2018).

Defra (2011a) *Greenhouse gas emission projections for UK agriculture to 2030*. Available at: https://www.gov.uk/government/publications/greenhouse-gas-emission-projections-for-uk-agriculture-to-2030 (Accessed 30 June 2019).

Defra (2011b) *Biodiversity 2020: A strategy for England's wildlife and ecosystem services.* Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69446/pb13583-biodiversity-strategy-2020-111111.pdf (Accessed 30 June 2019).

Defra (2014a) *Water Framework Directive implementation in England and Wales: new and updated standards to protect the water environment*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/307788/river-basin-planning-standards.pdf (Accessed: 6 April 2017).

Defra (2014b) *The new Common Agricultural Policy schemes in England: October 2014 update*. Available at: https://www.gov.uk/government/collections/common-agricultural-policy-reform (Accessed: 30 June 2019).

Defra (2015a) *Wild bird populations in the UK, 1970 to 2014*. Available at: https://www.gov.uk/government/statistics/wild-bird-populations-in-the-uk (Accessed: 30 June 2019).

Defra (2015b) *England natural environment indicators*. Available at: https://www.gov.uk/government/statistics/england-natural-environment-indicators (Accessed: 30 June 2019).

Defra (2015c) *Briefing pack RDPE schemes launch 2015*. Available at: https://www.cioslep.com/assets/file/RDPE%20Launch%20Briefing%20pack%20updated%20version%2029.03.15.pdf (Accessed: 30 June 2019).

Defra (2016a) *British food and farming at a glance, food chain analysis*. Available at: https://www.gov.uk/government/publications/british-food-and-farming-at-a-glance (Accessed: 30 June 2019).

Defra (2016b) *Farm topology by county*. Available at: https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june (Accessed: 30 June 2019).

Defra (2018a) *Farming statistics provisional crop areas, yields and livestock populations at June 2018 – United Kingdom*. Available at: https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june (Accessed: 30 November 2018).

Defra (2018b) *Health and Harmony: the future for food, farming and the environment in a Green Brexit.* Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/684003/future-farming-environment-consult-document.pdf (Accessed: 30 June 2019).

Defra (2018c) *A Green Future: Our 25 year plan to improve the environment*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf (Accessed: 30 June 2019).

Defra (2018d) *UK biodiversity indicators 2018*. Available at: www.jncc.defra.gov.uk/ukbi (Accessed: 30 June 2019).

Defra (2019a) *Total income from farming in the United Kingdom 2018.* Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815301/agricaccounts-tiffstatsnotice-09jul19.pdf (Accessed: 30 June 2019).

Defra (2019b) *Countryside Stewardship: an overview*. Available at: https://www.gov.uk/government/publications/countryside-stewardship-an-overview (Accessed: 30 June 2019).

Defra (2019c) *Countryside Stewardship: arable offer*. Available at: https://www.gov.uk/government/publications/arable-offer-countryside-stewardship (Accessed: 30 June 2019).

Defra (2019d) *Countryside Stewardship: hedgerows and boundaries grant manual*. Available at: https://www.gov.uk/government/publications/hedgerows-and-boundaries-grant-countryside-stewardship (Accessed: 30 June 2019).

Defra (2019e) *Countryside Stewardship mid tier and wildlife offers manual*. Available at: https://www.gov.uk/government/publications/countryside-stewardship-mid-tier-including-water-quality-capital-items-manual (Accessed: 30 June 2019).

Defra and Cranfield Soil and AgriFood Institute (no date) *Soilscapes*. Available at: http://www.landis.org.uk/soilscapes/ (Accessed: 28 March 2019).

Defra, Rural Payments Agency, Foresty Commission, Natural England &
Eustice, G. (2019) *Countryside Stewardship opens for applications in 2019.* Available at: https://www.gov.uk/government/news/countryside-stewardship-opens-for-applications-in-2019 (Accessed: 30 June 2019).

Dehnen-Schmutz, K., Foster, G.L., Owen, L. & Persello, S., 2016. Exploring the role of smartphone technology for citizen science in agriculture. *Agronomy for Sustainable Development,* 36(2), pp. 1–9.

Dennis, P., Young, M.R. & Gordon, I.J., 1998. Distribution and abundance of small insects and arachnids in relation to structural heterogeneity of grazed, indigenous grasslands. *Ecological Entomology,* 23(3), pp. 253–264.

de Vere, N., Rich, T.C., Ford, C.R., Trinder, S.A., Long, C., Moore, C.W., Satterthwaite, D., Davies, H., Allainguillaume, J., Ronca, S. and Tatarinova, T., 2012. DNA barcoding the native flowering plants and conifers of Wales. *PloS one*, *7*(6), p.e37945.

de Vere, N. (no date) *Barcode UK*. Available at: https://botanicgarden.wales/science/science-collections/barcode-uk/ (Accessed: 30 June 2019).

Diniz-Filho, J.A. F., Bini, L. M. & Hawkins, B. A., 2003. Spatial autocorrelation and red herrings in geographical ecology. *Global ecology and Biogeography*, 12(1), pp. 53–64.

Dodd, M., 2011. Where are my quadrats? Positional accuracy in fieldwork. *Methods in ecology and evolution*, 2(6), pp. 576–584.

Donal, P.F., Green, R.E. & Heath, M.F., 2001. Agricultural intensification and the collapse of Europe's farmland bird populations. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 268(1462), pp. 25-29

Dormann, C.F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., García Marquéz, J.R., Gruber, B., Lafourcade, B., Leitão, P.J., Münkemüller, T., McClean, C., Osborne, P.E., Reineking, B., Schröder, B., Skidmore, A.K., Zurell, D. & Lautenbach, S., 2013. Collinearity: A review of methods to deal with it and a simulation study evaluating their performance. *Ecography,* 36(1), pp. 027–046.

Dover, J. & Sparks, T., 2000. A review of the ecology of butterflies in British hedgerows. *Journal of Environmental Management,* 60(1), pp. 51–63.

Dover, J.W., 1996. Factors affecting the distribution of Satyrid butterflies on arable farmland. *Journal of Applied Ecology,* 33(4), pp. 723–734.

Dowdeswell, W.H., 1987. *Hedgerows and verges*. London: Allen & Unwin.

Downing, E., Coe, S. & Uberoi, E., (2018). *Brexit: future UK agriculture policy*. Available at: https://www.parliament.uk/documents/commons-library/Brexit-UK-agriculture-policy-CBP-8218.pdf (Accessed: 30 June 2019).

Duelli, P., 1997. Biodiversity evaluation in agricultural landscapes: an approach at two different scales. *Agriculture, ecosystems & environment,* 62(2-3), pp. 81–91.

Duelli, P. & Obrist, M. K., 1998. In search of the best correlates for local organismal biodiversity in cultivated areas. *Biodiversity and Conservation,* 309, pp. 297–309.

EFRA Committee (2013). *Objectives of the Common Agricultural Policy.* Available at: https://publications.parliament.uk/pa/cm201011/cmselect/cmenvfru/671/67105.htm (Accessed: 30 June 2019).

Egan, J.F. & Mortensen, D.A., 2012. A comparison of land-sharing and land-sparing strategies for plant richness conservation in agricultural landscapes. *Ecological Applications,* 22(2), pp. 459–471.

Eggers, S., Unell, M. & Pärt, T., 2011 Autumn-sowing of cereals reduces breeding bird numbers in a heterogeneous agricultural landscape. *Biological Conservation,* 144(3), pp. 1137–1144.

Ellenberg, H., 1974. Indicator values of vascular plants in Central Europe. *Scripta Geobotanica,* 9, p. 97.

European Commission (no date) *Agricultural Policy COP21: United for climate*. Available at: https://ec.europa.eu/agriculture/sites/agriculture/files/climate-change/pdf/cop21-what-eu-agricultural-policy-does-for-climate_en.pdf (Accessed: 30 June 2019).

European Commission (2015) *EU agriculture and climate change*. Available at: https://ec.europa.eu/agriculture/sites/agriculture/files/climate-change/factsheet_en.pdf (Accessed: 30 June 2019).

European Commission (2018) *CAP context indicators – 2018 update.* Available at: https://ec.europa.eu/agriculture/sites/agriculture/files/cap-indicators/context/2018/cap_context_indicators.pdf (Accessed: 30 June 2019).

Evans, L.C., Sibly, R.M., Thorbek, P., Sims, I., Oliver, T.H. & Walters, R.J., 2019. Quantifying the effectiveness of agri-environment schemes for a grassland butterfly using individual-based models. *Ecological Modelling*, *411*, p.108798.

Fahrig, L., Baudry, J., Brotons, L., Burel, F., Crist, T., Fuller, R., Sirami, C., Siriwardena, G. & Martin, J.L., 2011. Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. *Ecology Letters,* 14, pp. 101–112.

Fahrig, L., Girard, J., Duro, D., Pasher, J., Smith, A., Javorek, S., King, D., Lindsay, K.F., Mitchell, S. & Tischendorf, L., 2015. Farmlands with smaller crop fields have higher within-field biodiversity. *Agriculture, Ecosystems & Environment*, 200, pp.219-234.

FAO (2009) *How to feed the world in 2050.* Available at: http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf (Accessed: 30 October 2015).

FAOSTAT (2015) *Land use*. Available at: http://faostat3.fao.org/browse/E/EL/E (Accessed: 30 June 2019).

Feber, R.E., Smith, H. & MacDonald, D.W., 1996. The effects on butterfly abundance of the management of uncropped edges of arable fields. *The Journal of Applied Ecology,* 33(5), p. 1191.

Firbank, L.G., Barr, C. J., Bunce, R.G.H., Furse, M., Haines-Young, R., Hornung, M., Howard, D.C., Sheail, J., Sier, A., & Smart., S.M., (2003). Assessing stock and change in land cover and biodiversity: An introduction to Countryside Survey 2000. Journal of Environmental Management 67, pp.207-218

Firbank, L.G., 2005. Striking a new balance between agricultural production and biodiversity. *Annals of Applied Biology*, *146*(2), pp.163-175.

Firbank, L.G., Petit, S., Smart, S., Blain, A. & Fuller, R.J., 2008. Assessing the impacts of agricultural intensification on biodiversity: a British perspective. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1492), pp.777-787.

Fox, R., Brereton, T., Asher, J., Botham, M.S., Middlebrook, I., Roy, D.B. & Warren M.S., (2015) *The state of the UK's butterflies 2015*. Available at: https://butterfly-conservation.org/sites/default/files/soukb-2015.pdf (Accessed: 30 June 2019).

Froidevaux, J.S., Zellweger, F., Bollmann, K., Jones, G. & Obrist, M.K., 2016. From field surveys to LiDAR: shining a light on how bats respond to forest structure. *Remote Sensing of Environment*, *175*, pp.242-250.

Goodfellow, S. & Peterken, G.F., 1981. A method for survey and assessment of woodlands for nature conservation using maps and species lists: the example of Norfolk woodlands. *Biological Conservation,* 21, pp. 177–195.

Gove, M. (2018) *Farming for the next generation*. Available at: https://www.gov.uk/government/speeches/farming-for-the-next-generation (Accessed: 30 June 2019).

Gove, M. and Defra (2018) *Once-in-a-generation opportunity to shape future farming policy*. Available at: https://www.gov.uk/government/news/once-in-a-generation-opportunity-to-shape-future-farming-policy (Accessed: 30 June 2019).

Grau, R., Kuemmerle, T. & Macchi, L., 2013. Beyond "land sparing versus land sharing": environmental heterogeneity, globalization and the balance between agricultural production and nature conservation. *Current Opinion in Environmental Sustainability.* Elsevier B.V., 5(5), pp. 477–483.

Gravel, D., Canham, C.D., Beaudet, M. & Messier, C., 2006. Reconciling niche and neutrality: the continuum hypothesis. *Ecology letters*, *9*(4), pp.399-409.

Greaves, M.P. & Marshall, E.J.P., 1987. Field margins: definitions and statistics. *Field Margins,* 35, pp. 3–10.

Gregory, R.D., Noble, D.G. & Custance, J., 2004. The state of play of farmland birds: population trends and conservation status of lowland farmland birds in the United Kingdom. *Ibis,* 146, pp. 1–13.

Grime, J.P., 1973. Competitive exclusion in herbaceous vegetation. *Nature,* 242, pp. 344–347.

Grime, J.P., 1977. Evidence for the existence of three primary strategies in plants and Its relevance to ecological and evolutionary theory. *The American Naturalist,* 111(982), pp. 1169–1194.

Grime, J.P., Hodgson, J.G. & Hunt, R., 1988. *Comparative plant ecology: a functional approach to common British species*. Springer.

Hackett, M. & Lawrence, A. (2014) *Multifunctional role of field margins in arable farming*. Available at: http://www.ecpa.eu/sites/default/files/Field%20Margins%20Arable%20Farming_V02%20%281%29.pdf (Accessed: 30 June 2019).

Haddaway, N.R., Brown, C., Eggers, S., Josefsson, J., Kronvang, B., Randall, N. & Uusi-Kämppä, J., 2018. The multifunctional roles of vegetated strips around and within agricultural fields. A systematic map protocol. *Environmental Evidence*, 7(14), pp. 1–43.

Hall, F.G., Bergen, K., Blair, J.B., Dubayah, R., Houghton, R., Hurtt, G., Kellndorfer, J., Lefsky, M., Ranson, J., Saatchi, S., Shugard, H.H. & Wickland, D., 2011. Characterizing 3D vegetation structure from space: mission requirements. *Remote sensing of Environment,* 115(11), pp. 2753–2775.

