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‘Habitat and Landscape-Scale Effects on the Abundance and Diversity of Macro-Moths (Lepidoptera) in Intensive Farmland.’

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Abstract

Since 1968 UK macro-moths have declined by 28%, with the most notable trends revealed for the south of England; the dual influences of climate change and intensive land use are thought to be the main drivers for this trend. This study aimed to determine the landscape and local-scale factors influencing moth abundance and species richness in intensive Northamptonshire farmland. The research consisted of four parts: 1. the analysis of historic county moth records using landscape-analysis, 2. Moth trapping in areas of intensive lowland farmland and subsequent local and fine-scale landscape-scale analysis of trap yields, 3. Moth movement studies along farmland hedgerows and 4. Moth visitation surveys of hedgerow flora. The results of the analysis of county moth records revealed that land-use statistics had a highly significant relationship with the abundance of moths across Northamptonshire. Woodland cover was found as having a positive relationship with the abundance of moths, but that urban cover was negatively associated. The farmland moth trapping study recorded a total of 121 species, the majority of which were generalist (98%) and none of which have Biodiversity Action Plans. For this trapping, hedgerow length, width and cross-sectional area, vegetative diversity and the numbers of hedgerow gaps all had an influence on the abundance of some of the species trapped, but no hedgerow or margin variables had a significant influence on overall abundance or species richness. Moth movement surveys found that a significant proportion of moths were travelling parallel along hedgerows (69% of moths observed at 1m from the hedgerow) in farmland and that moth activity was higher close to hedgerows. Nocturnal visitation surveys of hedgerow flora found that 53% of visitors were Lepidoptera and that the most visited species was Bramble (*Rubus fruticosus* agg.). The results of the combined studies suggest that land use influences moth abundance at a range of spatial scales and that hedgerows may be providing sheltered dispersal routes and nectar resources for these species.

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Chapter One: Introduction

Agriculture is the dominant land use in the United Kingdom, with approximately 18 million hectares (around 76% of the total land area) of the British countryside being actively farmed (Department for Farming and Rural Affairs (DEFRA), 2012a). Intensification of agricultural techniques in the UK accelerated during World War Two (WW2) and was essential for economic growth and UK food production, but has been subsequently detrimental to biodiversity (Soffe, 2005). This national trend has in turn reflected global biodiversity declines of birds, insects, small mammals and numerous other taxonomic groups (Benton *et al.,* 2002; Chamberlain and Fuller, 2001; Gregory *et al.,* 2004; Clausnitzer *et al.,* 2009; Conrad *et al.,* 2006 Wickramasinghe *et al.,* 2003).

Specific taxonomic groups such as farmland birds and butterflies have been well researched in relation to farmland habitats, however relatively little research has been carried out on moth species in agricultural land, despite their significant diversity (Fox *et al.,* 2011b; Gregory *et al.,* 2004; Merckx *et al.,* 2010a; Merckx *et al.,* 2010b). Indeed, some researchers have suggested that moth species may be an ideal biodiversity indicator group due to their high species richness, taxonomic diversity and varied ecology (Conrad *et al.,* 2006; Fox *et al.,* 2011b; Ricketts *et al.,* 2002).

This chapter aims to summarise the literature surrounding farmland management for biodiversity conservation, with a specific focus on hedgerows, component hedge-bottoms and adjacent field margins. The chapter also aims to assess what recommendations have been made for the conservation of moths in farmland and evaluate the possibilities for further research.

1.1 Global Biodiversity Declines

Towards the end of the 20th century global biodiversity declines reached a critical point, with researchers labelling it a 'global biodiversity crisis' and suggesting recent diversity losses and species abundance declines are comparable to those of a mass extinction event (Butchart *et al.*, 2010; Brooks *et al.,* 2006; Clausnitzer *et al.,* 2009; Cumberlidge *et al.,* 2009; Grehan, 1993; Singh, 2002; Western, 1992). It is more important than ever to assess the status of a wide range of taxa in order to present the case for, and better aid, their conservation (IUCN, 2011; McGeoch *et al.,* 2010; Meyer, 2006; Noss, 1990).

Since 1993, the International Convention on Biological Diversity (CBD) has been in operation with the aim to protect the world's natural resources (CBD Secretariat, 2003). There are three main objectives of the Convention: conservation of biodiversity, sustainable use of biodiversity, and fair distribution of benefits from biodiversity (International Union for the Conservation of Nature (IUCN), 2010). In 2002, targets were set to halt biodiversity loss across the globe by 2010. Despite intentions, assessments using key indicators of change showed the targets for 2010 were missed and very little progress had been made in reducing biodiversity declines (Butchart *et al.,* 2010). As a result the deadline was revised to 2020 (CBD Secretariat, no date). Small-scale successes in conservation have been greatly overshadowed by such large-scale failings, and concerns have been raised about poor financing and monitoring of conservation projects (Brooks *et al.,* 2006; James *et al.,* 1999; Rands *et al.,* 2010). Monitoring systems such as a 'Global Biodiversity Monitoring Network' using indicator taxa were proposed, incorporating the idea of 'focal species groups' raised previously (Lambeck, 1997; Pereira and Cooper, 2006). A Biodiversity Change Index was developed as another assessment method to measure progress towards the new 2020 targets (Normander *et al.,* 2012). Organisations such as the International Union for the Conservation of Nature (IUCN) monitor the status of threatened species richness and abundance across the globe. The IUCN produces the ‘Red List of Threatened Species’ identifying which species require the most protection from extinction (IUCN, 2011). Analysis of this list has shown that insects are particularly overlooked, with analysis revealing large-scale declines in taxonomic groups such as dragonflies and moths, as well as serious gaps in recording of some species (Clausnitzer *et al.,* 2009; Conrad *et al.,* 2006; Groenendijk and Ellis, 2011; Schweitzer *et al.*, 2014; Wagner, 2012; Warren and Bourn, 2010). The 2010 Red List of European butterflies suggested that of the 483 species considered, one was regionally extinct, 37 threatened and 44 near threatened (van Swaay *et al.,* 2010). van Swaay *et al*. (2011) suggested that the IUCN criteria for determining red list species does not work well for invertebrates, causing underestimation of declines. The authors suggested that finer scale distribution data is needed for accurate estimation of populations (van Swaay *et al.,* 2011). There have been suggestions that species from threatened and or under-recorded groups such as moths or dragonflies could be used as ‘focal species’ or indicators of wider biodiversity (Clausnitzer *et al.,* 2009; Conrad *et al.,* 2006). Monitoring of focal groups or biodiversity indicators can highlight which taxa groups and species are at risk, but clearer goals and critical analysis of results would improve the usefulness of monitoring and its application to conservation projects (Holland *et al.*, 2012; Legg and Nagy, 2006).

Indicator species and taxa have been regularly used as a way to analyse the status of species and habitat biodiversity, farmland birds and butterflies for example are used as indicators of ecosystem health (Blair, 1999; Gregory and van Strien, 2010). Use of such indicators has been questioned, however, particularly when making assumptions about trends in other taxonomic groups (Ricketts *et al.,* 2002, van Strien *et al.,* 2009; Carignan and Villard, 2001; Prendergast and Eversham, 2006). Gerber (2011) highlighted the issues in defining and measuring biological diversity and suggested new methods for assessment based on species-level dissimilarities.

Technological advancements in recent years have opened up a wealth of options for biodiversity monitoring and analysis. Geographical Information Systems (GIS) for example are effective tools for mapping global biodiversity, allowing analysis of the relationships between diversity and landscape features. The Countryside Survey is a project aiming to map, track and analyse the land use of the UK at regular intervals, providing data and statistics, as well as UK land use maps in the form of the Land Cover Map (Centre for Ecology and Hydrology [CEH], 2007). Along with interactive and more accessible data sets from the UK Biological Records Centre (BRC) and the National Biodiversity Network (NBN), analysis of the relationships between land use and species trends have never been easier (Biological Records Centre, no date; National Biodiversity Network, 2011). The BRC and NBN encourage amateur enthusiasts to upload data on species sightings via interactive applications, increasing the possibilities for up-to-date records across the country (Biological Records Centre, no date; National Biodiversity Network, 2011). Public interactivity with biodiversity recording is undoubtedly of benefit; however such systems require continuous monitoring by experienced recorders if they are to avoid inaccurate or inconsistent data submission (Bell *et al.,* 2008; Ellis and Waterman*,* 2004; Institute for Environment, Philosophy and Public Policy [IEPPP], 2005).

1.2 UK Biodiversity Declines

Declines in the UK's species diversity have been widely recorded since WW2, with numerous taxa affected. Both farmland birds and insects are groups recorded as declining particularly heavily over the last forty years, reportedly due to the intensification of agriculture and other related influences (Benton *et al.,* 2002; Clausnitzer *et al.,* 2009; Conrad *et al.,* 2006; Goulson *et al.,* 2008; Gregory *et al.,* 2004; Smart *et al.,* 2000). Robinson and Sutherland (2002) reported that since 1945 the number of farms had reduced by 65% and the number of farm workers by 77%, statistics which clearly show how much more intensive 21st century farming has become. The authors went on to stress the importance of local and landscape-scale approaches to conservation in such intensive landscapes.

The Lawton Review (Lawton, 2010), commissioned by DEFRA, assessed the state of UK wildlife sites and stressed the importance of creating a landscape which formed a strong ecological habitat network for the protection and recovery of biodiversity in the UK. Lawton also highlighted the urgency of global action in response to the failure to meet 2010 targets for biodiversity. The review recommended three key objectives for England's ecological networks: recovering habitats and species, creating a sustainable network for the future, and improving public access to wildlife. Sutherland *et al.,* (2009) proposed 100 key questions of importance to the conservation of biodiversity and many of these related to the impact of agricultural practices and 'biodiversity friendly' schemes.

Across Europe there have been reported declines in bird populations and it appears the UK is no exception (British Trust for Ornithology, 2013; Reidsma *et al.,* 2006). The latest 'State of the UK's Birds' report showed that farmland birds were the group most noticeably in decline, with populations reaching critical lows (BTO, 2013). Many UK farmland bird species have been in decline for decades, with land-use change and agricultural policy often suggested as the cause (Fuller *et al.*, 1995; Gillings and Fuller, 1998). A 2004 review of UK farmland bird populations found that nine species had suffered declines of over 50% in the last few decades and many did not seem to be recovering even after years of conservation effort (Gregory *et al.,* 2004). Chamberlain and Fuller (2001) found that the abundance of several farmland bird species had been significantly affected by changes in agricultural land use since the late 1960s. A further study investigating the factors affecting farmland birds found that declines began around the same time as the post-war agricultural intensification and that populations have been closely linked to land-use change and increases in chemical applications (Chamberlain *et al.,* 2000). These findings are not surprising given the impact of such applications on core food chain groups such as insects and herbaceous plants (Brittain *et al.,* 2010; Sonoda *et al.,* 2011).

Until the 1990s, declines in populations of pollinating insects such as butterflies and bees had been under-detected due to minimal recording, but latest reports suggest that approximately 60% of all insect species are declining in the UK (Horsley *et al.,* 2013; State of Nature Partnership, 2013). Significant losses of insects have been reported particularly for butterflies (Lepidoptera), dragonflies (Odonata) and bees (Hemiptera) (Conrad *et al.,* 2006; Smart *et al.,* 2000; Clausnitzer *et al.,* 2009; Goulson *et al.,* 2008). As with other taxonomic groups, insects are thought to be in decline due to changes in land use and such losses appear to have had a knock-on effect on other groups which rely on them as a food source (Benton *et al.,* 2002). In addition to their importance as a food source, many insects provide important ecosystem services, particularly when pollinating crops and other plants (Kremen *et al.,* 2007; Losey and Vaughan, 2006). The Natural Environment Research Council (NERC, 2009) announced an ‘Insect Pollinators Initiative’ to fund research into the declines in pollinating insect groups such as bees, butterflies and moths. Research from the IPI has provided extensive evidence of the detrimental effect of anthropogenic pressures, particularly of chemical applications, on pollinating insect populations (Brydon *et al.,* 2013; Drier *et al.,* 2014; IPI no date; Godfray *et al.,* 2014; Vanbergen and the IPI, 2013).

1.3 UK Agricultural Land-Use Change and Farmland Biodiversity

Changing and expanding human activities have had an increasing influence on the British landscape (Soffe, 2005). Indeed, biodiversity declines in the last 40 years can be explained in part by the major changes which arose along with the implementation of the Agricultural Act (HMSO, 1947). This Act aimed to improve British food production and subsequently the economy via more efficient, technical approaches to farming (Adams, 2003). This resulting drive to increase agricultural productivity and economic progress was later enforced by the UK joining the Common Agricultural Policy (CAP) in 1973 (Soffe, 2005). Some changes which came about as a result of the CAP were increased field sizes, increased chemical applications and a reduction in hedgerows (RSPB, 2013).

Despite changes in attitudes towards the environment, biodiversity targets, developments in policy, and more effective land management, there is still an imbalance between the positive and negative influences on UK biodiversity (Figure 1.1; Butchart *et al.,* 2010; Skinner *et al.,* 1997; Kleijn *et al.,* 2011).

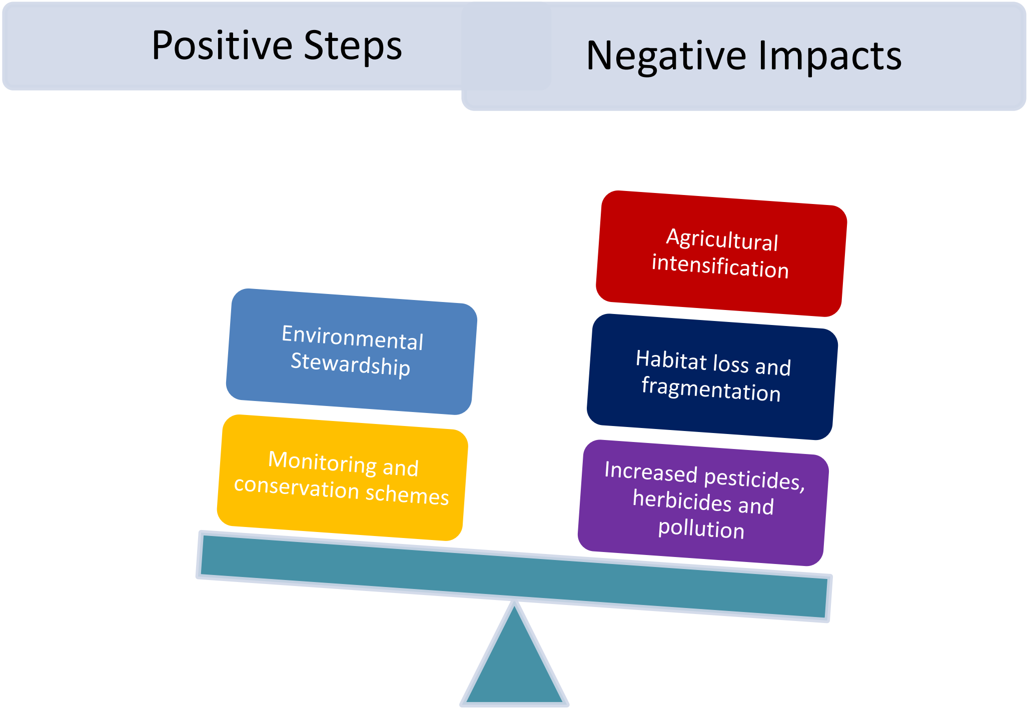

Figure 1.1: The imbalance between conservation efforts and land-use, which has resulted in biodiversity losses over the last few decades.