Hanski, I., 1999. *Metapopulation ecology*. Oxford University Press.

Hartman, T., Lydon, S.J. and Rasmussen, A., 2019. Hunting for answers: Linking lectures with the real world using a mobile treasure hunt app. *Plants, People, Planet*.

Hawthorne, W. & Marshall, C., (2016). *A manual for Rapid Botanic Survey (RBS) and measurement of vegetation bioquality*. Available at: https://herbaria.plants.ox.ac.uk/bol/Content/Projects/oxford/resources/Rapid_Botanic_Survey_manual_2016.pdf (Accessed: 30 June 2019).

Haydon, D. & Steen, H., 1997. The effects of large-and small-scale random events on the synchrony of metapopulation dynamics: a theoretical analysis. *Proceedings of the Royal Society B: Biological Sciences,* 264(1386), pp. 1375-1381.

Hayhow D.B., Burns, F., Eaton, M.A., Al Fulaij, N., August, T.A., Babey, L., Bacon, L., Bingham, C., Boswell, J., Boughey, K.L., Brereton, T., Brookman, E., Brooks, D.R., Bullock, D.J., Burke, O., Collis, M., Corbet, L., Cornish, N., De Massimi, S., Densham, J., Dunn, E., Elliott, S., Gent, T., Godber, J., Hamilton, S., Havery, S., Hawkins, S., Henney, J., Holmes, K., Hutchinson, N., Isaac, N.J.B., Johns, D., Macadam, C.R., Mathews, F., Nicolet, P., Noble, D.G., Outhwaite, C.L., Powney, G.D., Richardson, P., Roy, D.B., Sims, D., Smart, S., Stevenson, K., Stroud, R.A., Walker, K.J., Webb, J.R., Webb, T.J., Wynde, R. & Gregory, R.D. (2016) *State of Nature 2016*. The State of Nature partnership.

Hedgelink (2008) *Hedgelink - Survey database map*. Available at: https://secure.fera.defra.gov.uk/hedgerow/public/maps.cfm (Accessed: 4 March 2019).

HGCA (2005) *Field margins - guidelines for Entry Level Stewardship in England*. Available at: https://cereals.ahdb.org.uk/media/186921/g29-field-margins-guidelines-for-entry-level-stewardship-in-england.pdf (Accessed: 30 June 2019).

Hill, M.O., Mountford, J.O., Roy, D.B. and Bunce, R.G.H., 1999. *Ellenberg's indicator values for British plants. ECOFACT Volume 2 Technical Annex* (Vol. 2). Institute of Terrestrial Ecology.

Hill, S.L., Harfoot, M., Purvis, A., Purves, D.W., Collen, B., Newbold, T., Burgess, N.D. and Mace, G.M., 2016. Reconciling biodiversity indicators to guide understanding and action. *Conservation Letters*, *9*(6), pp.405-412.

Hillebrand, H., Blasius, B., Borer, E.T., Chase, J.M., Downing, J.A., Eriksson, B.K., Filstrup, C.T., Harpole, W.S., Hodapp, D., Larsen, S., Lewandowska, A.M., Seabloom, E.W., Van de Waal, D.B. & Ryabov, A.B., 2018. Biodiversity change is uncoupled from species richness trends: consequences for conservation and monitoring. *Journal of Applied Ecology,* 55(1), pp. 169–184.

Hodgson, J.G., 1986. Commonness and rarity in plants with special reference to the Sheffield flora part ii: the relative importance of climate, soils and land use. *Biological Conservation,* 36, pp. 253–274.

Hollingsworth, P.M., Li, D., van der Bank, M. & Twyford, A.D., 2016. Telling plant species apart with DNA: from barcodes to genomes. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 371(1702): 20150338.

House of Lords (2017) *House of Lords European Union Committee, Brexit: agriculture, HL Paper 169.* Available at: https://publications.parliament.uk/pa/ld201617/ldselect/ldeucom/169/169.pdf (Accessed: 30 June 2019).

Hooftman, D.A.P., Edwards, B. & Bullock, J.M., 2016. Reductions in connectivity and habitat quality drive local extinctions in a plant diversity hotspot. *Ecography* 39(6), pp. 583-592.

Hovd, H. & Skogen, A., 2005. Plant species in arable field margins and road verges of central Norway. *Agriculture, Ecosystems and Environment,* 110(3–4), pp. 257–265.

Hubbell, S.P., 2001. *The unified neutral theory of biodiversity and biogeography*. Princeton: Princeton University Press.

Hunt, R., Hodgson, J.G., Thompson, K., Bungener, P., Dunnett, N.P. & Askew, A.P., 2004. A new practical tool for deriving a functional signature for herbaceous vegetation. *Applied Vegetation Science,* 7, pp. 163–170.

Hutchinson, G.E., 1957. Cold spring harbour symposium on quantitative biology. *Concluding remarks,* 22, pp. 415-427.

Iknayan, K. J., Tingley, M.W., Furnas, B.J., and Beissinger S.R., 2014. Detecting diversity: emerging methods to estimate species diversity, *Trends in Ecology and Evolution,* 29(2), pp. 97–106.

iNaturalist (2019) *iNaturalist* [app]. Available at: https://www.inaturalist.org/ (Downloaded: 6 June 2019).

iRecord (2019) *iRecord Rare arable flowers app Info Centre*. Available at: https://www.brc.ac.uk/irecord/rare-arable-flowers-app-summary (Accessed: 4 June 2019).

Jantunen, J., Saarinen, K., Valtonen, A. & Saarnio, S., 2007. Flowering and seed production success along roads with different mowing regimes. *Applied Vegetation Science*, 10(2), pp. 285–292.

JNCC (2008) *UK Biodiversity Action Plan: priority habitat descriptions. Arable field margins.* Available at: http://jncc.defra.gov.uk/pdf/UKBAP_BAPHabitats-02-ArableFieldMargins.pdf (Accessed: 30 June 2019).

JNCC (2009) *NVC survey data & distribution maps*. Available at: http://jncc.defra.gov.uk/page-4267 (Accessed: 3 May 2019).

JNCC (2011) *UK Biodiversity Action Plan: priority habitat descriptions. Hedgerows*. Available at: http://jncc.defra.gov.uk/pdf/UKBAP_BAPHabitats-17-Hedgerows.pdf (Accessed: 30 June 2019).

JNCC (2016) *UK BAP priority habitats*. Available at: http://jncc.defra.gov.uk/page-5718 (Accessed: 30 March 2018).

JNCC (2018) *The UK Biodiversity Action Plan*. Available at: http://jncc.defra.gov.uk/ukbap (Accessed: 23 April 2019).

JNCC (2019a) *Sixth National Report to the United Nations Convention on Biological Diversity: United Kingdom of Great Britain and Northern Ireland*. Available at: http://jncc.defra.gov.uk/page-7731 (Accessed: 30 June 2019).

JNCC (2019b) *The UK Post-2010 Biodiversity framework*. Available at: http://jncc.defra.gov.uk/page-6189 (Accessed: 21 May 2019).

JNCC (2019c) *UK BAP list of priority habitats*. Available at: http://jncc.defra.gov.uk/page-5706 (Accessed: 21 May 2019).

Jobin, B., Boutin, C. & Desgranges, J., 1997. Effects of agricultural practices on the flora of hedgerows and woodland edges in southern Quebec. *Canadian Journal of Plant Sciences,* 77, pp. 293–299.

Johnson, C.N., Balmford, A., Brook, B.W., Buettel, J.C., Galetti, M., Guangchun, L. & Wilmshurst, J.M., 2017. Biodiversity losses and conservation responses in the Anthropocene. *Science*, *356*(6335), pp.270-275.

Jones, J., P. Silcock & T. Uetake (2015) *Public Goods and Externalities: Agri-environmental Policy Measures in the United Kingdom*. OECD Food, Agriculture and Fisheries Papers, No. 83, OECD Publishing, Paris. Available at: http://dx.doi.org/10.1787/5js08hw4drd1-en (Accessed: 30 June 2019).

Jones, P. M. (2016) *Agricultural enlightenment: knowledge, technology, and nature*, 1750-1840. Oxford: Oxford University Press.

Karp, D.S., Mendenhall, C.D., Callaway, E., Frishkoff, L.O., Kareiva, P.M., Ehrlich, P.R. & Daily, G.C., 2015. Confronting and resolving competing values behind conservation objectives. *Proceedings of the National Academy of Sciences,* 112(35), pp. 11132–11137.

Kendall, W.L., Peterjohn, B.G. & Sauer, J. R., 1996. First-time observer effects in the North American breeding bird survey. *The Auk*, 113(4), pp. 823–829.

Kersey, P.J., 2019. Plant genome sequences: past, present, future. *Current opinion in plant biology*, 48, pp.1-8.

Kéry, M., Spillmann, J.H., Truong, C. & Holderegger, R., 2006. How biased are estimates of extinction probability in revisitation studies? *Journal of Ecology,* 94(5), pp. 980–986.

Kéry, M. & Gregg, K.B., 2003 Effects of life-state on detectability in a demographic study of the terrestrial orchid *Cleistes bifaria*. *Journal of Ecology,* 91(2), pp. 265–273.

Kirby, K.J., Bines, T., Burn, A., Mackintosh, J., Pitkin, P. & Smith, I., 1986. Seasonal and observer differences in vascular plant records from British woodlands. *Journal of Ecology,* 74(1), pp. 123–131.

Kleijn, D. & Snoeijing, G.I.J., 1997. Field boundary vegetation and the effects of agrochemical drift : botanical change caused by low levels of herbicide and fertilizer. *Journal of Applied Ecology,* 34(6), pp. 1413–1425.

Kleijn, D., Berendse, F., Smit, R. & Gilissen, N., 2001. Agri-environment schemes do not effectively protect biodiversity in Dutch agricultural landscapes. *Nature,* 413(6857), pp. 723–725.

Kleijn, D., Baquero, R.A., Clough, Y., Díaz, M., De Esteban, J., Fernández, F., Gabriel, D., Herzog, F., Holzschuh, A., Jöhl, R., Knop, E., Kruess, A., Marshall, E.P.J., Steffan-Dewenter, I., Tscharntke, T., Verhulst, J., West, T.M. & Yela, J.L., 2006. Mixed biodiversity benefits of agri-environment schemes in five European countries. *Ecology Letters,* 9(3), pp. 243–254.

Kleijn, D., Rundlöf, M., Scheper, J., Smith, H.G. & Tscharntke, T., 2011. Does conservation on farmland contribute to halting the biodiversity decline? *Trends in Ecology and Evolution,* 26(9), pp. 474–481.

Kleijn, D. & Sutherland, W.J., 2003. How effective are European agri-environment schemes in conserving and promoting biodiversity? *Journal of Applied Ecology,* 40(6), pp. 947–969.

Klimeš, L., Dančak, M., Hájek, M., Jongepierová, I. & Kučera, T., 2001. Scale-dependent biases in species counts in a grassland. *Journal of Vegetation Science,* 12(5), pp. 699–704.

Koenig, W. D., 1999. Spatial autocorrelation of ecological phenomena. *Trends in Ecology and Evolution,* 14(1), pp. 22–26.

Krämer, B., Poniatowski, D. & Fartmann, T., 2012. Effects of landscape and habitat quality on butterfly communities in pre-alpine calcareous grasslands. *Biological Conservation,* 152, pp. 253–261.

Kremen, C., Williams, N.M., Aizen, M.A., Gemmill-Herren, B., LeBuhn, G., Minckley, R., Packer, R., Potts, S.G., Roulston, T., Steffan-Dewenter, I., Vázquez, D.P., Winfree, R., Adams, L., Crone, E.E., Greenleaf, S.S., Keitt, T.H., Klein, A.M., Regetz, J., Ricketts & T.H., 2007. Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. *Ecology Letters,* 10(4), pp. 299–314.

Kumar, N., Belhumeur, P.N., Biswas, A.V., Jacobs, D.W., Kress, W.J.C., Lopez, I.C. & Soares J.V.B. (2012) 'Leafsnap: a computer vision system for automatic plant species identification' in Fitzgibbon,

A., Lazebnik, S., Perona, P., Sato, Y. & Schmid C., (eds) *European Conference on Computer Vision*. Berlin, Heidelberg: Springer, pp. 502-516.

Lawton, J. H., Brotherton, P.N.M., Brown, V.K.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W.W., Hilborne, S., Leafe, R., Mace, G. & Southgate, M. (2010) *Making space for nature: a review of England's wildlife sites and ecological network.* Available at: https://webarchive.nationalarchives.gov.uk/20130402170324/http:/archive.defra.gov.uk/environment/biodiversity/documents/201009space-for-nature.pdf (Accessed: 30 June 2019).

Lawton, J.H. & Gaston, K.J. 2001. Indicator species. *Encyclopedia of Biodiversity,* 3, pp. 253–263.

Lazzaro, L., Otto, S. & Zanin, G., 2008. Role of hedgerows in intercepting spray drift: evaluation and modelling of the effects. *Agriculture, Ecosystems and Environment,* 123(4), pp. 317–327.

Le Coeur, D., Baudry, J. & Burel, F., 1997. Field margins plant assemblages: variation partitioning between local and landscape factors. *Landscape and Urban Planning,* 37(1–2), pp. 57–71.

Le Coeur, D., Baudry, J., Burel, F. & Thenail, C., 2002. Why and how we should study field boundary biodiversity in an agrarian landscape context. *Agriculture, Ecosystems & Environment*, *89*(1-2), pp.23-40.

Lepš, J. & Hadincová, V., 1992. How reliable are our vegetation analyses? *Journal of Vegetation Science,* 3(1), pp. 119–124.

Link, W. A. & Sauer, J. R., 1998. Estimating population change from count data: application to the North American breeding bird survey. *Ecological Applications,* 8(2), pp. 258–268.

MacArthur, R.H. & Wilson, E.O. (1967) *The theory of island biogeography*. Princeton: Princeton University Press.

MacDougall, A.S., Wilson, S.D. & Bakker, J.D., 2008. Climatic variability alters the outcome of long-term community assembly. *Journal of Ecology,* 96(2), pp. 346–354.

Magurran, A. E. (2013) *Measuring biological diversity*. Oxford: John Wiley and Sons.

Magurran, A. E. & McGill, B. J. (2014) *Biological diversity: frontiers in measurement and assessment*. Oxford: Oxford University Press.

Marshall, E., 1989. Distribution patterns of plants associated with arable field edges. *Journal of applied Ecology,* 26(1), pp. 247–257.

Marshall, E.J.P. & Arnold, G.M., 1995. Factors affecting field weed and field margin flora on a farm in Essex, UK. *Landscape and Urban Planning,* 31(1–3), pp. 205–216.

Marshall, E.J.P. & Moonen, A.C., 2002. Field margins in northern Europe: Integrating agricultural, environmental and biodiversity functions. *Agriculture, Ecosystems & Environment,* 89, pp. 5–21.

Marshall, E.J.P., West, T.M. & Kleijn, D., 2006. Impacts of an agri-environment field margin prescription on the flora and fauna of arable farmland in different landscapes. *Agriculture, Ecosystems and Environment,* 113(1–4), pp. 36–44.

Maskell, L.C., Norton, L.R., Smart, S.M., Scott, R., Carey, P.D., Murphy, J., Chamberlain, P.M., Wood, C.M., Bunce, R.G.H. & Barr, C.J. (2008) *Vegetation plots handbook. Centre of Ecology and Hydrology: Countryside Survey*. Available at: http://www.countrysidesurvey.org.uk/sites/default/files/CS_UK_2007_TR2%20-%20Vegetation%20Plots%20Handbook.pdf (Accessed: 30 June 2019).

May, R. M. (1988) How many species are there on Earth? *Science,* 241(4872), pp. 1441–1449.

McGill, B.J., Enquist, B.J., Weiher, E. & Westoby, M., 2006. Rebuilding community ecology from functional traits. *Trends in Ecology and Evolution,* 21(4), pp. 178–185.

Meek, B., Loxton, D., Sparks, T., Pywell, R., Pickett, H. & Nowakowski, M., 2002. The effect of arable field margin composition on invertebrate biodiversity. *Biological Conservation,* 106(2), pp. 259–271.

Met Office (2019) *Climate summaries*. Available at: https://www.metoffice.gov.uk/climate/uk/summaries (Accessed: 7 June 2019).

Milberg, P., Bergstedt, J., Fridman, J., Odell, G. & Westerberg, L., 2008. Observer bias and random variation in vegetation monitoring data. *Journal of Vegetation Science,* 19(5), pp. 633–644.

Milberg, P., Bergman, K.O., Cronvall, E., Eriksson, A.I., Glimskär, A., Islamovic, A., Jonason, D., Löfqvist, Z. & Westerberg, L., 2016. Flower abundance and vegetation height as predictors for nectar-feeding insect occurrence in Swedish semi-natural grasslands. *Agriculture, Ecosystems and Environment*, 230, pp. 47–54.

Miller, V., (2015) *House of Commons Briefing Paper. Exiting the EU : impact in key UK policy areas*. Available at: https://www.northants-chamber.co.uk/images/uploads/cbp-7213_(2).pdf (Accessed: 30 June 2019).

Mitchell, M.G.E., Suarez-Castro, A.F., Martinez-Harms, M., Maron, M., McAlpine, C., Gaston, K.J., Johansen, K. & Rhodes, J.R., 2015. Reframing landscape fragmentation's effects on ecosystem services. *Trends in Ecology & Evolution,* 30(4), pp. 1–9.

Moonen, A.C. & Marshall, E.J.P. 2001. The influence of sown margin strips, management and boundary structure on herbaceous field margin vegetation in two neighbouring farms in southern England. Agriculture, Ecosystems and Environment, 86(2), pp. 187–202.

Morris, E.K., Caruso, T., Fischer, M., Hancock, C., Obermaier, E., Prati, D., Maier, T.S., Müller, C., Obermaier, E., Prati, D. & Socher, S.A., 2014. Choosing and using diversity indices: insights for ecological applications from the German biodiversity exploratories. Ecology and Evolution, pp. 3514–3524.

Munguira, M.L. & Thomas, J.A., 1992. Use of road verges by butterfly and burnet populations, and the effect of roads on adult dispersal and mortality. *Journal of Applied Ecology,* 29(2), pp. 316–329.

Murphy, D.D., Launer, A.E. & Ehrlich, P.R., 1983. The role of adult feeding in egg production and population dynamics of the checkerspot butterfly *Euphydryas editha*. *Oecologia,* 56(2–3), pp. 257–263.

National Plant Monitoring Scheme (no date) *NMPS to NVC Summary*. Available at: https://www.npms.org.uk/sites/default/files/PDF/NPMS_to_NVC_Summary.pdf (Accessed: 30 June 2019).

National Plant Monitoring Scheme (2015) *National Plant Monitoring Scheme survey guidance notes*. Available at: https://www.npms.org.uk/sites/default/files/PDF/NPMS%20Guidance%20Notes_WEB_0.pdf (Accessed: 23 March 2018).

National Plant Monitoring Scheme (2018) *National Plant Monitoring Scheme flow diagram overview.* Available at: http://www.npms.org.uk/content/resources (Accessed: 23 March 2018).

Natural England (2009) *Agri-environment schemes in England 2009. A review of results and effectiveness.* Available at: http://www.naturalengland.org.uk/Images/AE-schemes09_tcm6-14969.pdf. (Accessed: 30 June 2019).

Natural England (2012) *Oxfordshire Agri-Environmental Schemes: Key information, scheme uptake and expenditure data*. Available at: http://publications.naturalengland.org.uk/file/3981998. (Accessed: 18 December 2019).

Natural England (2013) *National Vegetation Classification: MG5 grassland*. Available at: http://publications.naturalengland.org.uk/publication/6626052 (Accessed: 30 June 2019).

Natural England (2019) FOI request 9th April 2019.

Neumann, J. L., Griffiths, G.H., Hoodless, A. & Holloway, G.J., 2015. The compositional and configurational heterogeneity of matrix habitats shape woodland carabid communities in wooded-agricultural landscapes. *Landscape Ecology,* 31(2), pp.301-315.

Newman, A. (2016) *Let's make Defra data driven*. Available at: https://defradigital.blog.gov.uk/2016/02/01/lets-make-defra-data-driven/ (Accessed: 4 June 2019).

NFU (2017) *Contribution of UK agriculture: Final Report*. Available at: https://www.nfuonline.com/nfu-online/news/report-21117-contributions-of-uk-agriculture/ (Accessed: 30 June 2019).

Nilsson, I.N. & Nilsson, S.G., 1985. Experimental estimates of census efficiency and pseudoturnover on islands: error trend and between-observer variation when recording vascular plants. *The Journal of Ecology,* 73(1), pp. 65–70.

Öckinger, E. & Smith, H.G., 2006. Landscape composition and habitat area affects butterfly species richness in semi-natural grasslands. *Oecologia,* 149(3), pp. 526–534.

Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Henry, M., Stevens, H., Szoecs, E. & Wagner, H. (2017) *Vegan: community ecology package v2.4-2* [computer programme]. Available at: https://cran.r-project.org/web/packages/vegan/index.html (Downloaded: 30 January 2017).

Oliver, T.H., Roy, D.B., Hill, J.K., Brereton, T. & Thomas, C.D., 2010. Heterogeneous landscapes promote population stability. *Ecology Letters,* 13(4), pp. 473–484.

Oliver, T.H., Isaac, N.J., August, T.A., Woodcock, B.A., Roy, D.B. and Bullock, J.M., 2015a. Declining resilience of ecosystem functions under biodiversity loss. *Nature communications*, *6*, p.10122.

Oliver, T.H., Marshall, H.H., Morecroft, M.D., Brereton, T., Prudhomme, C. and Huntingford, C., 2015b. Interacting effects of climate change and habitat fragmentation on drought-sensitive butterflies. *Nature Climate Change*, *5*(10), p.941.

Ordnance Survey (2019a) *Oxfordshire in UK*, JPEG map, 1: 80 000 000, OS GB Overview, December 2014, https://digimap.edina.ac.uk/ (Downloaded: 7 December 2019).

Ordnance Survey (2019b) *Oxfordshire and surrounding counties,* JPEG map, 1: 800 000, OS MiniScale, January 2019, https://digimap.edina.ac.uk/, (Downloaded: 7 December 2019).

Ouin, A., Aviron, S., Dover, J. & Burel, F., 2004. Complementation/supplementation of resources for butterflies in agricultural landscapes. *Agriculture, Ecosystems and Environment,* 103(3), pp. 473–479.

Oxford University (2016a) *Mean maximum air temperature, Radcliffe Meteorological Station*. Available at: https://www.geog.ox.ac.uk/research/climate/rms/meanmax.html (Accessed: 16 May 2019).

Oxford University (2016b*) Mean minimum air temperature, Radcliffe Meteorological Station*. Available at: https://www.geog.ox.ac.uk/research/climate/rms/meanmin.html (Accessed: 16 May 2019).

Oxford University (2016c) *Total precipitation, Radcliffe Meteorological Station*. Available at: https://www.geog.ox.ac.uk/research/climate/rms/rain.html (Accessed: 16 May 2019).

Palumbo, M.J., Johnson, S.A., Mundim, F.M., Lau, A., Wolf, A.C., Arunachalam, S., Gonzalez, O., Ulrich, J.L., Washuta, A. & Bruna, E.M., 2012. Harnessing smartphones for ecological education, research, and outreach. *Bulletin of the Ecological Society of America,* 93(4), pp. 390–393.

Parker, J., Helmstetter, A.J., Devey, D., Wilkinson, T. & Papadopulos, A.S.T., 2017. Field-based species identification of closely-related plants using real-time Nanopore sequencing. *Scientific Reports,* 7(1), pp. 1–8.

Peach, W.J., Lovett, L.J., Wotton, S.R. & Jeffs, C., 2001. Countryside stewardship delivers cirl buntings (*Emberiza cirlus*) in Devon, UK. *Biological Conservation,* 101(3), pp. 361–373.

Pescott, O.L., Walker, K.J., Pocock, M.J.O., Jitlal, M., Outhwaite, C.L., Cheffings, C.M., Harris, F. & Roy, D.B., 2015. Ecological monitoring with citizen science: the design and implementation of schemes for recording plants in Britain and Ireland. *Biological Journal of the Linnean Society,* 115(3), pp. 505–521.

Pescott, O.L. (2015) *The NPMS launch*. Available at: https://www.npms.org.uk/content/npms-launches-today (Accessed: 18 April 2019).

Pescott, O.L., Walker, K.J., New, H., Harris, F., Cheffings, C.M., Newton, N., Jitlal, M., Redhead, J., Smart, S.M., and Roy, D.B., 2019. The design and launch of a new volunteer-based plant monitoring scheme for the United Kingdom. *PLoSONE*, 14(4), pp. 1-30.

Peterken, G.F. (1981) *Woodland conservation and management*. Berlin, Heidelberg: Springer Science & Business Media.

Phalan, B., Onial, M., Balmford, A. & Green, R.E., 2011. Reconciling food production and biodiversity conservation: land sharing and land sparing compared. *Science*, 333(6047), pp. 1289–1291.

Phalan, B., Green, R.E., Dicks, L.V., Dotta, G., Feniuk, C., Lamb, A., Strassburg, B.B.N., Williams, D.R., Zu Ermgassen, E.K.H.J. & Balmford, A., 2016. How can higher-yield farming help to spare nature? *Science,* 351(6272), pp. 450–451.

Phalan, B., Green, R. & Balmford, A., 2014. Closing yield gaps: perils and possibilities for biodiversity conservation. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences,* 369, p. 20120285.

Pl@ntNet (2019) *App store: Pl@ntNet* [app]. Available at: https://play.google.com/store/apps/details?id=org.plantnet&hl=en_GB (Accessed: 6 June 2019).

Plantlife (2014a) *Important Arable Plant Areas Threatened Species*. Available at: https://www.plantlife.org.uk/application/files/4015/1784/3642/Important_Arable_Plant_Areas_-_Threatened_species_A.pdf (Accessed: 30 June 2019).

Plantlife (2014b) *Global strategy for plant conservation: a review of the UK's progress towards 2020*. Available at: https://www.plantlife.org.uk/application/files/6214/8232/2638/GSPC_2014_print_version_FINAL_web.pdf (Accessed: 30 June 2019).

PlantSnap (2019a) *App store: PlantSnap* [app]. Available at: https://play.google.com/store/apps/details?id=com.fws.plantsnap2&hl=en_GB (Accessed: 6 June 2019).

PlantSnap (2019b) *PlantSnap*. Available at: https://www.plantsnap.com/ (Accessed: 6 June 2019).

Pollard, E., 1977. A method for assessing changes in the abundance of butterflies. *Biological Conservation,* 12(2), pp. 115–134.

Porter, K. (1992) 'Eggs and egg laying' in Dennis R.L.H. (ed.) *The Ecology of Butterflies in Britain*. Oxford: Oxford University Press.