Over the last few years research has focused on the effects of landscape-scale impacts on biodiversity and the importance of spatial and/or temporal scale approaches to conservation (Baker *et al.,* 2012; Bates *et al.,* 2014; Fuentes-Montemayor *et al.*, 2012; Hodder *et al.,* 2014; Jones, 2011; Menz *et al.,* 2013; McKenzie *et al.*, 2013; Sayer *et al.*, 2012; Shreeve and Dennis, 2011). This wider scale approach has mainly been prompted by work on fragmentation, with conservation projects such as the Great Fen Project and the River Nene Regional Park (RNRP) attempting to link up large areas of habitat (Great Fen Partners, 2010; Field, 2009; RNRP, 2007). Linear landscape features such as hedgerows, field margins, riverbanks and road verges are some habitats which could serve to improve ecological habitat networks (Donald and Evans, 2006; Dover *et al.,* 2000; Sutcliffe and Thomas, 1996; Sutherland, 2009). The issues of landscape structure and connectivity in farmland are considered in the following section.

1.3.1 Landscape Structure: Fragmentation, Connectivity and Heterogeneity

Modern agricultural landscapes are typically made up of a fragmented mosaic of different habitats and fields ranging from arable fields and pasture to woodlands and meadows (Forman and Godron, 1986; MacArthur and Wilson, 1963; Stoate, 2001). As a result of increasing field sizes and the removal of habitat patches, many farmland habitat areas have become increasingly isolated and fragmented (Forman and Godron, 1986; Haila, 2002; MacArthur and Wilson, 1963; Simberloff and Abele, 1976; Stoate, 2001; Wilson and Willis, 1975). Fragmentation, habitat attrition, shrinkage and other such reductions in habitat quality, can lead to isolation of populations and eventually species extinctions across landscapes ([See Table 1.1] Dover and Settele, 2009; Fahrig, 1997; MacArthur and Wilson, 1963; Wilson and Willis, 1975) In a review of 104 connectivity and fragmentation papers it was found that patch size and isolation were the two main factors which influenced the ecological parameters (ecology, behaviour, and dispersal etc. of study organisms), but that the land-use surrounding the habitat patches also had a significant influence in 95% of studies (Prevedello and

Vieira, 2010). The clear effects of habitat fragmentation lend weight to the importance of landscape-scale conservation as well as just habitat-scale.

Table 1.1 Key terms and definitions relating to fragmentation and connectivity, in this case with regards hedgerows.

Term	**Definition**
Habitat	An area which provides resources for one or more life stages in an organism's life (Dennis et al., 2003).
Ecological connectivity	The functional or spatial connectivity of habitat areas and ecological systems in the landscape.
Landscape fragmentation	A landscape with isolated and reduced habitat areas (McIntyre and Hobbs, 1999).
Attrition	Loss of habitat areas in the landscape.
Isolation	Habitat areas are functionally or spatially cut off from others of the same type (not connected).
Heterogeneity	Variation in habitat or vegetative cover in the landscape.
Homogeneity	Uniformity in habitat or vegetative cover in the landscape.
Complementation	Changes in populations caused by the proximity of essential habitats and resources within the landscapes at large spatial scales.
Supplementation	Changes in populations caused by the proximity of non-essential habitats and resources within the landscapes at large spatial scales.
Node	Junction between two habitats, including intersections (Dover and Settele, 2009; Forman and Godran, 1986; Noss and Harris, 1986)

Despite the fragmented nature of UK agricultural land, there are still many valuable habitats which would not exist were it not for traditional land management practices. Coppiced woodland, hedgerows, wood pasture and meadows are some classic examples of anthropogenically derived habitats in which wildlife thrives, providing they are well managed (Bergmeier *et al.,* 2010; Baudry *et al.*, 2000; Burel, 1996; Joys *et al.,* 2004; Öckinger and Smith, 2006; Rackham, 1986). In mitigating against the effects of fragmentation on a landscape scale, linear habitats particularly are considered highly valuable due to their ability to link habitat areas (Lawton, 2010; Sawyer *et al.,* 2011; Simberloff and Cox, 1987). Linear features are found in many landscapes, but within farmland in particular, they have historically been a prominent feature (Baudry *et al.*, 2000; Burel, 1996; Hooper *et al.,* 1977).

Hedgerows and field margins are both typical linear habitats within UK farmland and are often suggested as possible dispersal corridors for wildlife (Bright, 1998; Charrier *et al.,* 1997; Entwhistle *et al.,* 2001; Moorhouse, *et al.,* 2014; Sitzia, 2007). Although it is often suggested that connective linear habitats may help sustain populations in fragmented landscapes a review of connectivity studies suggested that the majority of research focuses on structural connectivity (the linkage between habitat patches) rather than functional (the dispersal of species between patches) (Kindlmann and Burel, 2008). This lack of clarity is reflected elsewhere in the literature, where papers both support and disprove the idea of wildlife corridors for dispersal. For example one Mark-Release-Recapture study (MRR) on butterflies showed no significant relationship between the presence of hedgerows and butterfly dispersal behaviour (Öckinger and Smith, 2008). The study instead found that habitat quality and population densities were significant factors in habitat patches (Öckinger and Smith, 2008). Saarinen *et al.* (2005) found that the abundance of butterflies and diurnal moth species along road verges was significantly affected by the proximity to other different habitat areas, rather than any feature of the verges themselves. Dover and Sparks (2000) reviewed the literature surrounding butterflies and hedgerows and suggested that with regards this taxonomic group at least the evidence for use as corridors was unclear. A MRR study of the Ringlet butterfly (*Aphantopus hyperantus)* in woodland found that a significant number of butterflies recaptured were using woodland rides to travel between open areas, and that a relatively small number were travelling through dense woodland (Sutcliffe and Thomas, 1996). The results suggested that for this particularly species, connectivity may be essential for maintaining populations. A further MMR study of both the Ringlet and the Scare Copper (*Lycaena virgaureae)* had similar results in agricultural land (Sutcliffe *et al.,* 2003). The researchers found that open, grassy landscape features were most conducive to dispersal, whereas features such as forest, buildings and even arable crops acted as barriers to movement (Sutcliffe *et al.,* 2003). Unsurprisingly, a recent review of the literature regarding butterfly dispersal stated that generalist and specialist species have very different requirements with regards connectivity, with specialist species having more difficulty with dispersal than generalists, and requiring much more continuous habitat linkage in order to disperse (Dennis *et al.,* 2013). Dover and Settele (2009), reviewed the literature surrounding butterfly populations and landscape structure, and highlighted the detrimental effects of habitat shrinkage and isolations, suggesting that these factors are having significant effects on butterfly populations across Europe. The authors also stressed the complexity of the situation, with generalists and specialists responding differently to landscape change, and effects varying between landscapes (Dover and Settele, 2009). Such reviews stress the complications of understanding the influences of landscape structure on diverse taxa such as Lepidoptera, and indeed, addressing these issues in landscape-scale conservation.

Green lanes are linear features also shown to be beneficial for invertebrates (Croxton *et al.,* 2002; Croxton *et al.,* 2005; Dover *et al.*, 2000). Dover *et al.* (2000) surveyed green lanes across lowland, arable farmland and found that these linear features were being used for nectar sources and had a high abundance and species richness of butterflies compared with hedgerows and grass banks. The researchers also found that green lanes had higher abundance of Bramble (*Rubus fruticosus* agg.) plants compared with either hedgerows or grass banks, and suggested the importance of these nectar resources within farmland (Dover *et al.*, 2000). Similar findings were made by Croxton *et al.* (2005), who revealed a significantly higher number of butterfly species in green lanes than other linear features, and noted the relationship between butterfly abundance and floral resources. A significantly higher abundance of bumblebees has also been found in green lanes compared with field margins in farmland, with the authors suggesting that higher floral resources may be the reason for these findings (Croxton *et al.*, 2002). The work on green lanes and invertebrates suggests that sheltered linear features with high abundance of nectar resources are essential for invertebrates in farmland (Croxton *et al.,* 2002; Croxton *et al.,* 2005; Dover *et al.*, 2000).

The possibility of linear features acting as 'barriers' has been raised by many authors (Besnard and Secondi, 2014; Hess and Fischer, 2001; Krewenka *et al.,* 2011; Rantalainen *et al.,* 2004). Whatever the effects of hedgerows and associated margins as wildlife corridors, it is likely that their presence in intensive farmland is preferable as opposed to their removal, due to their benefits for shelter and food resources (Boughey *et al.,* 2011; Merckx *et al.,* 2012; Wolton *et al.,* 2013). Farmland birds for example are often known to rely on hedgerows and margins for both nesting and feeding resources (Hinsley and Bellamy, 2000; Fuller *et al.,* 2001; Vickery *et al.,* 2002). Linear boundary features are also shown to be important habitats for a range of bee, butterfly and other insect species, providing nectar resources, shelter and larval food plants, which may otherwise be sparse in intensive farmland (Cranmer *et al.,* 2011; Dover and Sparks, 2001; Krewenda *et al.,* 2011; Maudsley, 2000 Merckx *et al.,* 2009a; Merckx *et al.,* 2010; Merckx *et al.,* 2012; Ouin and Burel, 2002; Pollard and Holland, 2006). The benefits of various aspects of hedgerows and their management are discussed further under section 1.5.

Dennis *et al.* (2003; 2006) underlined some key issues with defining habitat patches and the implications of these issues for functional landscape ecology. The authors suggested that a resource-based approach to population ecology would be more effective, whereby a species' resource requirements are identified and used to inform conservation biology (Dennis *et al.,* 2003; Dennis *et al.,* 2006). It was suggested that for butterflies, due to their complex life cycle, this method would be more effective than traditional habitat focused approaches (Dennis *et al.,* 2003; Dennis *et al.,* 2006). This method would be equally effective for moth species, however this was not discussed by the authors.

1.3.2 Land Management for Biodiversity

Countryside Stewardship is a UK policy which evolved from initial legislation in the 1980s, with the purpose of encouraging management focused on the benefits for the environment (Natural England, 2012). Prior to this, the only real conservation policies in the UK were designations of Environmentally Sensitive Areas (ESAs), which were limited in number (Potter, 1988). Launched fully in 1992, Countryside Stewardship offered flat rate payments for management which promoted conservation (Pretty, 2001). CS was replaced by Environmental Stewardship, which is an Agricultural Environment Scheme set in place in 2005 which has two main tiers; Entry Level Stewardship (ELS) and Higher Level Stewardship (HLS), as well as upland and organic options (DEFRA, 2008; Natural England, 2013a). Single Farm Payments Schemes additionally reward environmentally friendly farming practices under the Common Agricultural Policy (DEFRA, 2012b). Over time changes have been made to prescribed eligible/compliance actions to improve measures to protect and improve biodiversity on farmland, and another more targeted scheme is due to be introduced in 2015/16 with the latest EU CAP reforms (Natural England, 2013a).

Initial studies into the latest AES revealed mixed results for the impact on the diversity and abundance of species within intensive farmland areas (Aviron *et al.,* 2007; Donald and Evans, 2006; Feehan *et al.,* 2005; Kleijn *et al.,* 2006; Taylor and Morecroft, 2009; Wickramasinghe *et al.,* 2003). Later studies however have found generally positive associations between abundance and species richness and the AES prescriptions studied (See Table 1.2).

Table 1.2: Summary of key publications relating to the effects of AES on species richness and abundance of selected taxa.

Author(s)	**Target Group/Species**	**Summary of Findings**
Perkins *et al.* (2011)	Corn bunting	Found that abundance increased by 4-5% under targeted AES, remained constant under normal AES and declined by 14-15% with no AES.
Prince *et al.* (2012)	Farmland birds	No significant response to AES from farmland birds in France. Targeted AES suggested as more effective.
Boughton *et al.* (2014)	Small mammals	Significantly higher abundance after field margin creation of all types, ELS options were more beneficial than cross-compliance.
Fuentes-Montemayor *et al.* (2011)	Moths	Rough grassland and scrub land cover was the most significant influence on moth species abundance and richness. Grassland, field margins and water margins were significantly influential on species richness and abundance.
Hirons *et al.* (2012)	Farmland birds	Species richness was significantly associated with AES pasture management. Abundance was associated with grasslands and set-aside.
Facey *et al.* (2014)	Moth larvae	Less frequent hedgerow cutting had a significant impact on the abundance of some larval guilds. Winter cut hedgerows had higher species richness and diversity.
MacDonald *et al.*(2012)	Birds, hares, beetles, vascular plants, butterflies and bumblebees	Abundance of all groups was higher in AES stone curlew plots than twinned crop areas.
Wilkinson *et al.* (2012)	Forbs, butterflies, bumblebees and Arthropods	Species richness was significantly increased for most groups on one or both of the AES corncrake applications. Significant negative relationships were found for forb species richness and springtail abundance.
Holland *et al.* (2014)	Invertebrates	Area of uncropped land was found to be significantly associated with the abundance and biomass of invertebrates. No one habitat type had the highest density, suggesting heterogeneity of habitats as preferable.
Merckx *et al.* (2010)	*Polia bombycina (*macro-moth species)	AES field margins with hedgerow trees had a significantly higher abundance of the target species.

Prescribed actions for field margins, hedgerows, targeted species and set-aside have all been shown to improve the abundance of wildlife (Table 1.2; section 1.4.1). Wide field margins particularly have been shown to have a significant positive relationship with invertebrate species richness and abundance (Asteraki *et al.,* 2004; Carvell *et al.,* 2004; Meek *et al.,* 2002; Merckx *et al.,* 2010; Sheridan *et al.,* 2008). Insect species richness in turn results in obvious benefits for foraging species such as farmland birds (Vickery *et al.,* 2002). Walker *et al.* (2007) suggested that although margins maintained under AES do provide conservation benefit, those benefits could be improved by the inclusion of more environmentally sympathetic management practices such as rotational management or selective herbicide management to control grasses and perennials.

1.3.3 Chemical Applications

Both the intensification of agriculture and the associated increase of chemical applications have been linked to the declines of a number of taxa, however determining the specific effects of the various influences has been difficult (Chamberlain *et al.,* 2000; Donald *et al.,* 2001; Krebs *et al.,* 1999; Stoate *et al.,* 2001). McCollin *et al.* (2000b) proposed that the application of fertilisers and resulting increases in soil nitrogen were leading to a landscape-scale shift in floral distributions in Northamptonshire, with species of nitrogen-rich habitats unsurprisingly increasing in abundance. A further study of hedgerow flora found that hedgerows had a higher proportion of species typical of nitrogen-rich habitats than woodlands (McCollin *et al.,* 2000a).