Porter, K., Steel, C.A., Thomas, J.A. (1992) 'Butterflies and communities' in Dennis R.L.H. (ed.) *The Ecology of Butterflies in Britain*. Oxford: Oxford University Press.

Prosser, M. & Wallace, H. (2008) *Countryside Survey 2007: quality assurance exercise*. Available at: http://www.countrysidesurvey.org.uk/sites/default/files/QA_PLOTS_1.pdf (Accessed: 30 June 2019).

Rands, M.R.W. & Sotherton, N.W., 1986. Pesticide use on cereal crops and changes in the abundance of butterflies on arable farmland in England. *Biological Conservation,* 36, pp. 71–82.

Ratnieks, F.L.W., Schrell, F., Sheppard, R.C., Brown, E., Bristow, O.E., Garbuzov, M. & McPherson, J., 2016. Data reliability in citizen science: learning curve and the effects of training method, volunteer background and experience on identification accuracy of insects visiting ivy flowers. *Methods in Ecology and Evolution,* 7(10), pp. 1226–1235.

Reichenberger, S., Bach, M., Skitschak, A. & Frede, H.G., 2007. Mitigation strategies to reduce pesticide inputs into ground- and surface water and their effectiveness; a review. *Science of the Total Environment,* 384(1–3), pp. 1–35.

Rich, T.C.G. & Woodruff, E. R., 1992. Recording bias in botanical surveys. *Watsonia,* 95, pp. 73–95.

Rich, T.C.G. & Woodruff, E.R., 1996. Changes in the vascular plant floras of England and Scotland between 1930-1960 and 1987-1988: the BSBI monitoring scheme. *Biological Control,* 75(3), pp. 217–229.

Robinson, R.A. & Sutherland, W. J., 2002. Post-war changes in arable farming and biodiversity in Great Britain. *Journal of Applied Ecology,* 39(May), pp. 157–176.

Rodwell, J. (1992) *British plant communities. Vol 3. Grasslands and mountain communities*. Cambridge: Cambridge University Press.

Rodwell, J. (2000) *British plant communities: Volume 5, Maritime communities and vegetation of open habitats.* Cambridge: Cambridge University Press.

Rodwell, J. (2006) *National Vegetation Classification: users' handbook*. Available at: http://jncc.defra.gov.uk/pdf/pub06_NVCusershandbook2006.pdf (Accessed: 25 October 2014).

Rose, F. & O'Reilly, C. (2006) *The wild flower key - how to identify wild plants, trees and shrubs in Britain and Ireland*. London: Warne.

Rundlöf, M., Edlund, M. & Smith, H.G., 2010. Organic farming at local and landscape scales benefits plant diversity. *Ecography,* 33(3), pp. 514–522.

Rural payments agency (2017) *Basic Payment Scheme: rules for 2018*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/705756/BPS_2018_scheme_rules_v5.0.pdf (Accessed: 30 June 2019).

Rural Payments Agency (2019) *Greening workbook for the Basic Payment Scheme in England*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/807837/Greening_Workbook_2019_v1.0.pdf (Accessed: 30 June 2019).

Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leeans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M. & Wall, D.H., 2000. Global biodiversity scenarios for the year 2100. *Science*, 287(5459), pp. 1770–1774.

Sauer, J.R., Peterjohn, B.G. & Link, W.A., 1994. Observer differences in the North American breeding bird survey. *American Ornithological Society,* 111(1), pp. 50–62.

Schneider, M.K., Lüscher, G., Jeanneret, P., Arndorfer, M., Ammari, J., Bailey, D., Balázs, D., Báldi, A., Choisis, J.P., Dennis, P. & Eiter, S., 2014. Gains to species diversity in organically farmed fields are not propagated at the farm level. *Nature communications,* 5, p. 4151.

Sheppard, S.C., Sheppard, M.I., Long, J., Sanipelli, B. & Tait, J., 2006. Runoff phosphorus retention in vegetated field margins on flat landscapes. *Canadian Journal of Soil Science,* 86(5), pp. 871–884.

Silvertown, J., 2004. Plant coexistence and the niche. *Trends in Ecology & evolution*, *19*(11), pp.605-611.

Smart, S.M., Firbank, L.G., Bunce, R.G.H. & Watkins, J.W., 2000. Quantifying changes in abundance of food plants for butterfly larvae and farmland birds. *Journal of Applied Ecology,* 37(3), pp. 398–414.

Smart, S. M., Bunce, R. G. H. & Stuart, R. C. (2001) 'An assessment of the potential of British hedges to act as corridors and refuges for ancient woodland indicator plants' in Barr, C. and Petit, S. (eds) *Hedgerows of the world: their ecological functions in different landscapes*. Birmingham: University of Birmingham, pp. 137–146.

Smart, S.M., Marrs, R.H., Le Duc, M.G., Thompson, K.E.N., Bunce, R.G., Firbank, L.G. & Rossall, M.J., 2006. Spatial relationships between intensive land cover and residual plant species diversity in temperate farmed landscapes. *Journal of Applied Ecology*, *43*(6), pp.1128-1137.

Soga, M., Kawahara, T., Fukuyama, K., Sayama, K., Kato, T., Shimomura, M., Itoh, T., Yoshida, T. & Ozaki, K., 2015. Landscape versus local factors shaping butterfly communities in fragmented landscapes: Does host plant diversity matter? *Journal of Insect Conservation*, 19(4), pp. 781–790.

Sparks, T.H. & Parish, T., 1995. Factors affecting the abundance of butterflies in field boundaries in Swavesey Fens, Cambridgeshire, UK. *Biological conservation*, 73(3), pp. 221–227.

Starr, J., Schweik, C.M., Bush, N., Fletcher, L., Finn, J., Fish, J. & Bargeron, C.T., 2014. Lights, camera... citizen science: assessing the effectiveness of smartphone-based video training in invasive plant identification. *PLoS ONE,* 9(11).

Stickland, E. (2017) *Factors that influence butterfly abundance in field margins and their implications on agriculture*. BA Thesis. University of Oxford.

Stoate, C., Boatman, N.D., Borralho, R.J., Rio Carvalho, C., De Snoo, G.R. & Eden, P., 2001. Ecological impacts of arable intensification in Europe. *Journal of Environmental Management,* 63(4), pp. 337–365.

Storkey, J., Meyer, S., Still, K.S. & Leuschner, C., 2012. The impact of agricultural intensification and land-use change on the European arable flora. *Proceedings of the Royal Society B: Biological Sciences,* 279(1732), pp. 1421–1429.

Su, J.C., Debinski, D.M., Jakubauskas, M.E. & Kindscher, K., 2004. Beyond species richness: Community similarity as a measure of cross-taxon congruence for coarse-filter conservation. *Conservation biology*, *18*(1), pp.167-173.

Sutcliffe, O.L. & Kay, Q.O.N., 2000. Changes in the arable flora of central southern England since the 1960s. *Biological Conservation,* 93(1), pp. 1–8.

Teacher, A.G., Griffiths, D.J., Hodgson, D.J. & Inger, R., 2013. Smartphones in ecology and evolution: a guide for the app-rehensive. *Ecology and Evolution*, *3*(16), pp.5268-5278.

Ter Braak, C.J.F., 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology,* 67(5), pp. 1167–1179.

Thomas, J.A., Bourn, N.A.D., Clarke, R.T., Stewart, K.E., Simcox, D.J., Pearman, G.S., Curtis, R. & Goodger, B., 2001. The quality and isolation of habitat patches both determine where butterflies persist in fragmented landscapes. *Proceedings of the Royal Society B: Biological Sciences,* 268(1478), pp. 1791–1796.

Thomas, J. A., Telfer, M.G., Roy, D.B., Preston, C.D., Greenwood, J.J.D, Asher, J., Fox, R., Clarke, R.T. & Lawton, J.H., 2004. Comparative losses of British butterflies, birds, and plants and the global extinction crisis. *Science*, 303(5665), pp. 1879–1881.

Thompson, K. & Jones, A., 1999. Human population density and prediction of local plant extinction in Britain. *Conservation Biology,* 13(1), pp. 185–189.

Tilman, D., Clark, M., Williams, D.R., Kimmel, K., Polasky, S. & Packer, C., 2017. Future threats to biodiversity and pathways to their prevention. *Nature*, *546*(7656), p.73.

Tscharntke, T., Klein, A., Kruess, A., Steffan-Dewenter, I. & Thies, C., 2005. Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. *Ecology Letters,* 8, pp. 857–874.

Tuck, S.L., Winqvist, C., Mota, F., Ahnström, J., Turnbull, L. & Bengtsson, J., 2014. Land-use intensity and the effects of organic farming on biodiversity: A hierarchical meta-analysis. *Journal of Applied Ecology,* 51(3), pp. 746–755.

UKBMS (2018) *Methods for recording butterfly transects.* Available at: http://www.ukbms.org/Methods.aspx (Accessed: 15 January 2018).

Verboom, B. & Huitema, H., 1997. The importance of linear landscape elements for the pipistrelle *Pipistrellus pipistrellus* and the serotine bat *Eptesicus serotinus*. *Landscape Ecology,* 12(2), pp. 117–125.

Vickery, J.A., Feber, R.E. & Fuller, R.J., 2009. Arable field margins managed for biodiversity conservation: a review of food resource provision for farmland birds. *Agriculture, Ecosystems and Environment,* 133(1–2), pp. 1–13.

Vittoz, P., Bayfield, N., Brooker, R., Elston, D.A., Duff, E.I., Theurillat, J.P. & Guisan, A., 2010. Reproducibility of species lists, visual cover estimates and frequency methods for recording high-mountain vegetation. *Journal of Vegetation Science,* 21(6), pp. 1035–1047.

Vittoz, P. & Guisan, A., 2007. How reliable is the monitoring of permanent vegetation plots? A test with multiple observers. *Journal of Vegetation Science,* 18(3), pp. 413–422.

Wäldchen, J., Rzanny, M., Seeland, M. & Mäder, P., 2018. Automated plant species identification—Trends and future directions. *PLoS computational biology*, *14*(4), p.e1005993.

Walker, K.J., 2003. One species lost every year? An evaluation of plant extinctions in selected British vice-counties since 1900. *Watsonia* 23(3), pp. 359-374.

Warren, M. S. (1992) 'Butterfly populations' in Dennis, R. (ed.) *The Ecology of Butterflies in Britain*. Oxford: Oxford University Press.

Water Environment (Water Framework Directive) (England and Wales) Regulations 2017. Available at: http://www.legislation.gov.uk/uksi/2017/407/made (Accessed: 11 April 2019).

Watt, W., Hoch, P. & Mills, S., 1974. Nectar resource use by *Colias* butterflies. *Oecologia,* 14, pp. 353–374.

Weibull, A.C., Bengtsson, J. & Nohlgren, E. 2000. Diversity of butterflies in the agricultural landscape: the role of farming system and landscape heterogeneity. *Ecography,* 23(6), pp. 743–750.

Weibull, A.C. & Ostman, O., 2003. Species composition in agroecosystems: the effect of landscape, habitat and farm management. *Basic and Applied Ecology,* 4, pp. 349–361.

Whittaker, R.J., 1972. Evolution and measurement of species diversity. *Taxon,* 21(2), pp. 213–251.

Wiens, J. A., 1989. Spatial scaling in ecology. *Functional ecology,* 3(4), pp. 385–397.

Wilson, E.O., 1989. Threats to biodiversity. *Scientific American,* 261(3), pp. 108–116.

Wilson, J.B., 1995. Testing for community structure: a Bayesian approach. *Folia Geobotanica & Phytotaxonomica,* 30(4), pp. 461–469.

Wolton, R. (2009) *UK Biodiversity Action Plan: Priority species linked to hedgerows. Hedgelink*. Available at: http://www.hedgelink.org.uk/cms/cms_content/files/70_hedgelink_-_bap_species_linked_to_hedgerows_report%2C_v2%2C_16_nov_2009.doc (Accessed: 30 June 2019).

Yoccoz, N.G., Nichols, J.D. & Boulinier, T., 2001. Monitoring of biological diversity in space and time. *Trends in Ecology and Evolution,* 16(8), pp. 446–453.

Zhang, J., Nielsen, S.E., Grainger, T.N., Kohler, M., Chipchar, T. & Farr, D.R., 2014. Sampling plant diversity and rarity at landscape scales: importance of sampling time in species detectability. *PLoS ONE,* 9(4).

Appendix 1

Supplementary information for Chapter 2.

9.1 Supplementary methods

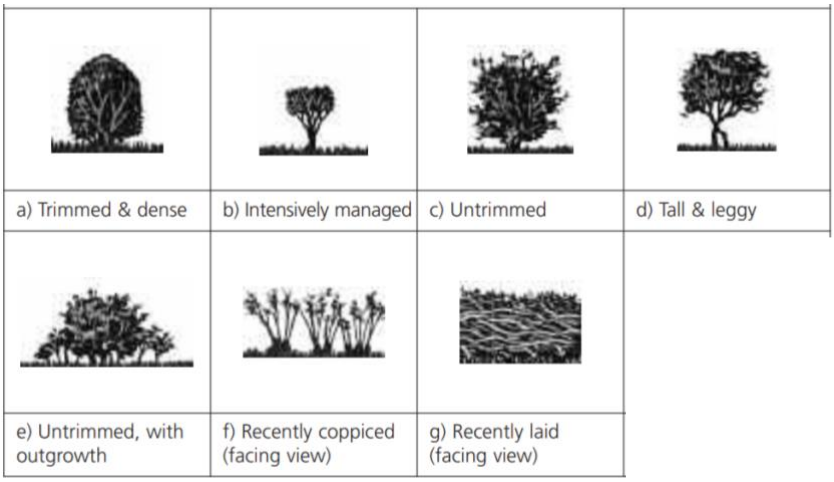


Figure 9.1 Cross-section diagrams of hedgerow shapes. Diagram from the Hedgerow Survey Handbook (p. 116, Defra, 2007).

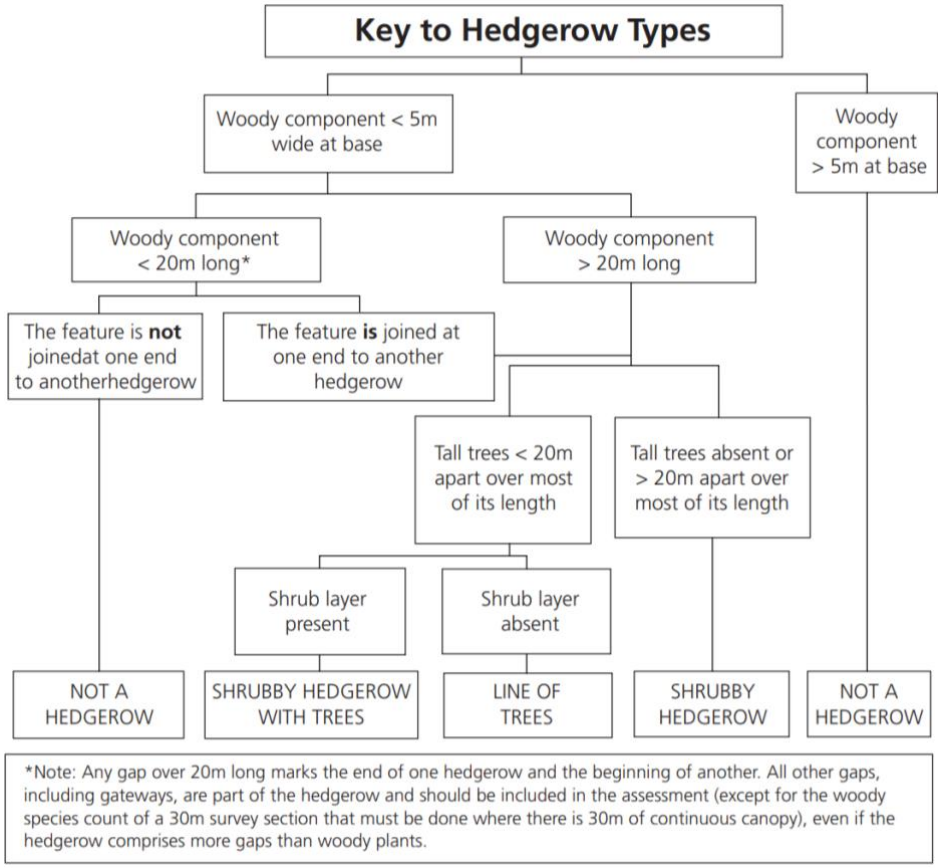


Figure 9.2 A key for determining if a feature is a hedgerow and the hedgerow type. In this work, type A = shrubby hedgerow; type B = line of trees; type C = shrubby with line of trees. Reproduced from The Hedgerow Survey Handbook (p. 49, Defra, 2007).

9.2 Supplementary results

Variable	Variable code		CCA axis 1	CCA axis 2	ANOVA-like permutation test
Adjacent land use	**ALU**	**Cropcrop (n=77)**	-0.0703	0.641	**$F_{3, 227}$ = 2.71, p = 0.001**
		Croproad (n=97)	-0.429	-0.0735	
		Grasscrop (n=46)	0.344	-0.0921	
		Grassroad (n=37)	0.827	-1.554	
Aspect	**Aspect**	**N (n=52)**	-0.270	-1.199	**$F_{3, 227}$ = 1.72, p = 0.001**
		S (n=42)	-0.0780	-0.0529	
		E (n=88)	-0.0673	0.265	
		W (n=75)	0.299	0.482	
Bank height	**BH**	**Side a**	-0.131	0.0650	**$F_{2, 227}$ = 1.41, p = 0.002**
		Side b	-0.0702	0.143	
Ditch	**D**		**-0.0118**	**0.115**	**$F_{1, 227}$ = 1.49, p = 0.029**
Fence	**F**		**0.297**	**-0.0297**	**$F_{1, 227}$ = 1.57, p = 0.013**
Hedgerow characteristics	**H**	**Height**	-0.0450	-0.120	**$F_{5, 227}$ = 1.45, p = 0.001**
		Width	-0.0131	0.0511	
		Gaps	-0.248	0.0236	
		Gaps >5 m	-0.256	-0.104	
		Height to base	-0.138	0.0446	
Hedgerow shape	HS	a (n=152)	0.00179	-0.131	$F_{4, 227}$ = 1.52, p = 0.122
		c (n=60)	0.198	0.365	
		d (n=21)	-0.474	-0.640	
		e (n=18)	-0.00136	0.438	
		h (n=6)	-0.455	-0.264	
Hedgerow type	**HT**	**a (n=148)**	0.0601	0.216	**$F_{2, 227}$ = 1.20, p = 0.002**
		b (n=24)	-0.339	-0.527	
		c (n=85)	0.00528	-0.211	
Herbaceous vegetation height	HH		-0.239	-0.0348	$F_{1, 227}$ = 0.83, p = 0.71
Indicator Species	**IS**	**Cleavers**	**-0.187**	**-0.0126**	**$F_{3, 227}$ = 2.00, p = 0.004**
		Docks	**0.155**	**0.307**	
		Nettles	**-0.195**	**0.0664**	
Margin width	**Width**	**Side a**	**0.289**	**0.229**	**$F_{2, 227}$ = 1.52, p = 0.001**
		Side b	**0.309**	**0.471**	
Quadrat position	**QP**	**Hedge (n=109)**	**-0.874**	**-0.0611**	**$F_{2, 227}$ = 2.78, p = 0.001**
		Middle (n=66)	**0.665**	**0.102**	
		Edge (n=82)	**0.586**	**-0.0157**	

Table 9.1 ANOVA-like permutation test and the CCA ordination plot coordinates of the explanatory variables included in CCA, 2015. Variables in bold are significant at p <0.05. Ten of the 12 explanatory variables significantly contributed to the CCA model. The number of plant communities surveyed associated with each categorical variable is given in table. n = 257.

Variable	Variable code	Levels	CCA axis 1	CCA axis 2	ANOVA-like permutation test
Adjacent land use	**ALU**	**Cropcrop (n=44)**	**-0.248**	**-0.289**	**$F_{3, 89}$ = 2.20, p = 0.001**
		Croproad (n=36)	**0.301**	**-0.361**	
		Grasscrop (n=22)	**-0.600**	**0.681**	
		Grassroad (n=16)	**0.890**	**0.554**	
Aspect	**Aspect**	**N (n=21)**	**-0.188**	**-0.160**	**$F_{3, 89}$ = 1.52, p = 0.001**
		S (n=15)	**0.202**	**-0.278**	
		E (n=41)	**0.0340**	**0.00487**	
		W (n=41)	**-0.00115**	**0.199**	
Bank height	BH	Side a	0.161	-0.0790	$F_{2, 89}$ = 1.19, p = 0.112
		Side b	-0.0734	-0.0602	
Ditch	**D**		**0.580**	**0.205**	**$F_{1, 89}$ = 2.26, p = 0.001**
Fence	**F**		**-0.259**	**0.181**	**$F_{1, 89}$ = 1.72, p = 0.001**
Hedgerow characteristics	**H**	**Height**	**0.0297**	**-0.0694**	**$F_{5, 89}$ = 1.60, p = 0.001**
		Width	**-0.151**	**-0.133**	
		Gaps	**-0.105**	**-0.258**	
		Gaps >5 m	**-0.00760**	**-0.0826**	
		Height to base	**0.269**	**-0.260**	
Hedgerow shape	**HS**	**a (n=61)**	**0.235**	**0.288**	**$F_{3, 89}$ = 1.79, p = 0.001**
		c (n=28)	**-0.466**	**-0.170**	
		e (n=17)	**-0.322**	**-0.408**	
		h (n=6)	**0.0744**	**-0.606**	
Hedgerow type	**HT**	**a (n=71)**	**0.0275**	**0.261**	**$F_{2, 89}$ = 1.35, p = 0.020**
		b (n=6)	**0.806**	**-0.694**	
		c (n=41)	**-0.142**	**-0.417**	
Herbaceous vegetation height	HH		0.151	-0.219	$F_{1, 89}$ = 1.07, p = 0.306
Indicator Species	**IS**	**Cleavers**	**0.0288**	**-0.0396**	**$F_{3, 89}$ = 2.01, p = 0.003**
		Docks	**0.746**	**0.412**	
		Nettles	**0.0356**	**-0.256**	
Margin width	**Width**	**Side a**	**-0.0790**	**0.190**	**$F_{2, 89}$ = 1.78, p = 0.001**
		Side b	**-0.226**	**0.281**	
Quadrat position	**QP**	**Hedge (n=45)**	**0.387**	**-0.704**	**$F_{2, 89}$ = 2.15, p = 0.001**
		Middle (n=33)	**-0.402**	**0.288**	
		Edge (n=40)	**-0.133**	**0.571**	

Table 9.2 ANOVA-like permutation tests and the CCA ordination plot coordinates of the explanatory variables included in CCA, 2016. Variables in bold are significant at p <0.05. Nine of the 12 explanatory variables significantly contributed to the CCA model. The number of plant communities surveyed associated with each categorical variable is given in table. n = 118.

Variable	Variance Inflation Factor	
	2015	2016
Quadrat position: hedge	1.54	1.36
Quadrat position: middle	1.49	1.36
Aspect: North	2.20	5.36
Aspect: South	1.91	3.55
Aspect: West	1.41	2.17
Width: side A	1.63	2.32
Width: side B	2.01	3.40
Adjacent land use: crop-road	4.09	10.20
Adjacent land use: grass-crop	3.50	5.09
Adjacent land us: grass-road	3.01	9.80
Indicator Species: nettles	1.73	5.14
Indicator Species: cleavers	1.44	1.94
Indicator Species: docks	1.50	3.21
Herbaceous vegetation height	1.91	3.78
Hedge type: B	14.97	11.05
Hedge type: C	2.31	3.11
Hedge shape: C	2.25	3.43
Hedge shape: D	12.2	-
Hedge shape: E	2.78	3.78
Hedge characteristic: height	1.92	19.12
Hedge characteristic: width	2.71	13.01
Hedge characteristic: gaps	3.15	8.42
Hedge characteristic: gaps >5 m	3.62	6.75
Hedge characteristic: height to base	2.77	5.89
Fence	3.6	7.61
Bank height: side A	1.86	4.51
Bank height: side B	3.72	3.91
Ditch	1.99	4.51

Table 9.3 Variance inflation factors associated with each variable in two CCAs (2015 and 2016).

Variable	Variance Inflation Factor
Margin width: side A	1.20
Margin width: side B	1.20
Quadrat position: hedge	1.44
Quadrat position: middle	1.44

Table 9.4 Variance inflation factors associated with each variable in the CCA from 2015, with margin width and quadrat position as explanatory variables.

Variable	Variance Inflation Factor
Adjacent land use: crop-road	1.31
Adjacent land use: grass-crop	1.22
Adjacent land us: grass-road	1.17
Quadrat position: hedge	1.47
Quadrat position: middle	1.43

Table 9.5 Variance inflation factors associated with each variable in the CCA from 2015, with adjacent land use and quadrat position as explanatory variables

Appendix 2

Supplementary information for Chapter 3.

10.1 Supplementary methods

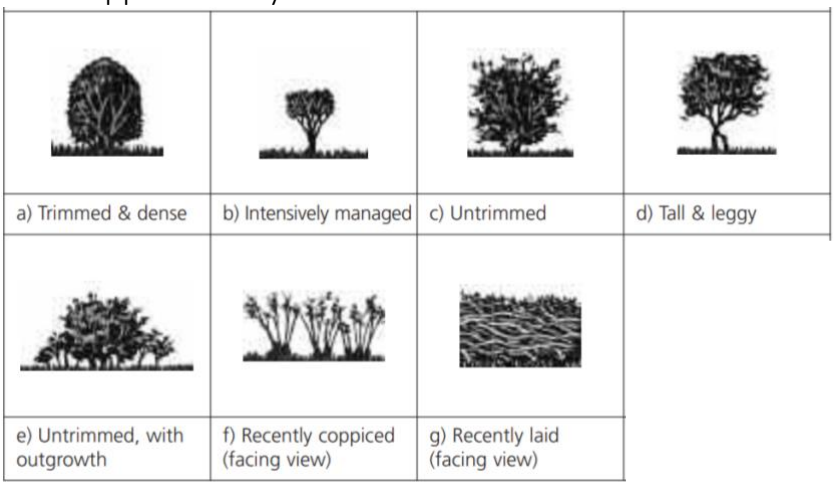


Figure 10.1 Cross-section diagrams of hedgerow shapes. Diagram from the Hedgerow Survey Handbook (p. 116, Defra, 2007).