In the 1980s the Game and Wildlife Conservation Trust (GWCT) ran trials which initially intended to reduce the declines of game birds in agricultural land through practical management (Dover, 1991; Game and Wildlife Conservation Trust, 2014). A number of studies directly compared species abundance in sprayed and unsprayed cereal headlands (Moreby *et al.,* 1997; Rands and Sotherton, 1986; Sotherton *et al.,* 1989). Although some studies focused on game birds specifically and found a significant relationship between unsprayed cereal margins and bird brood survival rates (Moreby *et al.,* 1997; Rands and Sotherton, 1986; Sotherton *et al.,* 1989), further research concentrated on invertebrate abundance and unsprayed margins (Chiverton and Sotherton, 1991; Dover, 1989; Dover *et al.,* 1990; Hassall *et al.,* 1992; Sotherton, 1984; Sotherton, 1985). Conservation headlands in arable farmland have subsequently been shown to improve the abundance of beetles (Chiverton and Sotherton, 1991; Hassall *et al.,* 1992; Sotherton, 1984; Sotherton, 1985), butterflies (Dover, 1989; Dover *et al.,* 1990; Sotherton *et al.,* 1989), and spiders (Hassall *et al.,* 1992). Not only have cereal margins been revealed as beneficial for a number of taxa, but analysis has shown that the yield reduction for unsprayed headlands is 5-10% compared with those from sprayed areas (Boatman and Sotherton, 1988).

A large-scale study of Carabidae, floral and bird diversity across farmland in eight European countries found that increased applications of fungicides and insecticides both had significant negative effects on species richness of all three groups (Geiger *et al.,* 2010). Brittain *et al.* (2010) studied the effect of pesticide applications on the species richness of wild bees, butterflies and bumblebees. It was found that species richness of wild bees was negatively affected by second and third applications of pesticides, although no significant relationships were found with bumblebees or butterflies. Although population data on bumblebees are not readily available, Thompson and Hunt (1999) suggested that the risks to these bees were likely to be at least as significant as those to honeybees. In a recent review Potts *et al.* (2010) concluded that chemical applications such as pesticides are one of the main drivers in pollinator declines across the globe, along with habitat loss and fragmentation.

Initial research into the risk of chemical spray drift to vegetation found that for ground spraying, no significant lethal effects were shown at six metres from the sprayer (Merrs *et al.,* 1989). Conversely, during spray drift trials Davis *et al.* (1990) found that under low wind speeds chemical deposition extended to five metres, and suggested that under high wind speeds, this would be significantly increased. Further trials on high wind speed deposition showed that the sheltering effects of boundary vegetation were limited and deposition on the far side of hedgerows was still significant (Davis *et al.,* 1994). Studies on the specific mortality rates of butterfly larvae (*Pieris* *brassicae*) showed that to reduce mortality rates to under 10%, buffer zones needed to be between 12 and 24m dependant on the insecticide used (Davis *et al.,*1993). De Snoo and de Wit (1998) found that six metre unsprayed margins significantly reduced spray drift into ditches and suggested that these margins were sufficient for protecting aquatic ecosystems in farmland.

Inorganic fertilisers have been shown to reduce soil fertility, inhibit root growth and impede water uptake (Arden-Clarke *et al.,* 1988). High concentration nitrogen fertilisers particularly have been shown to impact heavily on field boundary flora, changing the species composition, reducing overall vegetative species richness and increasing weed growth (Kliejn and van der Voort, 1997). In a paired farm study of organic versus conventional non-organic systems, Aude *et al.* (2003) found significantly higher numbers of typically semi-natural species amongst hedge-bottom vegetation. Inorganic fertilisers have also been shown to increase the numbers of weedy arable species including *Bromus sterilis, Galium aparine* and *Elymis repens* (Boatman *et al.,* 1994). Field margin buffer zones of 6m have been shown to reduce spray drift into hedgerows and decrease mortality rates of Cabbage White butterflies (*Pieris brassicae*) and Mediterranean Brocade larvae(*Spodoptera littoralis*) (Longley *et al.,*1997; Longley and Sotherton, 1997).

Neonicotinoids are one class of systemically applied insecticides which are widely used in today's global agriculture (van der Sluijs *et al*., 2013). Due to their application, persistence in the local environment, and their transfer to both pollen and nectar, pollinators are exposed to these chemicals throughout the year to varying degrees (van der Sluijs *et al*., 2013). In one laboratory study, colonies of *Bombus terrestris* (Buff-tailed bumble bee) were exposed to the neonicotinoid imidacloprid. These colonies had an 85% reduction in queen bee production compared with those not exposed to the chemical (Whitehorn *et al.,* 2012). Researchers have also shown the significant impact of neonicotinoids on bee behavioural functions including learning and memory processes, suggesting an impact of such chemicals on the effectiveness of pollinator services (Decourtye *et al.,* 2004a; Decourtye *et al.,* 2004b; Guez *et al.,* 2001; Guez *et al.,* 2003). In a 2013 review of the research surrounding neonicotinoids and pollinators, the authors listed foraging success, brood development, memory and learning, susceptibility to disease, and damage to central nervous systems, as areas all affected by these chemical applications, and stressed the importance of finding pollinator-friendly alternatives (van der Sluijs *et al.,* 2013). In a positive step, the European Commission has restricted the use of three neonicotinoid insecticides (clothianidin, imidacloprid and thiametoxam), citing 'high acute risks to bees' among other reasoning (European Commission, 2014).

1.4 Hedgerow Management

Many hedgerows in the UK were originally planted as a result of the Enclosures Act in the 18th century, which created property rights on areas previously considered common land (Pollard *et al.,* 1974). As mentioned under 1.4.1, hedgerows are now key habitats within agricultural landscapes. Hedgerows and adjacent margins serve as important refuges or habitats for a wide variety of species, especially where woodland is scarce (Wehling and Diekmann, 2009). Globally, hedgerows have played an important part in many landscapes, both ecologically and culturally (Baudry *et al.,* 2000). Used as stock-proof barriers and to mark boundaries, hedgerows have typically been important features of British landscapes since early in UK farming history (Rackham, 1986). Along with post-war changes in farming came the removal of hedgerows to increase field size, which resulted in a loss of 50% of the total length of hedgerow in the UK (Rackham, 1986; Robinson and Sutherland, 2002; Soffe, 2005). In the latest Countryside Survey Report (Countryside Survey, 2007), it was reported that 147,000km of hedgerow have been lost since 1984, with fencing up by 93,000km and that overall vegetative species richness of linear boundary features has decreased by 14.6% since 1978.

Hedgerow management is one component of Environmental Stewardship, which can result in payments for farmers (Natural England, 2013a). Currently landowners and tenants are encouraged not to cut hedges back too severely, to rotate hedgerow management on a biannual management basis, avoid flailing mature components and to avoid local application of pesticides (Natural England, 2013a). It is also encouraged that gaps be planted up, mature hedgerow trees retained, and management techniques such as coppicing and hedge-laying be used where appropriate, to maintain the thickness of the hedge-bottom (Natural England, 2013a). These hedgerow management techniques and the suggested prescriptions can have positive effects on numerous taxa (Table 1.3). Long-term experimental studies are still needed to determine the effect of these management regimes on species richness and abundance (Hole *et al.,* 2005; Sitzia *et al.,* 2012).

Table 1.3: Examples of farmland hedgerow management studies and their implications for biodiversity.

Author(s), Date	Target Group/Species	Summary of Findings
Bates and Harris (2009)	Small mammals	No link found between small mammal abundance and hedgerow size. Suggested that an increase of non-crop habitat areas could be most beneficial for small mammals.
Gelling *et al.* (2007)	Small mammals	Hedgerow quality and length were linked to numbers of Wood Mice (*Apodemus sylvaticus*) and Bank Voles (*Myodes glareolus*), and width was linked to Yellow-Necked Mouse (*Apodemus flavicollis*) numbers. Flailing and 'gappiness' were negative indicators of bank voles.
Boughey *et al.* (2011)	Bats	Some bat species were positively associated with hedgerow density. Bat abundance was also linked with proximity of hedgerows to woodland areas.
Vickery *et al.* (2004)	Farmland birds	Hedgerows are shown to be important habitats areas for many bird species. Different features of hedges are shown as important for bird species. Varied management of hedgerows is also suggested.
Hinsley and Bellamy (2000)	Farmland birds	Hedge depth and height and mature or veteran hedgerow trees were found to be the most significant factors in farmland bird abundance. Connectivity with semi-natural habitats is very important.
Maudsley (2000)	Invertebrates	The main features of a hedgerow which are positive for invertebrates are hedgerow composition, plant diversity and shelter. Different invertebrates have different requirements. Management of hedgerows for invertebrates should be varied and sympathetic, to benefit a diverse range of invertebrates. Structure, diversity and hedgerow bottom should be focused on.
Croxton *et al.* (2004)	Hedgerow plants	Coppicing to restore hedgerows is not sufficient for all species. *Fagus sylvatica* (Beech) and *Carpinus betulus* (Hornbeam) require pollarding to improve their density and growth. Planting and hedge-laying should also be carried out.
Fuller *et al.* (2001)	Farmland birds	Some bird species were specifically associated with hedgerows. Hedgerow specialists had different requirements to other farmland birds frequenting hedgerows. Hedgerow management should be on a rotational and diverse basis, to produce a range of hedgerow resources for birds.
Staley *et al.* (2012)	Hedgerow flowering shrubs	The frequency of cutting affected the yields of flowers and berries in hawthorn. Cutting timing also affected the yields. Hedgerows should be cut on a three yearly cycle and preferably in late autumn or early winter as opposed to late summer or early autumn to allow for full resource use by wildlife.

The studies summarised in Table 1.3 suggest that botanical and structural diversity as well as effective management techniques are key influences on the abundance of many species. Structured management and restoration of poor quality hedgerows can increase the biodiversity of many taxa groups, particularly invertebrates (Maudsley, 2000). It is likely that a combination of both local habitat management and landscape-scale conservation would be the most effective method for farmland habitats (Duelli, 1997).

In a study of hedgerow management techniques and vegetative diversity Staley *et al.* (2013) found that a multitude of factors had an impact on floral diversity, depending on species, including: past and present management, soil conditions and local land use influences. It was apparent that a varied management system was important to improve farm scale biodiversity. Wolton *et al.* (2013) found that there were five key components of hedgerows, but that both shrubs and trees combined were the most influential and affected 65% of species studied (158 priority and farmland indicator species from a range of taxa). Other important factors were hedgerow base, field margins and ditches.

1.5 UK Invertebrates and Hedgerows

1.5.1 Invertebrates

Invertebrates constitute around 80% of life on Earth, with around 10 million of all described species falling into the Hexapoda sub-phylum and the majority of these are species of Insecta (Barnes, 1998; Wilson, 2002). Compared with the few thousand species of class Mammalia, their comparative diversity is clear. Despite this, they are generally understudied and for the most part unknown to the general public (Cardoso *et al.,* 2011). The value of insects for humans is now well recognised, with the economic value of insect services equating to billions of pounds every year. For instance, pollination services alone are thought to value around £400 million in the UK (Losey and Vaughan, 2006; POST, 2010).

Linear features such as hedgerows and dry stone walls in agricultural landscapes provide sheltered areas for invertebrates. Research has shown that for flying insects, the shelter benefits of linear features in farmland result in a higher concentration of individuals on the lee side (Bowden and Dean, 1977; Lewis, 1969; Lewis, 1970; Lewis and Dibley, 1970; Pasek, 1988). This effect has been shown for hedgerows (Bowden and Dean, 1977; Lewis, 1969), wooded shelterbelts (Lewis, 1970) and even artificial windbreaks (Lewis and Dibley, 1970) and is discussed further in Chapter Seven which addresses the uses of hedgerows as corridors by farmland moths.

1.5.2 Order Lepidoptera

The order Lepidoptera (butterflies and moths) alone counts for over one hundred thousand species in the world, and around 2300 resident in the UK (Butterfly Conservation, 2007; Wilson, 2002). Additional to these resident breeding species of Lepidoptera, there are a further 300 or so species of migrants which can be found across the British Isles (Butterfly Conservation, 2007; Lewington *et al.,* 2003; Stirling *et al.,* 2012; Waring *et al.,* 2009). Of the resident UK Lepidoptera, only 59 species are butterflies (Butterfly Conservation, 2007; Fox *et al.,* 2011a; Lewington *et al.,* 2003). Comparatively, in the UK there are around 800 resident macro-moth species, and around 1500 micro-moths (macro-moths are generally considered to be those over 1cm in length, however the distinction is generally based on classification, with micro-moths for the most part from more primitive taxa) (Stirling *et al.,* 2012; Waring *et al.,* 2009). Despite this diversity, moths seem almost to be forgotten pollinators, with most attention focusing on more charismatic and diurnal taxa groups such as bumblebees and butterflies.

In assessing biodiversity, invertebrate indicator species such as butterflies are used to assess general biodiversity of similar taxa groups. Indeed a study comparing moth and butterfly diversity showed that the two did not correlate and suggested that moth diversity needed attention (Ricketts *et al.,* 2002). Fox *et al.* (2011a) suggested that macro-moths could serve as an ideal biodiversity indicator group as they are an ecologically diverse taxa group aside from regularly studied groups such as butterflies and dragonflies. New *et al.* (1997) have previously made the case for Lepidoptera as a good 'umbrella group' for biodiversity, stating that their responses to environmental change, diversity and accessibility for sampling make them a suitable choice. It has been suggested more recently that moths provide a much more effective biodiversity indicator group than butterflies, because of their comparative species richness (Fox *et al.,* 2011b). Moths have also been identified as preferable indicators for the biodiversity of some habitats (Rákosy and Schmitt, 2011).

1.5.3 UK Moths

Around two-thirds of the UK's most common moth species have declined over the last 35 years, data which highlights how even once widespread and common insect species are now at risk of extinction (Fox *et al*., 2013). Current suggested threats to moth species include habitat loss, poor habitat management, global warming and environmental deterioration due to pesticides and pollution (Conrad *et al.,* 2006; Fox *et al.,* 2011b, 2014). Conversely the abundance of 53 moth species is known to be increasing significantly; however the majority are still threatened (Fox *et al*., 2013, 2014). In Britain, some moths reported to be in serious decline are the Garden Tiger (*Arctia caja*), Sussex Emerald (*Thalera fimbrialis*) and the Sandhill Rustic (*Luperina nickerlii*), with many more listed as common or widespread but nevertheless in decline (Anderson *et al*, 2008; Butterfly Conservation, 2007; Fox *et al*., 2013). A study of the records of UK moths between 1970 and 2010 showed changes in populations and distributions which were consistent with the effects of land-use and climate change; however the findings also suggested that responses were diverse and specific to families or species. Fox *et al.* (2014) found that moths which had a widespread geographical distribution were more susceptible to land-use change and that species associated with nitrogen-poor habitats were most threatened with changes in agricultural practice. Despite heavily reported declines, only eight species currently have legal protection under The Wildlife and Countryside Act and 81 have Priority Biodiversity Action Plans (BAPs) assigned to them. A further 71 have been given research priority action plans (Butterfly Conservation, 2010). A total of 21 of these research priority species are found mainly in hedgerows and farmland areas (Tables 1.3 and 1.4). Of the remaining species, the majority are also found in pasture, woodland and grass marginal habitats, which are common in most agricultural landscapes (Kimber, 2014; Waring *et al.,* 2009). Of the 81 Priority BAP moth species, eight are known to rely specifically on farmland or hedgerow habitats and are thought to be in decline due to changes in agricultural practice (Butterfly Conservation, 2010; Kimber, 2014; Table 1.4).

Table 1.4: Priority BAP moth species in the UK reliant on hedgerows and farmland (Sources: [Declines: Butterfly Conservation, 2010] [Habitat information: Waring *et al.,* 2009; Kimber, 2014]).

Common Name	**Scientific Name**	**Preferred Habitat(s)**	**Notes**
Fuscous Flat-body Moth	*Agonopterix capreolella*	Hedgerows, woodland edge and roadsides.	Possibly extinct. Unknown.
Barberry Carpet	*Pareulype berberata*	Hedgerows, farmland, woodland edge.	'Flagship barberry species'. Very limited distribution.
Barred Tooth-striped	*Trichopteryx polycommata*	Hedgerows, open woodland and scrub.	Distribution has grown increasingly limited.
Brighton Wainscot	*Oria musculosa*	Arable farmland.	90% decline over 24 years.
The Four-spotted Moth	*Tyta luctuosa*	Arable field margins.	Declines continuing due to changes in agriculture.
Liquorice Piercer	*Grapholita pallifrontana*	Hedgerows.	60% decline in 15 years.
Grey Carpet	*Lithostege griseata*	Arable field margins.	37% decline in 15 years.
Heart Moth	*Dicycla oo*	Open woodland, hedgerows and wood pasture.	74% decline over 24 years.

Table 1.5: Research priority (widespread but in decline) moth species in the UK reliant on hedgerows and farmland (Sources: [Declines: Butterfly Conservation, 2010]; [Habitat information: Kimber, 2014; Waring *et al.,* 2009]).

Common Name	Scientific Name	Preferred Habitat(s)	Notes (Declines since 1968)
Beaded Chestnut	*Agrochola lychnidis*	Hedgerow, grassland and woodland	93% declines.
Blood-Vein	*Timandra comae*	Grassland, woodland, hedgerow and farmland.	Declines slowing.
Brown-spot Pinion	*Agrochola litura*	Woodland, heathland and hedgerow.	83% declines.
Buff Ermine	*Spilosoma luteum*	Woodland, parkland, urban and hedgerow.	68% declines.
Centre-barred Sallow	*Atethmia centrago*	Woodland and hedgerow.	70% declines.
Dusky Thorn	*Ennomos fuscantaria*	Woodland and hedgerow.	98% declines.
Dusky-lemon Sallow	*Xanthia gilvago*	Woodland and hedgerow.	94% declines.
Figure of Eight	*Diloba caeruleocephala*	Woodland and hedgerow.	96% declines.
Green-brindled Crescent	*Allophyes oxyacanthae*	Woodland, hedgerow and urban.	81% declines.
Grey Dagger	*Acronicta psi*	Woodland, hedgerow and urban.	Declines slowing.
Knot Grass	*Acronicta rumicis*	Woodland, hedgerow and urban.	75% declines.
Mottled Rustic	*Caradrina morpheus*	Urban, woodland, wasteland, grassland and hedgerow.	84% declines.
Pale Eggar	*Trichiura crataegi*	Heathland, woodland and hedgerow.	90% declines.
Pretty Chalk Carpet	*Melanthia procellata*	Hedgerow and scrub.	88% declines.
Rosy Rustic	*Hydraecia micacea*	Wasteland, marsh and farmland.	86% declines.
Rustic	*Hoplodrina blanda*	Grassland and farmland.	78% declines.
September Thorn	*Ennomos erosaria*	Woodland, parkland, urban and hedgerow.	87% declines.
Small Emerald	*Hemistola chrysoprasaria*	Woodland, hedgerow and chalk downland.	Declines slowing.
Small Phoenix	*Ecliptopera silaceata*	Woodland, scrub and farmland.	Declines slowing.
Spinach	*Eulithis mellinata*	Urban, woodland, wasteland and hedgerow.	96% declines.

Priority BAP moth species are mostly found only in a small number of specific UK habitats, with the majority relying on coastal, grassland or woodland habitats (See Figure 1.2).

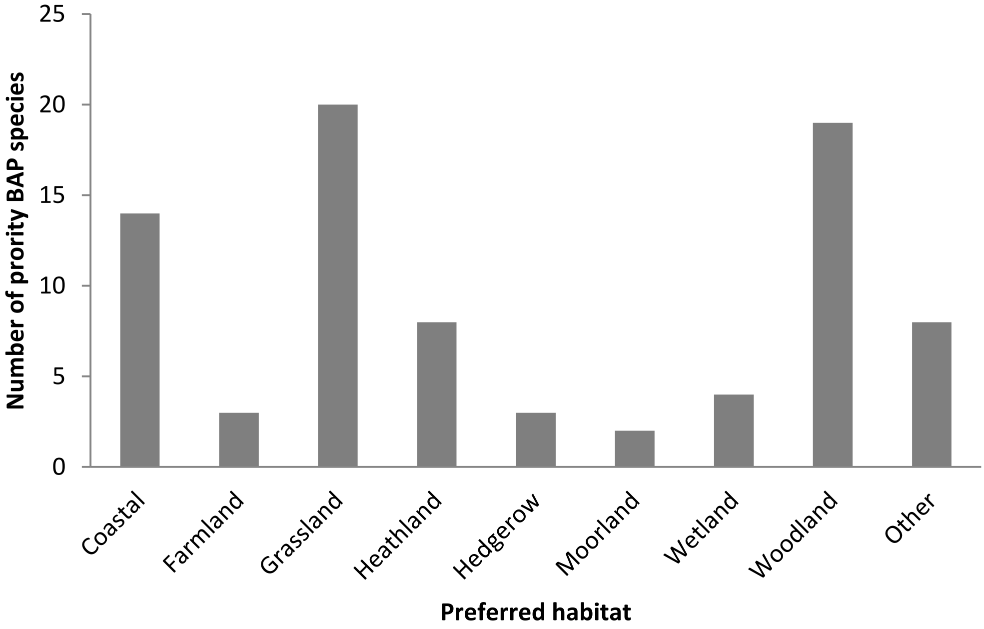

Figure 1.2: Priority and research only BAP moth species and their preferred habitat (data derived and collated from Butterfly Conservation, 2010; Fox *et al*., 2013; Kimber, 2014; Waring *et al.,* 2009).

An intensive study of farm woodlands by Usher and Keiller (1998) across the Vale of York suggested that woodlands over five hectares would be the most valuable for sustaining populations, but that herbaceous plant species richness had the strongest positive relationship with moth species richness. The study also showed that for the ecologically vulnerable (poor dispersal abilities) family Geometridae, both woodland area and shape were positively associated with species richness (Fox *et al*., 2013; Ricketts *et al.,* 2002; Usher and Keiller, 1998). Fuentes-Montemayor *et al.* (2012) also found that both vegetative species richness and woodland area had positive relationships with moth species richness in intensive farmland landscapes. The management of farm woodlands will also have an impact on moth abundance; for example, coppiced woodlands have a high diversity of moths, due to changes in structural diversity and herbaceous species (Fuller and Warren, 1993; Merckx *et al.,* 2012). A change in management from traditional coppice to commercial plantation can result in declines of rare moth species due to the loss of veteran trees and wet areas (Waring, unpublished). Mature and darker areas of woodland patches are found to result in increased numbers of specialist woodland moth species and woodland edges are thought to be beneficial to a wide range of more generalist moths (Merckx *et al.*, 2012). Merckx *et al.* (2012) found a significant relationship between woodland area and both species richness and abundance of moths in farmland landscapes. Natural England (2010) suggest that around one hundred of the UK's rarest moth species reside in SSSI woodlands across the country, something which highlights the importance of established and traditionally managed, protected woodland areas. UK conservation projects carried out by Butterfly Conservation have focused in part on woodlands as areas for threatened butterflies and moths, with rare species such as the Argent and Sable moth (*Rheumaptera hastata*) responding well to open woodland restoration and management (Ellis *et al.,* 2012).

The presence of AES field margins have been linked to increased moth populations, with wider field margins shown to have a positive correlation with the abundance of moths recorded in an area (Merckx *et al.,* 2009a). Hedgerows are clearly an important habitat feature for moths in agricultural landscapes; it has been suggested that hedgerow trees in particular are a valuable resting shelter and feeding resource for moths in intensive farmland (Merckx *et al.*, 2009b; Merckx *et al.,* 2010). Habitats such as hedgerow, vegetated margins and woodland patches provide shelter, egg laying sites and nectar resources (Butterfly Conservation, 2010; Kimber, 2014; Waring *et al.,* 2009). Moths and their larvae serve as important food sources for many species as well as being pollinators of many plants worldwide (Holland and Fleming, 2002; Oliveira *et al.,* 2004; Waring *et al.,* 2009). Many of the UK's protected bat species feed on moths within farmland landscapes. At least six of the

UK species eat mainly moths and beetles, providing further argument for moth conservation if bats themselves are to be conserved (Vaughan, 1997; Vaughan *et al.*, 1997).

1.6 Rationale and Summary

The role of insects within ecosystems and their importance globally for humans is well documented (Losey and Vaughan, 2006). Over recent years, declines in many insect groups have been reported, many of which are thought to be of great importance as food sources for other taxa such as birds and small mammals (Biesmeijer *et al.,* 2006). In the UK, agricultural intensification with its increased use of pesticides and herbicides has been considered as the cause for declines in biodiversity, particularly for groups of insects (Conrad *et al.,* 2006). Such insect declines have also been linked to further declines in other taxonomic groups, such as birds and bats, many of which are themselves Red List species (Benton *et al.,* 2002; Chamberlain *et al.,* 2000). Agri-environmental schemes have been implemented in an attempt to improve the biodiversity of farmland and adjacent habitats, with mixed success. It has been suggested that research is still needed to improve such schemes and help create more specific management objectives for land-owners, which will effectively increase biodiversity of certain species (Holland *et al.,* 2014; Prince et al., 2012). Moths in particular are threatened by significant declines (Conrad *et al.,* 2006; Butterfly Conservation, 2007; Fox *et al.,* 2013). The specific effects of local and landscape-scale factors on moths are still understudied (Fox *et al*., 2011b, 2013 and 2014; Merckx *et al.*, 2009b).

Hedgerow management is one area of AES which may need more focused research (Croxton *et al.,* 2004; Fuller *et al.,* 2001; Maudsley, 2000; Staley *et al.,* 2012). The value of hedgerows and field margins as flight paths or corridors for animals in farmland landscapes is arguably significant (Bright, 1998; Charrier *et al.,* 1997; Entwhistle *et al.,* 2001; Moorhouse, *et al.,* 2014; Sitzia, 2007), but without sympathetic management hedges can become derelict and may eventually require rejuvenation, which in itself could be disruptive to wildlife in the short term (Entwhistle *et al.,* 2001; Natural England, 2008). Both the composition and structure of hedgerows have been suggested as factors which might influence both moth and bat numbers (Bat Conservation Trust, no date, Oakeley and Jones, 1998, Russ and Montgomery, 2002; Verboom and Huitema, 1997). Mature trees in hedgerows are shown to serve as important sheltering areas for some moth species, due to the use of the canopy areas (Merckx *et al.,* 2010).

1.7 Study Aims and Objectives

This project aims to determine 1) the ecological importance of hedgerows and farmland landscapes for macro-moth species, to 2) pinpoint the management aspects most important for such species and 3) to investigate the possible benefits of hedgerows as nocturnal nectar resources and flight paths for moths.

This will be investigated through a variety of both standardised and novel survey methods outlined in Chapter Two. The movement of macro-moth species along hedgerows will be observed along sections of selected hedgerows. The aims and objectives of this research are covered in this section.

Aim 1: To assess the possible relationships between moth abundance and species richness and local and landscape-scale variables (Chapters Four, Five and Six).

- **Objective 1:** To analyse the relationships between moth abundance and species richness, and habitat cover at a range of spatial scales (resource patches, urban and agricultural areas)).

- **Objective 2:** To analyse the relationships between moth abundance and species richness and local-scale hedgerow and margin features (hedgerow width, height and cross-sectional dimensions, vegetative diversity, margin width and type, hedgerow length, nodes, connectivity with woodland and overall connectivity scoring).

Aim 2: To assess the possible uses of hedgerows and field margins as nectar resources and wildlife corridors (Chapters Seven and Eight).

- **Objective 3:** To categorise and compare the directional movements of moths along hedgerows in intensive farmland.
- **Objective 4:** To determine which hedgerow flowering species are being visited nocturnally by moths in intensive farmland.
- **Objective 5:** To determine the numbers of moths visiting hedgerow flowers in intensive farmland and compare the proportions of insect orders visiting flowers.

Chapter Two: Methods and Study Sites

This chapter begins by outlining the historic county wide landscape analysis carried out using Northamptonshire's moth data records and goes on to describe the two study sites used throughout the applied research element of the project. The field methods used are then summarised and discussed for the local and landscape-scale analysis of this data, as well as the more specific methods, including moth movement and floral visitation studies.

2.1 Analysis of Historic County Moth Records

For the purposes of biodiversity recording, data is submitted according to Vice Counties; a system based on the ancient counties of the UK that provides consistency for records (Eeles, 2014). Unlike the current county area, the Vice County of Northamptonshire includes the city of Peterborough and is number 32 (Eeles, 2014; Figure 2.1).

Moth trapping data from the Northamptonshire records was obtained from the county recorder for the years 2004 through to 2007 (appropriate to the last Land Cover Mapping from CEH (NERC, 2007) Figure 4.1). Records were pared down to the first two weeks in July (peak of emergence; See Figure 2.7) to help reduce the possible effects of moth emergence and phenology on the data (See Chapter Three). Trapping data consisted of records from across the Vice County from nocturnal light captures (See Figure 2.1; Blincow and Ward, 2002). Records where only presence or absence was recorded were excluded, as were yearly summary records submitted to the county recorder (to allow for means and diversity indices to be calculated). The records included in the analysis came from a total of 28 locations across Northamptonshire (See Figure 2.1). The majority of data came from garden trap records obtained as part of the Garden Moth Scheme; however the remainder of the records came from county moth trapping events across a variety of habitats (Grundy, 2014). The mean number of moths and species richness per occasion was calculated for each location, as well as both Shannon's and Simpson's Diversity Indices (DeJong, 1975; Lande, 1996; Simpson, 1949). Moth habitat and feeding preferences were also used to give trap point statistics for different moth 'guilds' (Blincow and Ward, 2002; Kimber, 2014; Waring *et al.,* 2009). All summary statistics were tested for normality using SPSS and transformed where necessary using a variety of transformations, which allowed for parametric testing using correlation and regression (Field, 2013; Krebs, 2014; Zar, 1984).