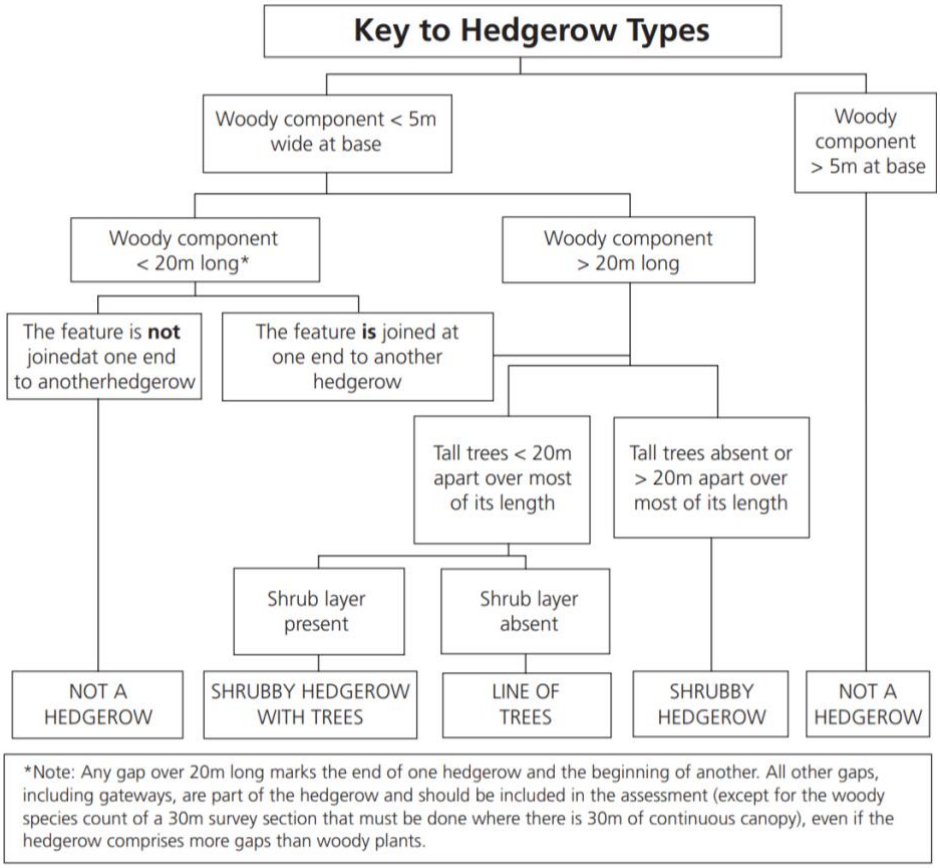


Figure 10.2 A key for determining if a feature is a hedgerow and the hedgerow type. In this work, type A = shrubby hedgerow; type B = line of trees; type C = shrubby with line of trees. Reproduced from The Hedgerow Survey Handbook (p. 49, Defra, 2007).

10.2 Supplementary results

Variable	Variable code	Levels	CCA axis 1	CCA axis 2	ANOVA-like permutation test
Adjacent land use	**ALU**	**Cropcrop**	**-0.350**	**0.806**	**$F_{3, 58}$ = 1.44, p = 0.002**
		Croproad	**-0.338**	**-0.240**	
		Grasscrop	**0.146**	**-0.354**	
		Grassroad	**0.705**	**-0.369**	
Aspect	**Aspect**	**N**	**0.0328**	**-0.156**	**$F_{3, 58}$ = 1.28, p = 0.011**
		S	**-0.404**	**-0.190**	
		E	**0.254**	**0.202**	
		W	**0.0746**	**0.165**	
Bank height	**BH**		**-0.152**	**0.168**	**$F_{1, 58}$ = 2.76, p = 0.001**
Farm	**Farm**	**A**	**0.632**	**0.176**	**$F_{3, 58}$ = 2.25, p = 0.001**
		B	**-0.572**	**0.0808**	
		C	**-0.405**	**0.0875**	
		D	**-0.088**	**-0.583**	
Fence	F		0.344	-0.0423	$F_{1, 58}$ = 0.895, p = 0.484
Hedgerow characteristics	**H**	**Height**	**-0.355**	**-0.209**	**$F_{5, 58}$ = 1.23, p = 0.039**
		Width	**-0.311**	**-0.0889**	
		Gaps	**0.0980**	**0.00192**	
		Gaps >5 m	**-0.231**	**-0.1399**	
		Height to base	**-0.371**	**0.0958**	
Hedgerow shape	**HS**	**C**	**-0.163**	**-0.464**	**$F_{3, 58}$ = 1.44, p = 0.002**
		D	**-0.467**	**-1.25**	
		E	**-0.514**	**1.27**	
Hedgerow type	**HT**	**A**	**0.276**	**0.144**	**$F_{2, 58}$ = 1.83, p = 0.001**
		B	**-0.553**	**-0.893**	
		C	**-0.404**	**-0.106**	
Herbaceous vegetation height	**HH**		**-0.377**	**-0.0693**	**$F_{1, 58}$ = 1.82, p = 0.001**
Indicator Species	**IS**	**Cleavers**	**0.263**	**-0.170**	**$F_{3, 58}$ = 1.46, p = 0.034**
		Docks	**-0.0605**	**-0.00805**	
		Nettles	**-0.183**	**-0.315**	
Margin width	**Width**	**Side a**	**-0.0287**	**0.295**	**$F_{2, 58}$ = 1.72, p = 0.002**
		Side b	**-0.136**	**0.133**	
Quadrat position	**QP**	**Hedge**	**-0.188**	**-0.550**	**$F_{2, 58}$ = 1.65, p = 0.001**
		Middle	**0.222**	**0.208**	
		Edge	**0.0145**	**0.367**	

Table 10.1 ANOVA-like permutation tests and the CCA ordination plot coordinates of the explanatory variables included in full CCA, 2017. Variables in bold are significant at p <0.05. 11 of the 12 explanatory variables significantly contributed to the CCA model. n = 120.

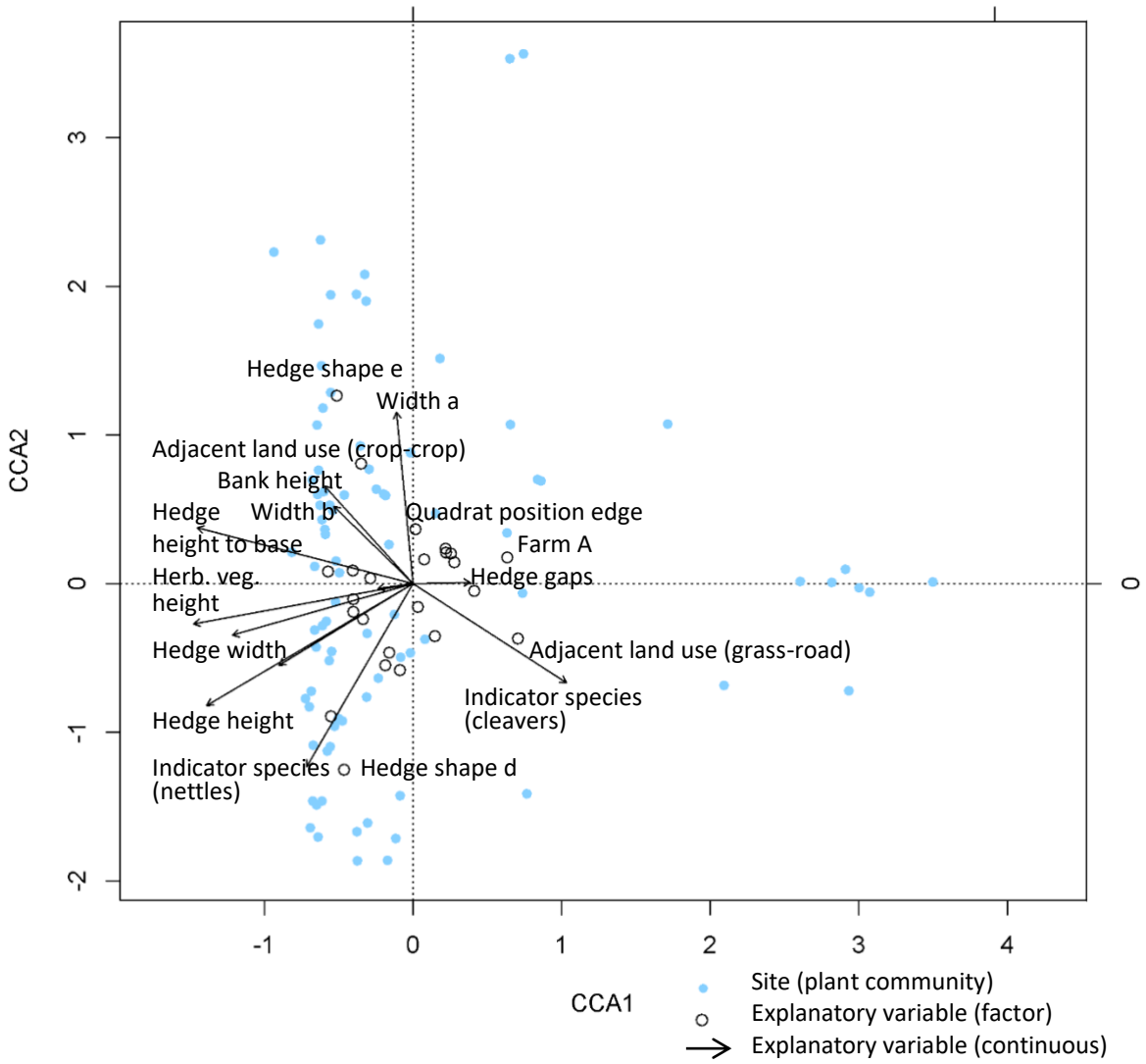


Figure 10.3 CCA ordination diagram (axis 1 and 2) from the full CCA, containing 12 margin characteristics. Variable code names are given in Table 3.2. 44% of the variation in plant community composition is explained for by the explanatory variables in this CCA. n = 120.

Variable	Full model: Variance Inflation Factor	Simplified model: Variance Inflation Factor
Quadrat position: hedge	1.4	1.4
Quadrat position: middle	1.4	1.4
Farm B	**54.7**	Excluded from model
Farm C	**47.0**	Excluded from model
Farm D	10.0	Excluded from model
Aspect: North	17.7	9.9
Aspect: South	14.7	9.1
Aspect: West	2.0	2.0
Width: side A	**20.2**	6.0
Width: side B	16.8	6.0
Adjacent land use: crop-road	18.7	11.4
Adjacent land use: grass-crop	**31.1**	19.2
Adjacent land us: grass-road	**81.6**	11.8
Indicator Species: nettles	3.8	3.0
Indicator Species: cleavers	3.4	2.7
Indicator Species: docks	4.3	3.8
Herbaceous vegetation height	**40.7**	**26.3**
Hedge type: B	33.2	15.4
Hedge type: C	10.2	7.4
Hedge shape: C	**210.1**	**44.9**
Hedge shape: D	62.0	15.1
Hedge shape: E	14.5	6.8
Hedge characteristic: height	**120.5**	**43.0**
Hedge characteristic: width	**24.8**	10.3
Hedge characteristic: gaps	9.1	8.0
Hedge characteristic: gaps >5 m	**89.5**	**27.9**
Hedge characteristic: height to base	**24.4**	19.3
Fence	13.7	5.1
Bank height	8.4	7.5

Table 10.2 Variance inflation factors associated with each variable in two CCAs (the full model and simplified model). Variance inflation factors of >20 are in bold, indicating high levels of collinearity between the variable and other variables in the model.

Variable	Variable code	Levels	CCA axis 1	CCA axis 2	ANOVA-like permutation test
Adjacent land use	**ALU**	**Cropcrop**	**-0.445**	**0.769**	**$F_{3, 61}$ = 1.56, p = 0.001**
		Croproad	**-0.329**	**-0.255**	
		Grasscrop	**0.200**	**-0.334**	
		Grassroad	**0.761**	**-0.324**	
Aspect	**Aspect**	**N**	**-0.0442**	**-0.216**	**$F_{3, 61}$ = 1.27, p = 0.016**
		S	**-0.413**	**-0.204**	
		E	**0.311**	**0.246**	
		W	**0.114**	**0.203**	
Bank height	**BH**		**-0.207**	**0.144**	**$F_{1, 61}$ = 2.75, p = 0.001**
Fence	F		0.381	-0.00884	$F_{1, 61}$ = 1.22, p = 0.157
Hedgerow characteristics	**H**	**Height**	**-0.328**	**-0.204**	**$F_{5, 61}$ = 1.21, p = 0.049**
		Width	**-0.285**	**-0.0808**	
		Gaps	**0.0643**	**0.00913**	
		Gaps >5 m	**-0.231**	**-0.131**	
		Height to base	**-0.433**	**0.0748**	
Hedgerow shape	**HS**	**a**	**0.179**	**0.220**	**$F_{3, 61}$ = 1.21, p = 0.001**
		c	**-0.128**	**-0.459**	
		d	**-0.460**	**-1.31**	
		e	**-0.410**	**1.37**	
Hedgerow type	**HT**	**a**	**0.236**	**0.137**	**$F_{2, 61}$ = 1.79, p = 0.001**
		b	**-0.597**	**-0.924**	
		c	**-0.323**	**-0.0881**	
Herbaceous vegetation height	**HH**		**-0.368**	**-0.0791**	**$F_{1, 61}$ = 1.71, p = 0.003**
Indicator Species	**IS**	**cleavers**	**0.261**	**-0.190**	**$F_{3, 61}$ = 1.88, p = 0.005**
		docks	**-0.0552**	**-0.0127**	
		nettles	**-0.158**	**-0.309**	
Margin width	**Width**	**Side a**	**-0.0933**	**0.262**	**$F_{2, 61}$ = 1.56, p = 0.002**
		Side b	**-0.193**	**0.0950**	
Quadrat position	**QP**	**Hedge**	**-0.302**	**-0.617**	**$F_{2, 61}$ = 1.62, p = 0.001**
		Middle	**0.279**	**0.256**	
		Edge	**0.0807**	**0.395**	

Table 10.3 ANOVA-like permutation tests and the CCA ordination plot coordinates of the explanatory variables included in simplified CCA, 2017. Variables in bold are significant at p <0.05. 11 of the 12 explanatory variables significantly contributed to the CCA model. n = 120.