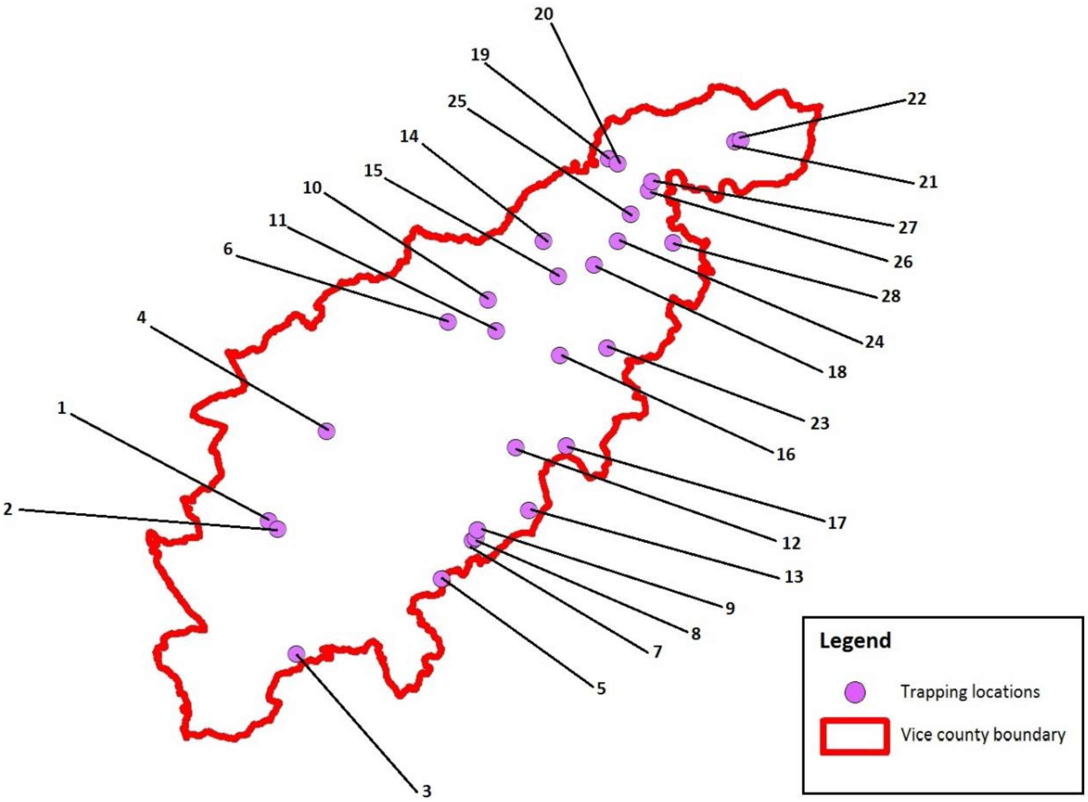

Figure 2.1: Northamptonshire Vice County map with key habitat coverage from the Land Cover Map data (NERC, 2007) and the 28 trapping locations (Created in ArcMap 10.2).

Land-cover maps produced by CEH were obtained from Edina's DigiMap to cover the entire area of the Vice County of Northamptonshire (Edina, no date; NERC, 2007; Morton *et al.,* 2011). These files were imported into ArcMap 10.2 (Esri, 2014). The radii of 250, 500, 1000, 1500, 2000 and 3000m were used to select data as per the varying dispersal capabilities of macro-moths (Fuentes-Montemayor, 2012; Merckx *et al.,* 2009a; Nieminen *et al.,* 1999). Land cover statistics (total area of each LCM habitat classification) were extracted using buffer zones of the above mentioned radii and these data exported into Excel (Microsoft, 2013). Bivariate correlations and subsequent multiple linear regression was used to assess the relationship between the moth summary statistics and land cover metrics.

2.2 Field Research Study Sites

Studies into the effects of farmland management generally fall into two categories in terms of methods: those which compare several paired sites (Feehan *et al.,* 2005; Macdonald *et al.,* 2012) and those which focus on a smaller number of localities, but have a more intensive sampling approach (Merckx *et al.,* 2009a; Taylor and Morecroft, 2008). Part of the requirements of the funding for this project was that the research should focus primarily on the Moulton College Estate, which along with the difficulties of setting up and collecting moth trap over large areas meant that there was little scope for a large-scale paired study. With this in mind, and the aim to investigate both local habitat features and landscape-scale variables, it was decided that a more intensive, smaller scale study would be the only practical option. As such, a second local site was chosen to be compared directly with the College Estate and it was decided that both sites would be studied in detail for moth usage of linear boundary features. Throughout this study these two sites will be referred to as 'Moulton' and 'Kelmarsh' for simplicity. See Figure 2.2 for geographic location of the two sites within Northamptonshire.

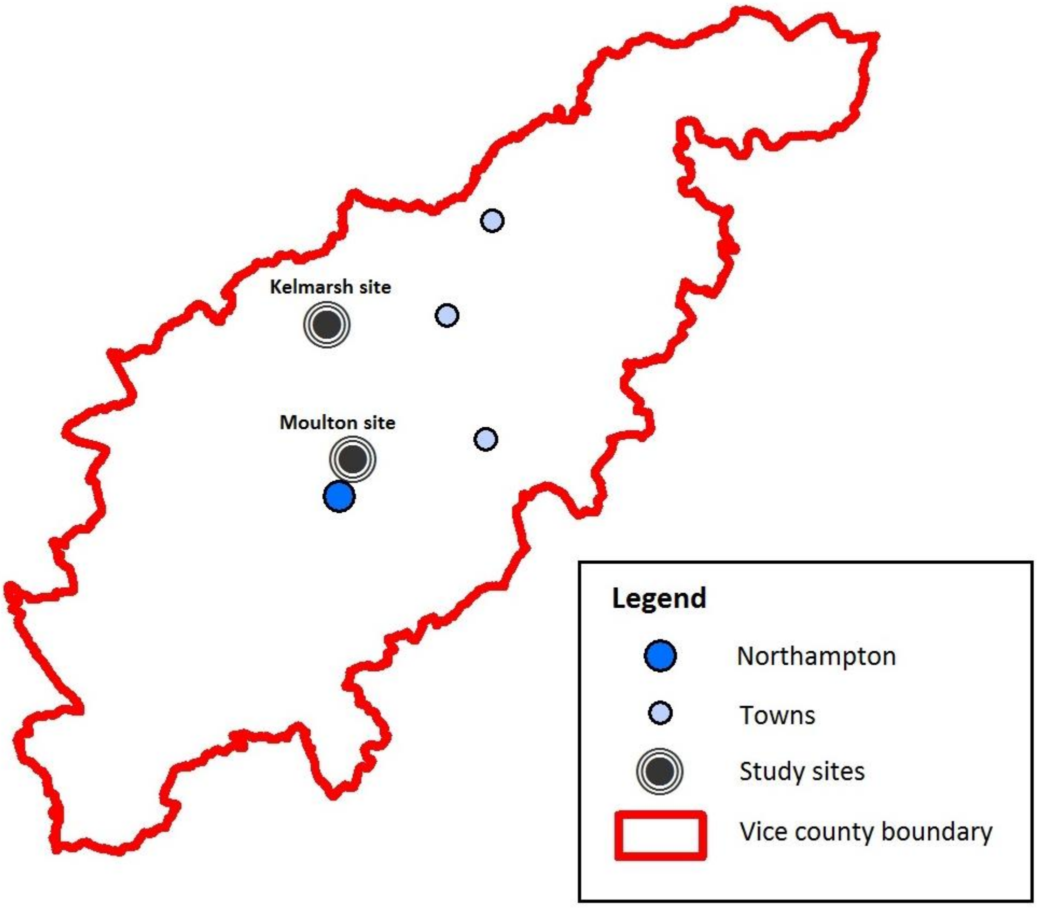

Figure 2.2: Geographical location of the two study sites within the vice county of Northamptonshire.

Criteria for selection of the second site included: geological proximity within the county, contrasting level of stewardship and subsequent hedgerow management (HLS), land-use (mixed lowland farming; non-organic), varied aspect (north-south, east-west etc.) and landscape scale factors (Marshall *et al.,* 2005; Hof and Bright, 2010). Kelmarsh Estate, Northamptonshire provided an ideal option for a second site, as it comprises a number of medium sized and smaller farms which were set to enter HLS in 2009, all in a local geographical area within ten miles of the Moulton Estate. One farm in particular was keen to get involved in the research and was comparable for land-use and landscape setting. Although the second chosen site was slightly smaller in total area, the trapping area used was comparable (Figures 2.3 and 2.4). The landscape make-up of the area surrounding the two sites was also comparable as it constituted mainly intensive farmland and urban areas; however the woodland and habitat coverage was varied, making landscape-scale analysis a possibility.

Of the chosen sites (Moulton and Kelmarsh), Manor Lodge Farm, Kelmarsh Estate entered into HLS in Summer 2009 and Moulton Farm into Entry Level Stewardship (ELS) in 2010 (Natural England, 2013a; Natural England, 2013b). This enabled a comparison of trap points on hedges under different management regimes, with different adjacent margins. Both sites were surveyed and GIS mapping for the two areas were entered in ArcMap, in order to display the selected trap points and analyse their proximity to other habitat areas (with measurement tools and circular buffer zones). The woodland cover of the two sites and surrounding areas was mapped into ArcMap and buffer zones were used to calculated the habitat coverage around each of the trap locations (250, 500, 1000, 1500, 2000 and 3000m [Fuentes-Montemayor *et al.,* 2012])

2.2.1 Moulton Estate

The Moulton College Estate Farm has only recently been entered into ELS (2010), and although conservation driven management is incorporated, it is a low priority when compared with sites in HLS. The 600ha site is composed of a mixed lowland farm with mainly arable areas and is run as both a commercial and teaching estate. Despite this, very little area of the farmland is used for teaching purposes, as the farm is a separate commercial unit. As such, the commercial farm area is comparable to that of any other working farm. Due to the high proportion of arable fields across the estate, many hedgerows are not laid, just flailed, resulting in dereliction. Additionally the Moulton estate is farmed intensively and most field margins are narrow and exhibit signs of chemical enrichment (high coverage of weedy nitrogen loving species; McCollin *et al.,* 2000a). Sixteen trap points (see Figure 2.3) were chosen across the estate, along hedgerows in various conditions from ‘gappy’ and derelict, to thick and regularly managed. Trap points three and ten were both along hedgerows adjacent to woodlands. Trap points were located at a centralised point along the hedgerow where possible (with relation to large gaps and logistical issues) and at a section of hedgerow typical of the majority of its length. On both sites, hedgerows needed to be at least 100m in length to be included in the study and readily accessible to researchers carrying trapping equipment.

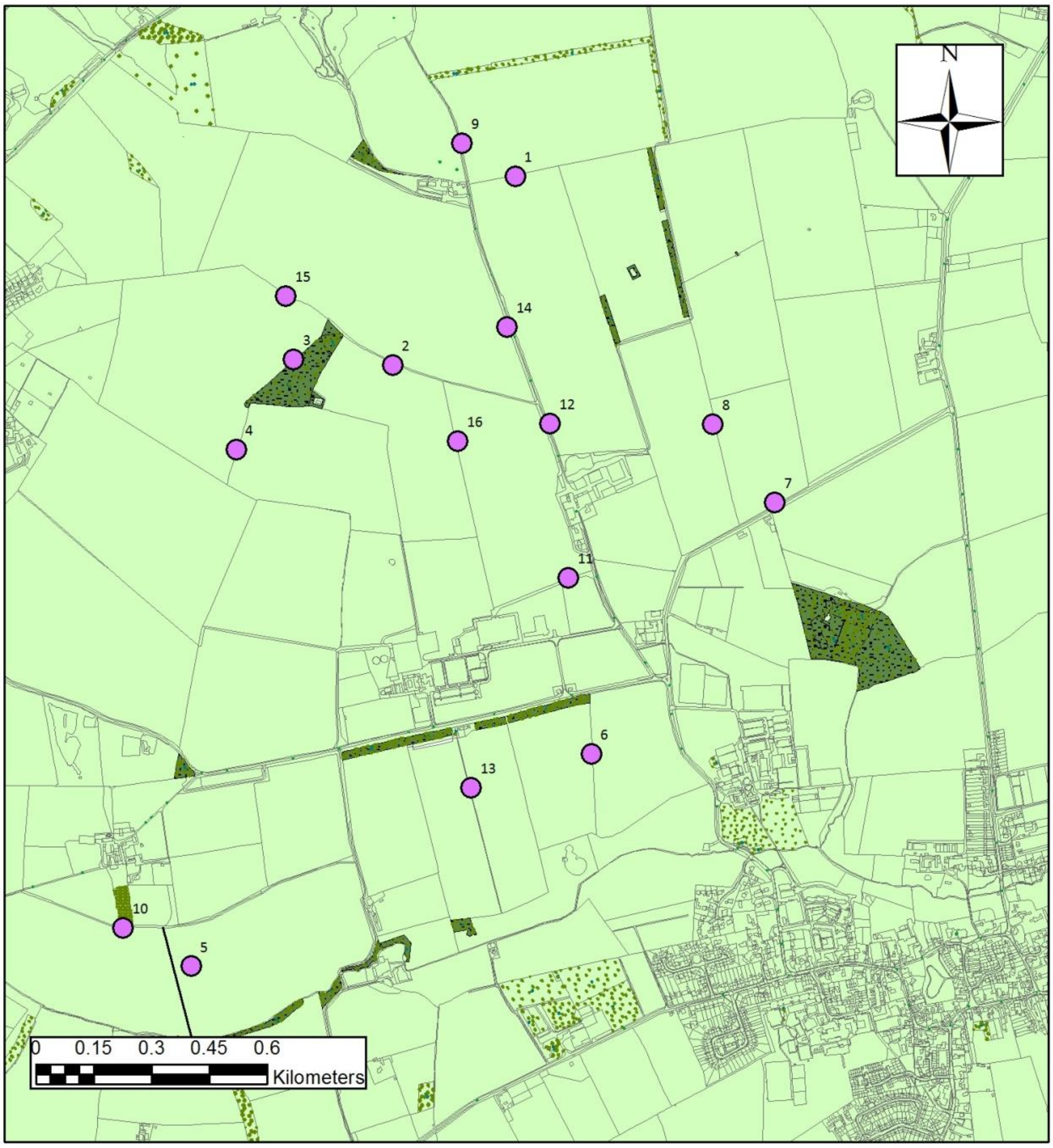

Figure 2.3: The 16 trap points used in the 2011/12 study across Moulton Estate Farm (Moulton Site). Grid Reference: SP 77199 68376. The farm covers an area of around 600ha surrounding the Agricultural College. Map layout created in Esri's ArcMap 10.2 (Purple points represent trap points).

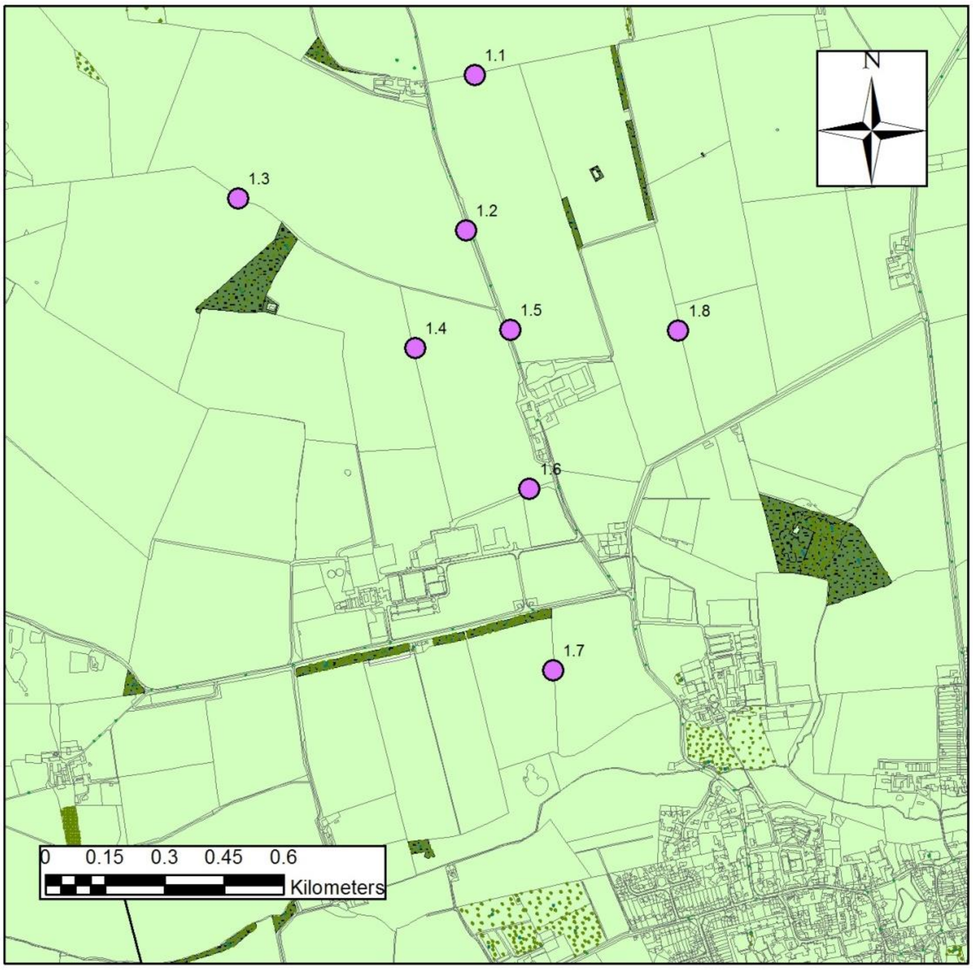

Figure 2.4: The eight trap points used in the 2013 study across the Moulton College Estate (Moulton Site). Map layout created in Esri's ArcMap 10.2 (Purple points represent trap points; both locations 3 and ten are along hedgerows adjacent to woodlands).

2.2.2 Kelmarsh Estate

The second study site, chosen from the Kelmarsh Estate, was a medium sized 400ha commercial farm, called Manor Lodge Farm, which consists of mixed lowland farmland. As a comparison for Moulton, this site was chosen as it is similar in terms of the land use, geographic location and field sizes, however the hedgerows and margins of the site were differently managed due to HLS prescriptions (See below). The site is located within the Kelmarsh Estate, near to

Arthingworth village (Figure 2.5). Unfortunately, due to the shape of the farm site at this location, many of the trapping locations were adjacent to roads, however traps were always placed on the field side of hedgerows (Figure 2.5).

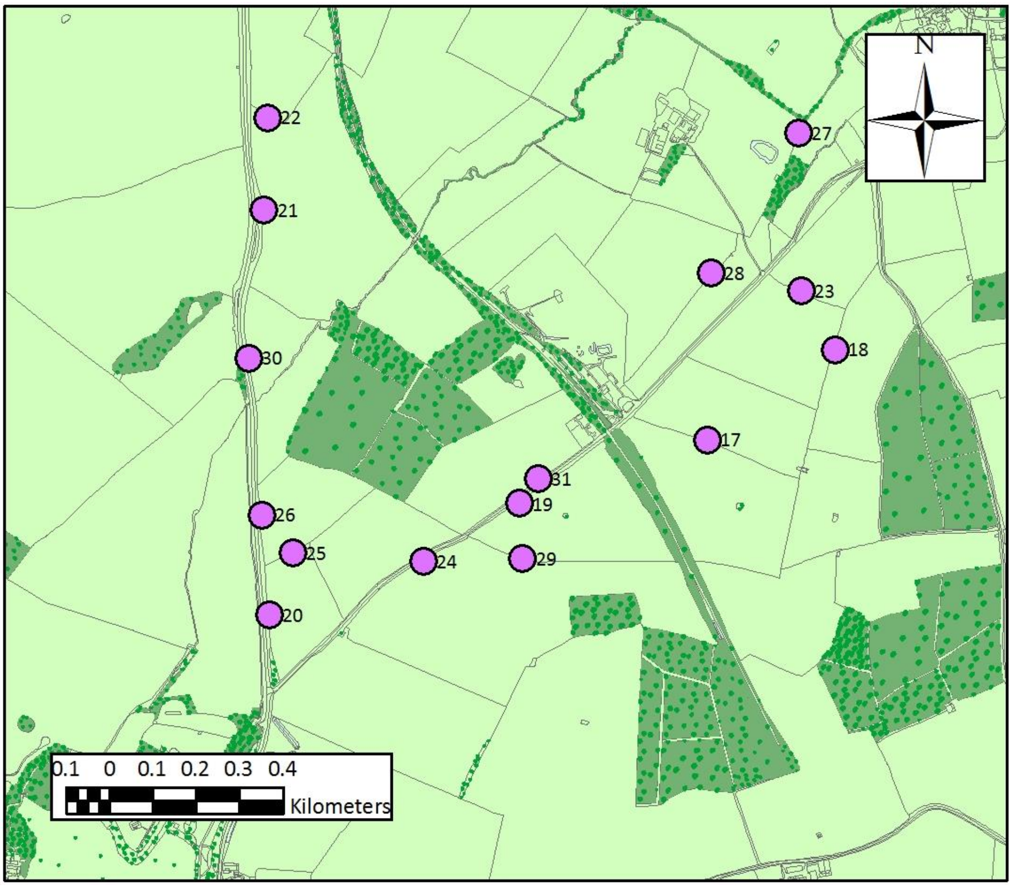

Figure 2.5: The 15 trap points used in 2011/12 study across Arthingworth Lodge Farm (Kelmarsh Site), Grid Reference: SP 73806 81004. The farm covers approximately 400ha. Map created in Esri's ArcMap 10.2 (Purple points represent trap points). All traps adjacent to road located on field side.

Manor Lodge Farm was entered into HLS the year before the study (Summer 2010). Many hedgerows on the estate had been laid in readiness for entering the agri-environmental scheme, so there was an availability of hedgerows which had been laid two or three years prior to the study and were well established. Margins across the farm were generally wider than on the Moulton site and in some cases planted with nectar-rich seed mixes. Fifteen trap points were chosen across the farm, some along recently laid hedgerows and some along more mature hedges (see Figure 2.5). It was not possible to find sixteen comparable hedgerows, however fifteen were chosen for the 2011 and 2012 trapping. Unfortunately due to the location and spread of this site, many locations at this site are adjacent to roads, however traps were always placed on the field side of hedgerow.

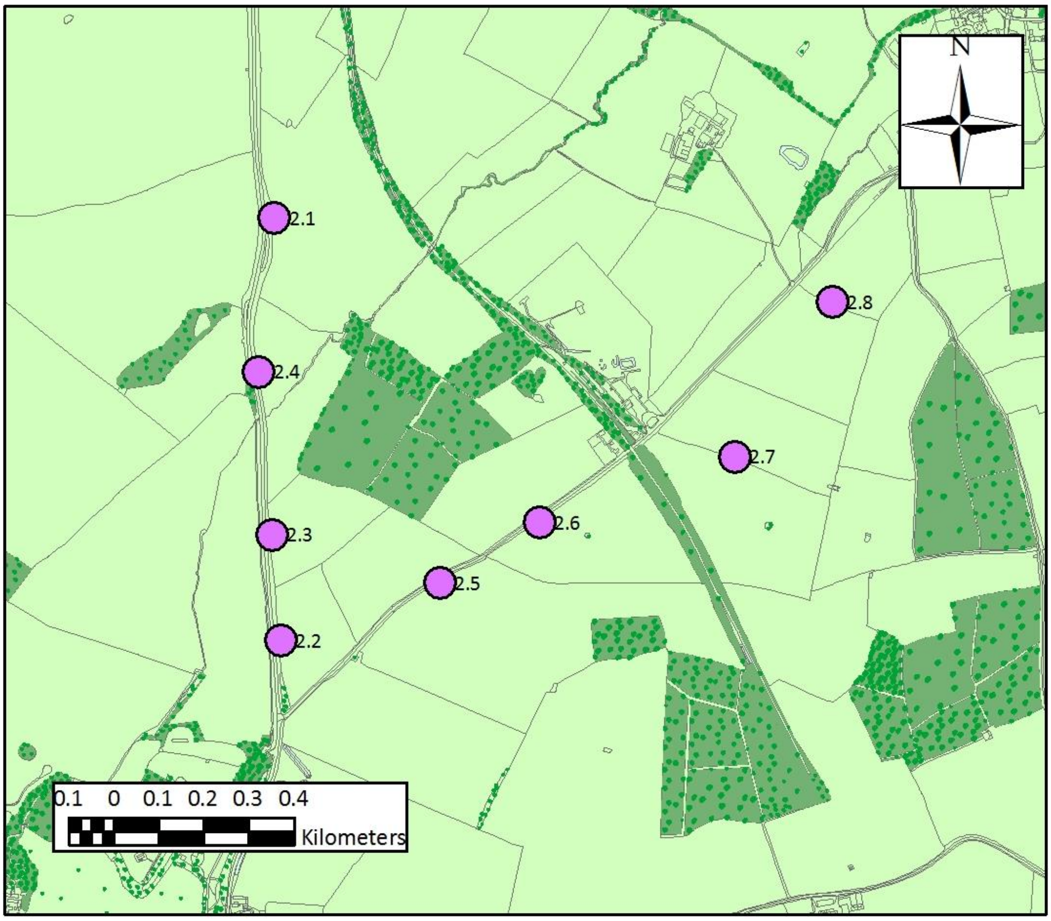

Figure 2.6 The eight trap locations used in the 2013 study across Manor Lodge Farm (Kelmarsh Site). Map layout created in Esri's ArcMap 10.2 (Purple points represent trap points).

2.3 Field Methods

2.3.1 Timing of Field Studies

Moth species fly throughout the year in the UK, however, the majority of moths generally emerge over the summer months (Waring *et al.,* 2009; Manley, 2008). Data from Pitsford Water's nightly-run moth trap, (located between the two study sites) shows the flight seasons of various locally abundant moth species (Figure 2.7). With this in mind, a field season of between May and early September was chosen for the initial trapping studies in 2011 and 2012. This also coincided with availability of field assistants and researchers.

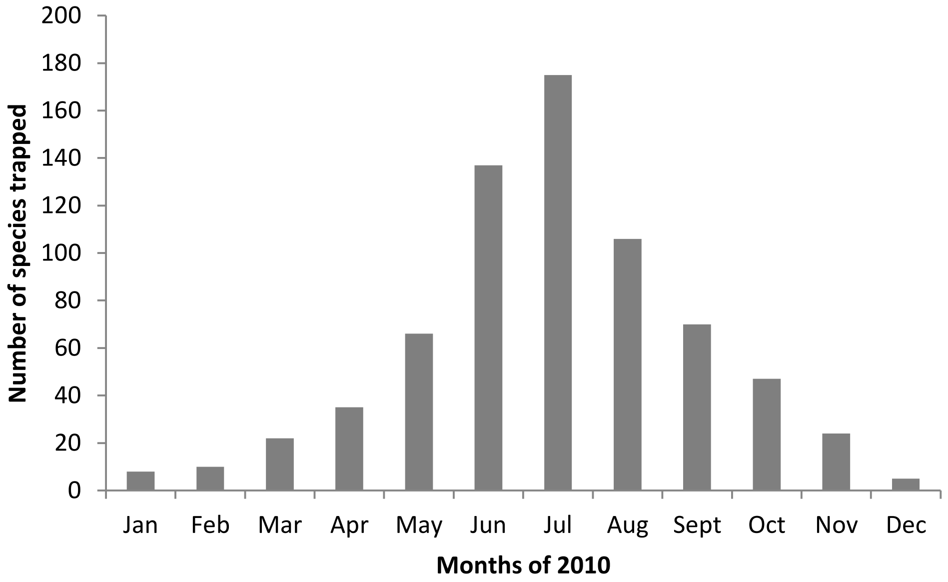

Figure 2.7: Moth species emergence from 2010. Created from regularly collected moth trap data (provided by Pitsford Water; Wildlife Trusts Northamptonshire).

After a short pilot study in the summer of 2010 to test equipment and movement survey methods, the surveys in the summers of both 2011 and 2012 provided the bulk of the data for this study which presents two consecutive years of data on both study sites. The management of the hedgerows and adjacent margins of the sites, such as hedge-laying, were monitored as a factor important in relation to the study aims. As mentioned previously, Manor Lodge Farm entered HLS in summer 2009 and Moulton entered ELS in summer 2010, so field seasons following this were ideal for comparing local-scale hedgerow and margin features.

Factors which could not be controlled, but which might have a significant effect on the studies' timing included local weather conditions and moon luminance. As discussed later under 2.3.3. Moth Trapping and in Chapter Three, weather and moon luminance greatly effect moth activity and therefore may impact on the trapping results for the proposed field seasons. These factors are investigated further in Chapter Three.

2.3.2 Hedgerow and Tree Surveys

Assessing the quality and diversity of hedgerows requires the surveying of representative stretches of hedge and recording factors such as species numbers, thickness and management quality or technique. DEFRA's Hedgerow Survey Handbook (DEFRA, 2007) suggests that height, width, gaps and species lists should be gathered along with management history to complete a comprehensive survey. The handbook also provides guidelines for quantifying the quality of hedgerow according to the above factors, particularly with relation to the number and length of gaps, as this, along with the thickness of the hedge are believed to influence invertebrate biodiversity (DEFRA, 2007; Maudsley, 2000). These factors may determine how valuable a hedgerow might be as a habitat and also a part of ecological networks within fragmented landscapes (Clements and Tofts, 1992; DEFRA, 2007; Lawton, 2010). Prior to moth studies, hedgerow surveys were carried out across both farms, to provide a baseline data set for comparison to moth abundance results.

Initial vegetation surveys were carried out in April 2011, prior to moth trapping, and repeated again in mid-summer of each year between July and August, to allow identification of the most plant species. Both herbaceous and woody species were identified, within the hedge itself and within the margin on the side adjacent to the trapping point selected. Only presence and absence of vegetative species was included in the data collection, due to the total lengths of hedgerow to be surveyed. Hedgerows were surveyed for a total of 100m, 50m either side of a trap point, and the number of mature standard trees above the hedge-line was noted, due to their suggested importance for moth species (Merckx *et al.*, 2010). Measurements of hedge height and width were made at 10m intervals along each 100m transect (allowing for mean dimensions calculation) and the total number of gaps and the total length of gaps over one metre in length were recorded. Any length of gap over 20m was counted as a break in the hedgerow according to the guidelines of the Hedgerow Survey Handbook (DEFRA, 2007).

The hedgerow data were used to create a ‘hedgerow quality’ indicator score, which allowed a score to be given to the hedgerow in relation to the hypothesized value for biodiversity. This indicator score was based on the suggestions from the Hedgerow Survey Handbook, Natural England and other sources (DEFRA, 2007). Hedgerows were given ‘species rich’ or ‘very species rich’ category according to the definitions in the handbook, which takes into account overall vegetative diversity as well as herbaceous and woody species richness (DEFRA, 2007). Other factors including the number of mature hedgerow trees, margin width and management were also used to determine a hedgerow quality score. All hedgerows were given a score of one to three (poor, fair or good [See Table 2.1]) for each of the different factors and the total was used to give an overall quality score.