Appendix 3

Supplementary information for Chapter 4.

11.1 Supplementary methods

Primary nectar source plant species	Butterfly species
Lotus corniculatus	Cryptic Wood White Wood White
Rubus fruticosus	Heath Fritillary Silver-washed Fritillary
Pulicaria dysenterica	Small Copper
Cirsium spp. and Carduus spp.	Brimstone Comma Dark Green Fritillary Essex Skipper Large White Marbled White Painted Lady Peacock Small White

Table 11.1 Adult butterfly primary nectar source plant species. This list is compiled from (Porter, 1992, Porter *et al.,* 1992 *and* Asher *et al.*, 2001).

Primary food plant Species	Butterfly species
Frangula alnus	Brimstone
Agrostis spp.	Gatekeeper Meadow Brown Small Heath Wall
Lotus corniculatus	Common Blue Dingy Skipper Wood White
Rhamnus cathartica	Brimstone
Sinapis arvensis	Green-veined White
Dactylis glomerata	Essex Skipper Large Skipper Meadow Brown Ringlet Speckled Wood Wall
Elytrigia repens	Ringlet Speckled Wood
Viola riviniana	Dark Green Fritillary Silver-washed Fritillary
Urtica dioica	Comma Peacock Red Admiral Small Tortoiseshell
Helianthemum nummularium	Brown Argus Green Hairstreak Northern Brown Argus Silver-studded Blue
Rumex acetosa	Small Copper
Brassicaceae (various)	Large White Small White

Continued on next page.

Primary food plant Species	Butterfly species
Cardamine pratensis	Green-veined White Orange-tip
Helictotrichon pubescens	Meadow Brown
Brachypodium sylvaticum	Meadow Brown Ringlet Speckled Wood Wall
Festuca spp.	Gatekeeper Meadow Brown Small Heath
Alliaria petiolate	Green-veined White Orange-tip
Lotus pedunculatus	Wood White
Sisymbrium officinale	Green-veined White
Ilex spp.	Holly Blue
Hedera helix	Holly Blue
Anthyllis vulneraria	Small Blue
Cardamine amara	Green-veined White
Poa spp.	Gatekeeper Meadow Brown Ringlet Small Heath
Tropaeolum majus	Small White
Festuca rubra	Marbled White
Rumex acetosella	Small Copper
Festuca ovina	Marbled White
Urtica urens	Small Tortoiseshell
Cirsium spp. and Carduus spp.	Painted Lady
Brachypodium pinnatum	Marbled White Wall
Deschampsia cespitosa	Ringlet
Rorippa nasturtium-aquaticum	Green-veined White
Deschampsia flexuosa	Wall
Brassica oleracea	Green-veined White
Raphanus raphanistrum	Green-veined White
Holcus lanatus	Marbled White Small Skipper Speckled Wood Wall

Table 11.2 Larval butterfly primary food plant species. This list is compiled from (Porter, 1992, Porter *et al.,* 1992 and Asher *et al.*, 2001)*.*

11.2 Supplementary results

Variable	Levels	CCA axis 1	CCA axis 2	ANOVA-like permutation test
Adjacent land use	Cropcrop	0.51642	0.004961	$F_{2, 51}$ = 1.408, p = 0.075
	Croproad	0.39144	0.418202	
	cropwoodland	-1.07683	-0.510085	
Aspect	North	0.06677	1.362247	$F_{3, 51}$ = 1.1755, p = 0.210
	South	-0.56420	-0.223263	
	East	0.75520	-0.775349	
	West	-0.28386	0.315372	
Margin vegetation height		0.15616	0.6267	$F_{1, 51}$ = 1.0862, p = 0.365
Margin width		-0.52515	0.1098	$F_{1, 51}$ = 1.4541, p = 0.111
Plant species richness		-0.05991	-0.2254	$F_{1, 51}$ = 1.0690, p = 0.372

Table 11.3 ANOVA-like permutation tests and the CCA ordination plot coordinates of the explanatory variables in the CCA analysis of butterfly communities in field margins. n = 60.

Variable	Variance Inflation Factor
Adjacent land: croproad	1.434926
Adjacent land: cropwoodland	2.118124
Aspect: North	1.301804
Aspect: South	1.437443
Aspect: West	1.503063
Margin vegetation height	1.354692
Margin width	1.332549
Plant species richness	1.098935

Table 11.4 Variance inflation factors associated with each variable in the CCA.

Appendix 4

Supplementary information for Chapter 5.

12.1 Supplementary methods

Below are the written instructions for plant surveys undertaken by volunteers.

Inter-observer differences in plant survey methods on agricultural land

This fieldwork contributes to work evaluating the effectiveness of plant survey work in agricultural environments. The government utilises volunteers, who undergo only a small amount of training, to surveying plants over the UK, using both transect and quadrat methods.

The aim of the study is to establish what different species are sampled using transect and quadrat methods, and the pros and cons of using each method in farmland. One possible variable is the possible inter-observer difference when using transects or quadrats: different people may be more suited to different species sampling methods.

Experimental design

Each surveyor will be required to visit three margins. A margin is a strip of vegetation, between the hedgerow and in this case crop. Please time how long it takes to survey the three quadrats, the 30m transect and the 100m transect individually.

Quadrats

At each margin, three quadrats should be surveyed, stretching the width of the margin, at the coordinates listed below. One should be as close to the hedge as possible, one in the middle, and one as close to the crop as possible.

Within each 1 m quadrat, either identify or take samples of every species you find. If you can't identify a species, label it using the tape with the hedgerow name, quadrat number and the species number e.g. if it's the 5th unidentified species in the Middle Quadrat of margin 91s, label it "91s mid species 5". If you later on find the same species in a quadrat or margin, you can then record the species as "91s mid species 5" – there is no need to take another sample.

Transects

At each margin, you are then required to do a walking transect survey, across the whole width of the margin of 2 lengths: 30m and 100m. As before, collect or identify every different species found.

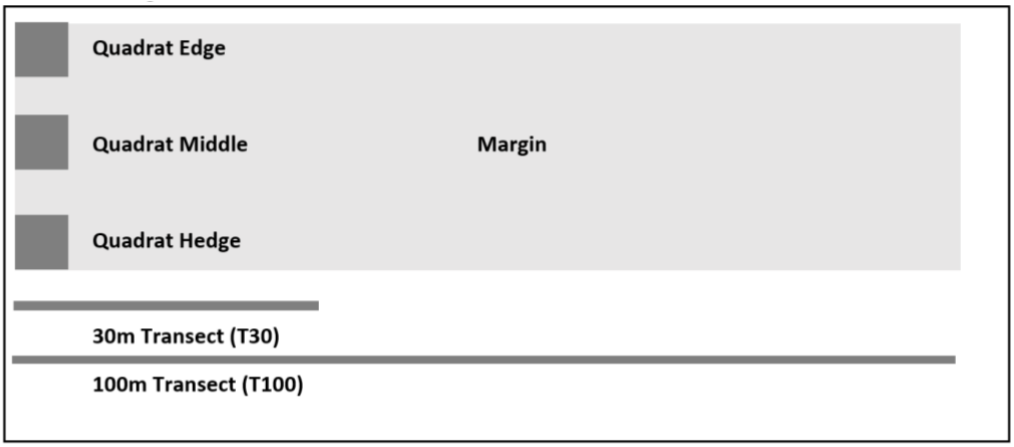


Figure 12.1 A diagram showing the three plant survey methods compared in this study.

Appendix 5

Supplementary plant species lists for surveys undertaken in Chapter 2, 3, 4 and 5.

Family	***Genus***	***Sp1***	**Author**	**2015 Farm A**	**2016 Farm A**	**2017 all farms**	**2017 Farm A**	**2017 Farm B**	**2017 Farm C**	**2017 Farm D**
Aceraceae	*Acer*	*campestre*	L.	x	x	x	x			
Aceraceae	*Acer*	*pseudoplatanus*	L.	x	x	x	x			
Apiaceae	*Aegopodium*	*podagraria*	L.		x					
Apiaceae	*Aethusa*	*cynapium*	L.	x	x					
Apiaceae	*Angelica*	*sp.*	L.	x	x					
Apiaceae	*Anthriscus*	*sylvestris*	(L.) Hoffm.		x	x	x	x	x	X
Apiaceae	*Daucus*	*carota*	L.		x	x	x			
Apiaceae	*Foeniculum*	*vulgare*	Miller	x	x					
Apiaceae	*Heracleum*	*sphondylium*	L.	x	x	x	x	x	x	X
Apiaceae	*Oenanthe*	*crocata*	L.			x		x		
Apiaceae	*Torilis*	*japonica*	(Houtt.) DC.	x	x	x	x	x	x	X
Araliaceae	*Hedera*	*helix*	L.	x	x	x	x		x	X
Asteraceae	*Achillea*	*millefolium*	L.	x	x	x	x	x		X
Asteraceae	*Arctium*	*sp.*	L.	x	x					
Asteraceae	*Artemisia*	*matricariodes*	auct.	x	x	x	x		x	
Asteraceae	*Artemisia*	*vulgaris*	L.	x	x					
Asteraceae	*Aster*	*sp.*	L.	x	x					
Asteraceae	*Bellis*	*perennis*	L.	x	x	x	x			
Asteraceae	*Carduus*	*crispus*	L.	x	x	x	x			X
Asteraceae	*Centaurea*	*nigra*	L.	x	x	x	x	x		
Asteraceae	*Centaurea*	*scabiosa*	L.	x	x					
Asteraceae	*Cirsium*	*acaule*	(L.) Scop.	x	x			x		x
Asteraceae	*Cirsium*	*arvense*	(L.) Scop.	x	x					
Asteraceae	*Cirsium*	*vulgare*	(Savi) Ten.	x		x	x	x	x	
Asteraceae	*Crepis*	*sp.*	L.	x	x					
Asteraceae	*Hieracium*	*agg.*	L.	x	x	x				x
Asteraceae	*Jacaobaea*	*vulgaris*	Gaertn.	x	x	x	x			x
Asteraceae	*Lactuca*	*serriola*	L.	x	x					
Asteraceae	*Lapsana*	*communis*	L.	x	x	x				x
Asteraceae	*Leontodon*	*hispidus*	L.	x	x					

Family	*Genus*	*Sp1*	Author	2015 Farm A	2016 Farm A	2017 all farms	2017 Farm A	2017 Farm B	2017 Farm C	2017 Farm D
Asteraceae	*Leontodon*	*saxatilis*	Lam.	x	x					
Asteraceae	*Leucanthemum*	*vulgare*	Lam.	x	x	x	x	x		
Asteraceae	*Matricaria*	*chamomilla*	L.	x	x					
Asteraceae	*Mycelis*	*muralis*	(L.) Dumort.			x				x
Asteraceae	*Picris*	*echioides*	L.	x	x					
Asteraceae	*Senecio*	*vulgaris*	L.	x	x					
Asteraceae	*Soldago*	*sp.*	L	x	x					
Asteraceae	*Sonchus*	*sp.*	L.	x	x					
Asteraceae	*Sonchus*	*arvensis*	L.	x	x					
Asteraceae	*Sonchus*	*asper*	(L.) Hill	x	x					
Asteraceae	*Sonchus*	*oleraceus*	L.			x		x		x
Asteraceae	*Taraxacum*	*agg.*	Zinn	x	x	x	x	x	x	x
Asteraceae	*Tragopogon*	*pratensis*	L.			x				x
Asteraceae	*Tripleurospermum*	*inodorum*	(L.)Sch.Bip.	x	x					
Betulaceae	*Corylus*	*avellana*	L.		x	x	x			
Boraginaceae	*Echium*	*vulgare*	L.	x	x					
Boraginaceae	*Myosotis*	*sp.*	L.	x	x					
Boraginaceae	*Myosotis*	*arvensis*	(L.)Hill	x	x	x				x
Boraginaceae	*Myosotis*	*scorpioides*	L.			x				x
Boraginaceae	*Symphytum*	*sp.*	L.	x	x					
Brassicaceae	*Alliaria*	*petiolata*	(M.Bieb.) Cavara & Grande	x	x					
Brassicaceae	*Brassica*	*sp.*	L.		x	x	x			
Brassicaceae	*Brassica*	*arvensis*	L.	x	x	x				x
Brassicaceae	*Brassica*	*napus*	L.	x	x					
Brassicaceae	*Brassica*	*nigra*	(L.) Koch	x	x					
Brassicaceae	*Brassica*	*rapa*	L.	x	x					
Brassicaceae	*Capsella*	*bursa-pastoris*	(L.)Medik.	x	x					
Brassicaceae	*Cardamine*	*hirsuta*	L.	x	x					
Brassicaceae	*Hirschfeldia*	*incana*	(L.)Lagr.-Foss.	x	x	x	x			
Brassicaceae	*Lepidium*	*sp.*	L.		x					
Brassicaceae	*Raphanus*	*raphanistrum*	L.	x	x					
Brassicaceae	*Sisymbrium*	*officinale*	(L.)Scop.	x	x					
Brassicaceae	*Thlaspi*	*arvense*	L.	x	x					