Table 2.1: Example of determination of a sample of hedgerow factor scores (1= poor, 2= fair and 3= good).

Trap Point	Number of shrub species (0-5= poor, 5-10=fair, 10+= good)	Shrub score	Mean Height	Mean Width	Cross-section (Height X Width [0-3m^2= poor, 3-5m^2= fair, 5m^2+= good)	Hedgerow Dimensions score
1	8	2	4.6	3.78	17.39	3
2	10	2	4	4.2	16.80	3
3	8	2	4.34	2.46	10.68	3
4	6	2	2.96	2.02	5.98	3
5	6	2	4.94	3.76	18.57	3
6	4	1	2.28	1.88	4.29	2
7	4	1	2.62	1.8	4.72	2

2.3.3 Moth Trapping

Moth trapping methods vary depending on the target species or taxa (Fry and Waring, 2001; Somers-Yeates *et al.*, 2013; Waring *et al.,* 2009). Most moth species will come to light, with some requiring pheromone lures or bait trapping (Meagher, 2002; Waring *et al.,* 2009). Light trapping has been used for around a century to capture moth species and some studies have investigated the effectiveness of this method for capturing moths (Baker and Sadovy, 1978; Fry and Waring, 2001; Merckx and Slade, 2014; Usher and Keiller, 1998). Weather conditions can impact heavily on moth trapping and this is considered further in the next chapter (Chapter Three, Dent and Pawar, 1988; McGeachie, 1989; Yela and Holyoak, 1997). A positive correlation has also been found with moonlight intensity and moth abundance in traps (Yela and Holyoak, 1997). One study also found a difference in the ratio of male to female moths caught with light-traps, revealing a bias towards males of some species (Altermatt *et al.,* 2009). Smaller, low wattage traps are known to have a particularly localised trapping effect for moths of the macro-moth families, with catches usually coming from within 30m of the light sources (Merckx and Slade, 2014; Somers-Yeates *et al.*, 2013). This effect is useful if local landscape or habitat features are to be surveyed specifically and wide-scale catches avoided.

2.3.3.1 2011 and 2012 Trapping

Four lightweight actinic heath moth traps were used for the trapping, each with a 9 inch 6W bulb and a lightweight 12V battery (Fuentes-Montemayor *et al.,* 2012; Heath, 1965; Merckx and Slade, 2014; Merckx *et al.,* 2009a; Merckx et al., 2010). These traps operate by producing bright unnatural light, thereby confusing nocturnal moths' navigation and drawing them to their light, which then fall down a funnel and into the body of the trap (Fry and Waring, 2001; Heath, 1965). Egg-boxes provided within the body of the trap give shelter for them to rest until morning when they are collected (Fry and Waring, 2001; Heath, 1965; Waring *et al.,* 2009). Trapping started at the beginning of May and continued on all viable occasions (fair weather) through to early September, in order to cover the main emergence period of UK moths (Figure 2.7). Due to the sensitive electrical components of the traps and batteries, traps could not be placed on nights for which heavy rain was forecast, although poor weather is known to limit moth trap yields anyway (See Chapter Three).

Each night when weather permitted, traps were placed rotationally at four of the designated trap points at either of the two study sites (Figures 2.3 and 2.5 for 2011 and 2012 trapping locations), with trapping alternating between sites on each occasion. All 31 trap points were sampled equally where possible, however access and environmental conditions caused issues on some occasions. Sampling ranged from four to 8 times per location. Access to individual trap points was sometimes hindered due to localised flooding, as well as logistical issues such as livestock movements, localised crop spraying and physical barriers. In these instances traps had to be put at other points on the same site. Both the years 2011 and 2012 were particularly poor for insect surveying due to heavy rainfall and low temperatures and as a result trapping was not as consistent as would have been preferred (See Chapter Three where these issues are investigated [Butterfly Conservation, 2013; Met Office, no date a and no date b]). Traps were switched on around 7.30pm, prior to dark and left out until being collected at first light each morning (dependant on daylight hours) when macro-moths were identified (Kimber, 2014; Manley, 2008; Waring *et al.*, 2009). All macro-moths were identified and released the same day at a separate location to prevent recaptures which might skew the data (Fuentes-Montemayor *et al.,* 2012; Merckx *et al.*, 2009a). Any species which were unidentifiable were photographed and images sent for verification by the county moth recorder or not included in the data set (this number was very low and generally due to poor condition older individuals). Pug moths (Geometridae: Larentiinae) were not identified down to species level, due to the difficulty in identification and the sheer number of species and frequency of trapping. Micro-moths were not included in this study, again due to the difficulty in identification and time constraints (Merckx *et al.,* 2009a).

2.3.3.2. 2013 Trapping

A total of 16 lightweight actinic heath moth traps were used for the 2013 trapping, ([as used in the 2011/2012 study] See 2.3.3.1.). Trapping was carried out for nine consecutive days at the beginning of June, selected due to favourable weather predictions and moth phenology (Figure 2.7). All locations included were sample each night for this round of research. The shorter trapping season was used to reduce the effects of moth phenology and climate on the spread of the resulting data (See Chapter Three). Of the 31 trap points from the initial study, eight from each study site were selected for further use based on the results of a hedgerow features ordination, and logistical practicality (Figure 2.4 and 2.6; Figure 5.1). A Canonical Correspondence Analysis of the hedgerow features revealed those hedges which were most varied in terms of the features recorded (2.4.2, Figure 5.1). Based on this analysis and the logistical issues faced in the first two years, hedgerows were selected for a broad representation of the following features across the study sites: presence or absence of hedgerow trees, field use and margin width, height, width and overall mass, 'gappiness' and vegetative diversity (See Chapter Five, Figure 5.1). A selection of eight points were made for each of the study sites to give a fair representation of the variation of hedgerows on the sites and allow for further investigation into the factors influencing moth abundance.

Each night the 16 traps were placed at the chosen trap points, and these were left out overnight. As in 2011 and 2012 the contents were identified and recorded each day. All 16 traps were placed out at the two study sites each night and as with the 2011/12 study any non-identifiable moths were sent on to the county recorder for verification or not included in the study. Due to more experienced assistance in 2013 Pug moths (Geometridae: Larentiinae) were included in the 2013 data set, but micro-moths were not identified (Merckx *et al.*, 2009a). All moths were collected after identification and released at a location between the two study sites.

2.3.4 Moth Movement Surveys

Although many research projects have focused on movements of butterfly species, very few studies have looked at moth movements (Merckx *et al.,* 2009a). Mark-Release-Recapture experiments have frequently been used to analyse the dispersal of insects such as butterflies. This method has been adapted for moths, using light traps to capture and recapture moth species and study their dispersal around landscapes (Merckx *et al.,* 2009a). This method could be used to investigate moth dispersal around farm landscapes, however it requires a large amount of human resources and has a very low return rate (3.9% with regards Merckx *et al.,* 2009a) and was therefore not chosen for this study.

A recent study investigating the movements of bumblebee species in relation to hedgerows used an observational method to categorise bee movements as parallel, right angles, diagonal or irregular in relation to the hedgerow orientation. For the purposes of this study (due to the sheer volume of moths on some nights, the orientation of diagonal and right angled movements were not recorded). Such observations were taken along a transect at distances of zero, 10, 20 and 30m from the hedgerow face (Cranmer *et al.,* 2011). Moth behaviour is affected by unnaturally bright lights; specifically those at the ultraviolet and blue ends of the spectrum, so any use of normal visible light torches might affect the results (Gilburt and Anderson, 1996; van Langevelde *et al.,* 2011). A red light torch was chosen instead for this study, as it would be less likely to affect moth behaviour due to its lower visibility to moths (Gilburt and Anderson, 1996; van Langevelde *et al.*, 2011). The method used by Cranmer *et al.* (2011) to assess pollinator movements around landscape structures was adapted for use in investigating moth movements along hedgerows. As with the Cranmer study, points were chosen at different distances from the hedgerow (in this case 1m, 5m and 10m; Figure 2.8). Observations took place on warm, clear nights, as Lepidoptera numbers are known to be significantly affected by adverse weather conditions (Ramamurthy *et al.* 2010). A total of 13 observation sets were made over the months of May-July in 2011, 2012 and 2013. Any nights where no moths were observed were discounted from the study as no comparisons could be made. Surveys were carried out along the hedgerows used in the moth trapping section of this research, however movement surveys were not done in areas being trapped with light traps, due to the possible effects on moth movements.

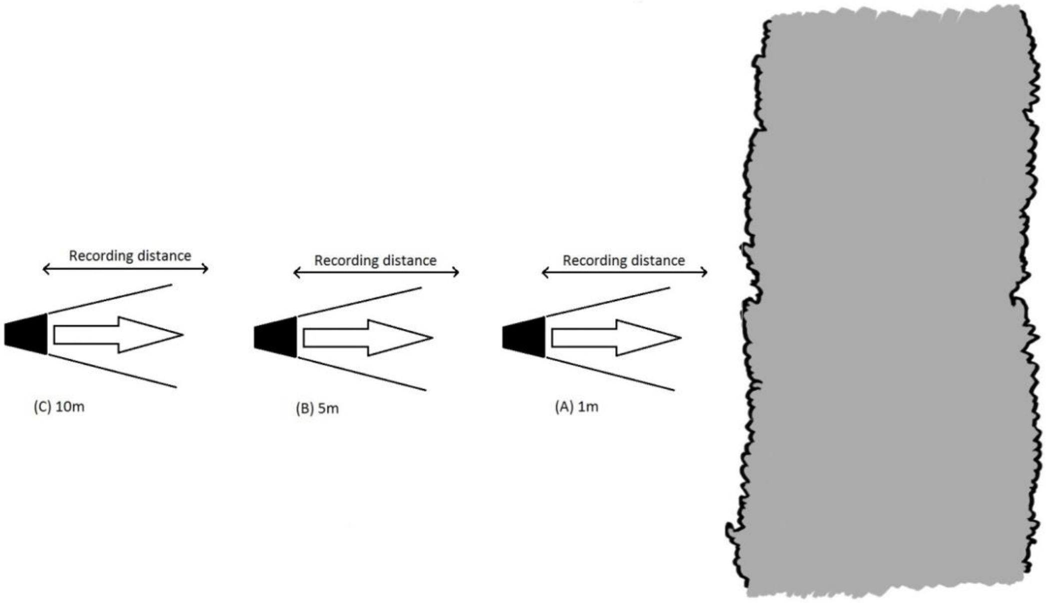

Figure 2.8: Moth movement surveying using red light torch. Torch was located at 1m, 5m and 10m from the hedgerow face for approximately 15 minutes observation time, with observations recorded from within 1m of the torch beam (Image not to scale).

2.3.5 Moth Feeding Surveys

Transect methods have been used for decades as a simple method for counting species numbers, particularly for Lepidoptera and other larger invertebrates (Pollard, 1977; Dover *et al.,* 2000). This method is particularly effective when studying linear features, as the transect selection follows the habitat, rather than providing a cross-sectional sample. The transect method has been used for moth species and provided useful data when carried out under torchlight (Spalding, 1997; Birkinshaw and Thomas, 1999).

Ten lengths of hedgerow were chosen across the two farms, from a mix of hedgerows in different states (hedgerow lengths adjacent to the trap points within the trapping study, Chapter

Two [Figures 2.9 and 2.10]). A 200m line transect was walked to observe and record invertebrate visitors to hedgerow and adjacent margin flowers (Ouin and Burel, 2002; Pollard and Yates, 1994). All hedgerow and margin flowers within 1m of the hedgerow face were included. Each night up to 4 of the 16 hedgerow lengths were surveyed, depending on weather conditions. Each of the hedgerows was surveyed between four and five times, although visitation by insects was not always recorded due to weather conditions or flowering phenology.

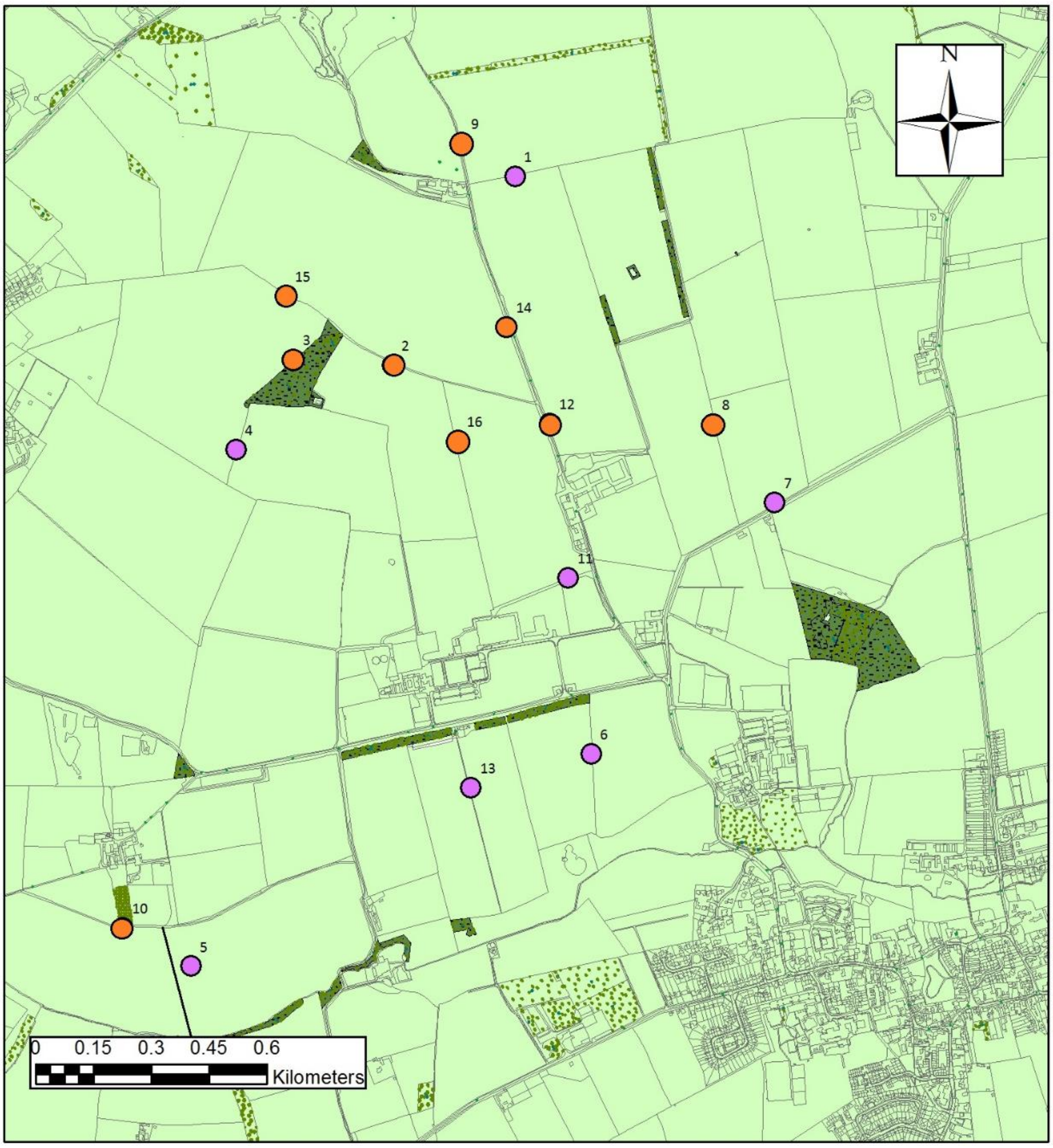

Figure 8.9: Moulton locations from 2011/12 trapping study used for moth visitation research (Locations used coloured in orange).