Family	*Genus*	*Sp1*	Author	2015 Farm A	2016 Farm A	2017 all farms	2017 Farm A	2017 Farm B	2017 Farm C	2017 Farm D
Caprifoliaceae	*Lonicera*	*periclymenum*	L.	x	x	x	x			
Caprifoliaceae	*Sambucus*	*nigra*	L.	x	x					
Caryophyllaceae	*Cerastium*	*fontanum*	Baumg.	x	x	x	x		x	x
Caryophyllaceae	*Silene*	*dioica*	(L.) Clairv.	x	x					
Caryophyllaceae	*Silene*	*latifolia*	Poir.	x	x	x	x			
Caryophyllaceae	*Stellaria*	*holostea*	L.	x	x					
Celastraceae	*Euonymus*	*europaeus*	L.	x	x					
Chenopodiaceae	*Atriplex*	*patula*	L.	x	x					
Chenopodiaceae	*Chenopodium*	*murale*	L.	x	x					
Clusiaceae	*Hypericum*	*hirsutum*	L.	x	x					
Clusiaceae	*Hypericum*	*perforatum*	L.	x	x	x				x
Convolvulaceae	*Calystegia*	*sepium*	(L.) R.Br.	x	x					
Convolvulaceae	*Convolvulus*	*arvensis*	L.	x	x	x	x	x	x	x
Cornaceae	*Cornus*	*sp.*	L.	x	x					
Cornaceae	*Cornus*	*sanguinea*	L.	x	x	x	x			
Cucurbitaceae	*Bryonia*	*dioica*	Jacq.	x	x					
Cyperaceae	*Carex*	*flacca*	Schreber	x	x					
Dioscoreaceae	*Tamus*	*communis*	L.			x				x
Euphorbiaceae	*Euphorbia*	*exigua*	L.	x	x					
Euphorbiaceae	*Euphorbia*	*helioscopia*	L.		x					
Euphorbiaceae	*Mercurialis*	*perennis*	L.	x	x	x	x		x	x
Fabaceae	*Lathyrus*	*pratensis*	L.	x	x	x	x	x		
Fabaceae	*Lotus*	*corniculatus*	L.	x	x	x	x		x	x
Fabaceae	*Medicago*	*lupulina*	L.	x	x	x				x
Fabaceae	*Medicago*	*sativa*	L.	x	x					
Fabaceae	*Melilotus*	*albus*	Medik.	x	x					
Fabaceae	*Onobrychis*	*viciifolia*	Scop.	x	x					
Fabaceae	*Trifolium*	*arvense*	L.		x	x	x		x	x
Fabaceae	*Trifolium*	*campestre*	Schreber		x					
Fabaceae	*Trifolium*	*dubium*	Sibth.			x				x
Fabaceae	*Trifolium*	*fragiferum*	L.	x	x					
Fabaceae	*Trifolium*	*hybridium*	L.	x	x					
Fabaceae	*Trifolium*	*medium*	L.	x	x					

Family	*Genus*	*Sp1*	Author	2015 Farm A	2016 Farm A	2017 all farms	2017 Farm A	2017 Farm B	2017 Farm C	2017 Farm D
Fabaceae	*Trifolium*	*ornithopodioides*	L.		x					
Fabaceae	*Trifolium*	*pratense*	L.	x	x					
Fabaceae	*Trifolium*	*repens*	L.	x	x	x	x	x	x	x
Fabaceae	*Vicia*	*cracca*	L.			x	x			
Fabaceae	*Vicia*	*sativa*	L.	x	x	x		x		x
Fabaceae	*Vicia*	*tetrasperma*	(L.) Schreber			x				x
Fagaceae	*Fagus*	*sylvatica*	L.	x	x					
Fagaceae	*Quercus*	*robur*	L.		x					
Fumariaceae	*Fumaria*	*sp.*	L.	x	x					
Gentianaceae	*Centaurium*	*erythraea*	Rafn	x	x					
Geraniaceae	*Geranium*	*dissectum*	L.	x	x	x	x	x	x	x
Geraniaceae	*Geranium*	*molle*	L.	x		x	x			x
Geraniaceae	*Geranium*	*pratense*	L.		x					x
Geraniaceae	*Geranium*	*pusillum*	L.	x						
Geraniaceae	*Geranium*	*pyrenaicum*	Burm. F.	x						
Geraniaceae	*Geranium*	*robertianum*	L.		x				x	
Lamiaceae	*Ajuga*	*reptans*	L.		x	x	x			
Lamiaceae	*Clinopodium*	*vulgare*	L.		x					
Lamiaceae	*Glechoma*	*hederacea*	L.	x	x	x	x			
Lamiaceae	*Lamium*	*album*	L.	x	x					
Lamiaceae	*Lamiastrum*	*galeobdolon*	(L.) Ehrend. & Polatschek			x	x			
Lamiaceae	*Prunella*	*sp.*	L.	x	x					
Lamiaceae	*Prunella*	*vulgaris*	L.	x	x					
Lamiaceae	*Stachys*	*sylvatica*	L.	x	x	x	x	x		x
Liliaceae	*Hyacinthoides*	*non-scripta*	(L.) Chouard ex Rothm.	x	x	x	x			
Linaceae	*Linum*	*catharticum*	L.	x	x					
Malvaceae	*Malva*	*sylvestris*	L.		x	x	x			
Oleaceae	*Fraxinus*	*excelsior*	L.	x	x	x	x			
Oleaceae	*Ligustrum*	*vulgare*	L.	x	x					
Onagraceae	*Circaea*	*lutetiana*	L.	x	x	x	x			x
Onagraceae	*Epilobium*	*hirsutum*	L.			x				x
Papaveraceae	*Papaver*	*rhoeas*	L.	x	x					

Family	*Genus*	*Sp1*	Author	2015 Farm A	2016 Farm A	2017 all farms	2017 Farm A	2017 Farm B	2017 Farm C	2017 Farm D
Plantaginaceae	*Kickxia*	*spuria*	(L.) Dumort	x	x					
Plantaginaceae	*Plantago*	*lanceolata*	L.	x	x	x	x	x		x
Plantaginaceae	*Plantago*	*major*	L.	x	x	x	x		x	x
Plantaginaceae	*Plantago*	*media*	L.	x	x					
Poaceae	*Agrostis*	*sp.*	L.	x	x	x	x		x	x
Poaceae	*Alopecurus*	*myosuroides*	Hudson	x	x	x	x	x	x	
Poaceae	*Alopecurus*	*pratensis*	L.		x	x				x
Poaceae	*Anisantha*	*sterilis*	(L.)Nevski			x	x	x	x	x
Poaceae	*Anthoxanthum*	*aristatum*	Boiss.	x	x					
Poaceae	*Anthoxanthum*	*sp.*	L.	x	x					
Poaceae	*Arrhenatherum*	*elatius*	(L.) P.Beauv. ex J.S.Presl & C.Presl.	x	x	x	x			x
Poaceae	*Avena*	*fatua*	L.	x	x					
Poaceae	*Brachypodium*	*sylvaticum*	(Hudson) P.Beauv.	x	x	x				x
Poaceae	*Bromus*	*commutatus*	Schrader		x	x	x			
Poaceae	*Bromus*	*diandra*	Roth	x	x					
Poaceae	*Bromus*	*erectus*	Hudson	x	x	x	x	x		
Poaceae	*Bromus*	*hordeaceus*	L.	x	x	x		x	x	
Poaceae	*Bromus*	*sterilis*	L.	x	x					
Poaceae	*Calamagrostis*	*epigejos*	(L.) Roth		x	x	x			
Poaceae	*Cynosurus*	*cristatus*	L.	x	x	x	x		x	x
Poaceae	*Dactylis*	*glomerata*	L.	x	x	x	x	x	x	x
Poaceae	*Deschampsia*	*flexuosa*	(L.) Trin.	x	x	x				x
Poaceae	*Elymus*	*caninus*	(L.) L.	x	x	x				x
Poaceae	*Elymus*	*repens*	(L.)Gould	x	x	x			x	x
Poaceae	*Festuca*	*heterophylla*	Lam.	x	x					
Poaceae	*Festuca*	*pratensis*	Hudson	x	x					
Poaceae	*Festuca*	*purpurea*	Schreb. ex Steud.	x	x					
Poaceae	*Festuca*	*rubra*	L.	x	x	x	x			x
Poaceae	*Helictotrichon*	*pratense*	(L.) Besser	x	x	x		x	x	x
Poaceae	*Holcus*	*lanatus*	L.	x	x					
Poaceae	*Holcus*	*mollis*	L.	x	x	x				x
Poaceae	*Hordeum*	*secalinum*	Schreber	x	x					
Poaceae	*Hordeum*	*vulgare*	L.	x	x	x	x	x		

Family	*Genus*	*Sp1*	Author	2015 Farm A	2016 Farm A	2017 all farms	2017 Farm A	2017 Farm B	2017 Farm C	2017 Farm D
Poaceae	*Koeleria*	*sp.*	Pers.	x	x					
Poaceae	*Lolium*	*perenne*	L.	x	x	x	x	x	x	x
Poaceae	*Milium*	*effusum*	L.	x	x					
Poaceae	*Phleum*	*pratense*	L.		x	x	x			x
Poaceae	*Poa*	*annua*	L.	x	x	x	x			
Poaceae	*Poa*	*pratensis*	L.	x	x	x	x	x	x	x
Poaceae	*Poa*	*trivialis*	L.	x	x	x			x	x
Poaceae	*Trisetum*	*sp.*	Pers.	x	x					
Poaceae	*Trisetum*	*flavescens*	(L.) P.Beauv.		x					
Poaceae	*Triticum*	*sp.*	L.	x	x					
Polygonaceae	*Persicaria*	*maculosa*	Gray	x	x					
Polygonaceae	*Polygonum*	*aviculare*	L.	x	x					
Polygonaceae	*Rumex*	*sp.*	L.	x	x	x	x	x	x	x
Polygonaceae	*Rumex*	*longifolius*	DC.			x				x
Polygonaceae	*Rumex*	*obtusifolius*	L.	x	x					
Polygonaceae	*Rumex*	*sanguineus*	L.			x				x
Primulaceae	*Anagallis*	*arvensis*	L.	x	x	x	x			
Primulaceae	*Primula*	*veris*	L.	x	x					
Ranunculaceae	*Clematis*	*vitalba*	L.	x	x					
Ranunculaceae	*Ranunculus*	*arvensis*	L.		x					
Ranunculaceae	*Ranunculus*	*bulbosus*	L.	x	x	x	x	x		x
Ranunculaceae	*Ranunculus*	*repens*	L.	x	x	x	x	x	x	x
Rosaceae	*Aphanes*	*arvensis*	L.			x				x
Rosaceae	*Crataegus*	*monogyna*	Jacq.	x	x	x	x			x
Rosaceae	*Geum*	*urbanum*	L.	x	x	x	x			x
Rosaceae	*Potentilla*	*erecta*	(L.) Räusch.	x	x	x	x			x
Rosaceae	*Prunus*	*avium*	(L.) L.	x	x					
Rosaceae	*Prunus*	*spinosa*	L.	x	x	x	x	x	x	
Rosaceae	*Rosa*	*sp.*	L.	x	x	x	x			
Rosaceae	*Rubus*	*fruticosus agg.*	L.	x	x	x	x	x	x	x
Rubiaceae	*Cruciata*	*laevipes*	Opiz		x					
Rubiaceae	*Galium*	*aparine*	L.	x	x	x	x	x	x	x
Rubiaceae	*Galium*	*mollugo*	L.	x	x	x	x			

Family	*Genus*	*Sp1*	Author	2015 Farm A	2016 Farm A	2017 all farms	2017 Farm A	2017 Farm B	2017 Farm C	2017 Farm D
Rubiaceae	*Galium*	*odoratum*	(L.) Scop.		x	x	x			
Rubiaceae	*Galium*	*sylvaticum*	L.	x	x					
Rubiaceae	*Galium*	*verum*	L.	x	x	x	x			
Rubiaceae	*Sherardia*	*arvensis*	L.	x	x					
Scrophulariaceae	*Melampyrum*	*pratense*	L.			x				x
Scrophulariaceae	*Odontites*	*vernus*	(Bellardi) Dumort.	x	x					
Scrophulariaceae	*Rhinanthus*	*minor*	L.		x	x	x			
Scrophulariaceae	*Veronica*	*sp.*	L.	x	x	x	x			
Scrophulariaceae	*Veronica*	*arvensis*	L.	x	x					
Scrophulariaceae	*Veronica*	*chamaedrys*	L.	x	x					
Scrophulariaceae	*Veronica*	*filiformis*	Sm.	x	x	x	x			
Scrophulariaceae	*Veronica*	*montana*	L.	x	x					
Scrophulariaceae	*Veronica*	*officinalis*	L.		x					
Scrophulariaceae	*Veronica*	*persica*	Poir.	x	x	x	x			x
Scrophulariaceae	*Veronica*	*polita*	Fr.	x	x					
Solanaceae	*Solanum*	*nigrum*	L.	x	x					
Ulmaceae	*Ulmus*	*sp.*	L.			x				x
Urticaceae	*Urtica*	*dioica*	L.	x	x	x	x	x	x	x
Urticaceae	*Urtica*	*urens*	L.		x					
Violaceae	*Viola*	*arvensis*	Murray	x	x					
Violaceae	*Viola*	*hirta*	L.	x	x					
Violaceae	*Viola*	*odorata*	L.	x	x					

Table 13.1 Plant species list from the field margin surveys undertaken in this thesis. Results are presented for each year surveys were undertaken (2015, 2016, 2017) and for each farm (A, B, C, D). Plant records from surveys undertaken by both quadrat and transect methods are included.