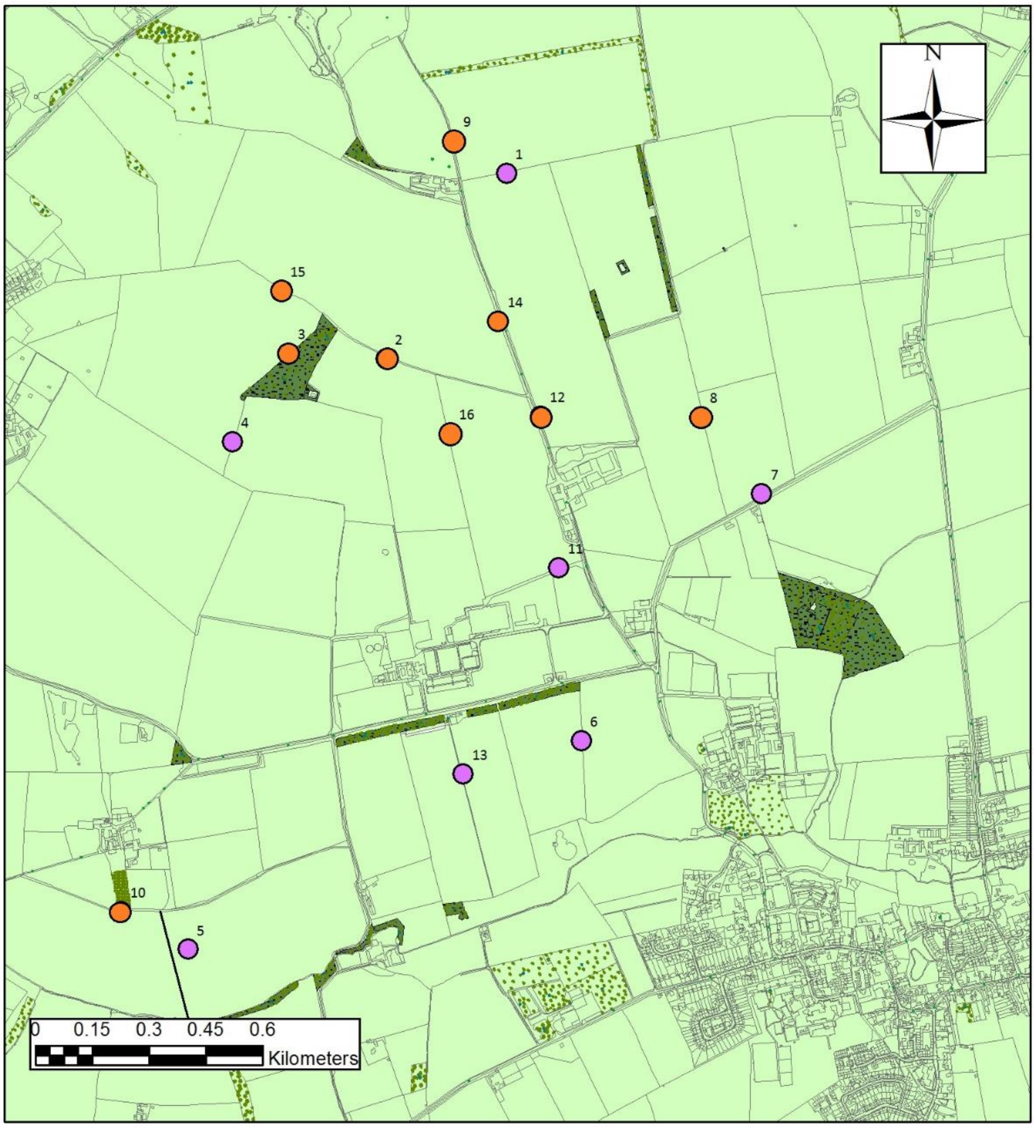

Figure 2.10: Kelmarsh locations from 2011/12 trapping study used for moth visitation research (Locations used coloured in orange).

Surveying was carried out from just after dusk until around midnight during May-August 2012 and 2013, as with the moth movement studies this research avoided nights where light traps were being used in the area to prevent any possible disruption to or from other studies. Where identification was not possible *in situ*; individuals were collected and identified later under more favourable conditions. As this was a small-scale project both macro and micro-moth species were included in the study. Due to the sensitivity of Lepidoptera to white light, red light torches were used to survey vegetation, in order not to disturb feeding behaviour (van Langevelde *et al*, 2011). Invertebrates were identified down to order, with the exception of moths, which were identified at species level.

Observations were carried out on dry, warm and still nights (over 10°C, under 2ms^{-1} wind speed and minimal precipitation), due to the effect of adverse weather conditions on moth flight behaviour (Yela and Holyoak, 1997). A total of 40 transects were walked over the course of the study period, however only 31 revealed nocturnal visitors to hedgerow flowering plants (most likely due to weather conditions) and were therefore included in the results (where no visitors were seen, data was not included as this was most considered to be due to weather conditions and could therefore bias results). Plant species flowering in the hedgerows were: Common Hawthorn (*Crataegus monogyna)*, Blackthorn (*Prunus spinosa)*, Bramble (*Rubus fruticosus* agg.*)*, Cow Parsley (*Anthriscus sylvestris*), Dog Rose (*Rosa canina*), Elder (*Sambucus nigra)*, Spear Thistle (*Cirsium vulgare*), Creeping Thistle (*C. arvense*), Burdock (*Arctium minus*), Common Nettle (*Urtica dioica*) and Viburnum (*Viburnum opulus)*. All these plant species were studied when in flower over the course of the study. The results from all the hedgerows were analysed together and separately to determine both overall and local abundance and diversity of moth visitors. The number of patches or ‘clumps’ or Bramble observed along each of the hedgerow lengths was recorded to give an indication as to the possible relationships between invertebrate activity and floral resources.

2.4 Statistical Analysis

Data collected was initially put into Excel (Microsoft, 2013), before being analysed further using SPSS v20 (IBM, 2011), MVSP (Kovach Computing Services, 2014) and CAP 3 (Pisces

Conservation, 2004). Initial exploration of the variables included testing of residuals for normality which was carried out in SPSS. Where these data did not conform to a normal distribution, transformations were carried out to allow the use of parametric testing (Square-root, Log [Field, 2013; Krebs, 2014; Zar, 1984]). Basic statistical analysis was carried out in SPSS, and included one-way ANOVA for the comparison of site and trap location abundance data, correlation analysis for the initial investigation of possible relationships and linear regression to determine the strength of any possible relationships (Field, 2013). Shannon's Diversity, Simpson's Diversity and Taxonomic Distinctiveness Indices were calculated for the trap points and these scores were included in the analysis. The Taxonomic Distinctiveness Index was calculated for each of the locations according to the methods outlined by Warwick and Clarke (1995), which took into account both abundance and the 'taxonomy distinctiveness' of the species from all others in the sample. As well as individual moth species abundance, moths were grouped into families and sub-families for taxonomic abundance analysis. Families and sub-families were only included in the analysis if they contained more than one trapped species and where trapped in high enough numbers. The Lasiocampidae family for example, only contained the Drinker moth and therefore was not included in the taxonomic analysis, only under individual species. In addition, moths were put into feeding and habitat 'guilds', based on their preferences for habitats or food plant types. They were also classed as either generalist (no specific preferences for habitat or food type, found in multiple varied habitats and/or feeding on a wide range of host plants) or specialist (with a preference for a small range of habitats and/or food plants).

All independent variables were tested for normality in SPSS and transformed using appropriate transformations dependent on distributions (Field, 2013; Krebs, 2014; Zar, 1984). Multivariate analysis was carried out in MVSP and CAP 3. Canonical Correspondence Analysis (CCA) was used with raw moth abundance data and environmental variables, due to their suitability for large ecological data sets with numerous independent variables (Hill and Gauch, 1980, Ter Braak, 1986; Ter Braak, 1987; Palmer, 1993). Although the 'arch effect' is recognised as a possible problem in CCA, it is generally considered to be a robust method of multivariate analysis (Palmer, no date;

Palmer, 1993). Only relationships with significance values of 0.01 or lower were included to help avoid Type I errors (Dytham, 1999; Field, 2013).

2.4.1 Local-Scale Analysis

Local-scale analysis involved the inclusion of all the variables recorded in the hedgerow and vegetation surveys (See 2.3.2). The hedgerow variables were initially investigated alone to reveal variability in the hedgerows across the two sites (See 6.4.1). Local hedgerow and margin variables were also correlated with the moth variables (mean species richness and moth totals, Shannon's and Simpson's Diversity, Taxonomic Distinctiveness, feeding and habitat guilds and species abundance totals). Any highly significant correlations were used to inform bivariate multiple and singular linear regression analysis using transformed variables (Field, 2013; Krebs, 2014; Zar, 1984). In cases where more than one independent variable was shown as correlated, multiple linear regression was used to avoid collinearity. Multivariate analysis in the form of CCA was also carried out using the local-scale hedgerow and margin variables as well as the moth abundance data (Ter Braak, 1986; Ter Braak, 1987; Palmer, 1993).

2.4.2 Moth Movement Analysis

Tallied movement results were totalled for the entire course of the study to allow percentages to be calculated. Due to non-normal distributions of the directional movement categories, a Kruskal-Wallis test was used to compare the medians for each group (Field, 2013). The same approach was used to compare the numbers of moths at each of the different distances from the hedgerow.

2.4.3 Moth Visitation Analysis

The total visitors from each invertebrate group were calculated and compared initially in Microsoft Excel. Percentages and graphs were produced to compare the numbers of different invertebrate groups on all hedgerow flowering plants as well as for Bramble alone. Species lists were produced for the study and the numbers of micro and macro-moth species were compared as a percentage (See Appendix 5 and 6). Due to the simplicity of the data from this study, no statistical analysis was carried out.

Chapter Three: Environmental Factors Influencing Trapping: Weather, Moth Emergence and Phenology

3.1 Introduction

Invertebrates can be susceptible to changes in weather (Martinat, 1987; Neale *et al.,* 2008) and Lepidoptera abundance is particularly known to have a significant relationship with weather fluctuations (Butler *et al.,* 1999; Raimondo *et al*, 2004; Williams and Liebhold, 1995; Yela and Holyoak, 1997). It has also been suggested that climate change is one of the factors influencing the biodiversity of Lepidoptera in the UK and that fluctuating weather conditions over recent years may be contributing to declines in these species (Butterfly Conservation, 2013; Fox *et al.,* 2011b; Fox *et al*., 2013; Fox *et al.,* 2014).

3.2 Annual variation of moth catches

The summer of 2011 saw an average temperature of 13.7°C, 0.6°C below average for the season. Rainfall across the summer was also 18% higher than average for the time of year (267mm) (MetOffice, no date [a]). The summer of 2012 however, was reported to be the wettest in 100 years, with an average temperature of 13.9°C and rainfall of 371mm (57% above average) (MetOffice, no date [b]). With unusually cold and wet conditions, 2012 was reported as a particularly poor year for bird and invertebrate populations (Davies, 2013; British Trust for Ornithology, 2012). Butterflies and moths were among those taxa worst affected by the poor weather in 2012, with 52 out of 56 butterfly species recorded in significantly lower numbers in 2012 than in 2011 (Butterfly

Conservation, 2013). These findings for UK butterflies are reflected in the trapping yields from moths in this study. The total numbers of moths trapped in the 2012 field study was down by 44% on the 2011 total (See Chapter Four for further details). The summer of 2013 had higher than average temperatures (0.8°C above) and rainfall of just 187mm (22% lower than long-term average) (Met Office, no date c).

The Northamptonshire moth records were collated and summarised from the last nine years. Summary data for catches since 2004 showed that 2011 through 2013 were the poorest for mean catch rate, as well as the lowest numbers of mean species (Figure 3.1 and Figure 3.2). Both Figures 3.1 and 3.2 show a similar trend in terms of abundance and diversity for the county. The years 2011, 2012 and 2013 were notably lower (32%, 43% and 35% respectively) in terms of trap yields for the county average, with 2012 being the poorest, while 2013 showed a moderate increase on 2012, but still lower than 2011. The summer of 2013 had higher average temperatures (0.8°C above average), but still had poor catch rates and diversity; this is likely to be due to the result of several poor seasons of weather, which can impact heavily on invertebrate numbers (Butterfly Conservation, 2013; Fox *et al*., 2013). The effects of poor weather can have an even more significant effect depending on the species' brooding habitats (see section 3.2).

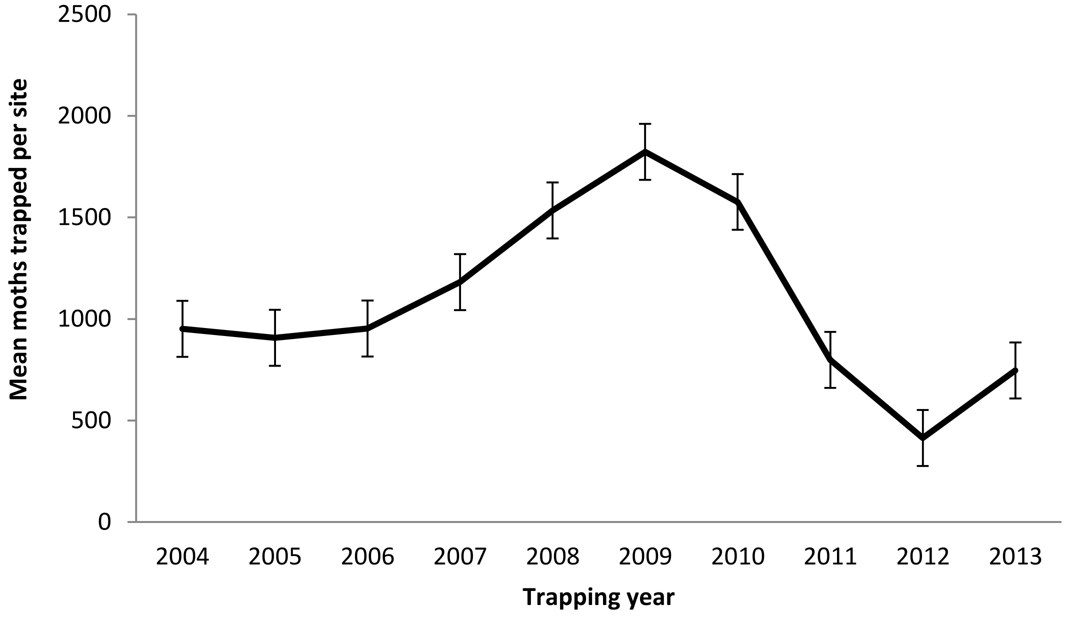

Figure 3.1: Mean number of moths trapped per site in Northamptonshire since 2004 with standard error bars (Data collated from Northamptonshire's historic moth records).

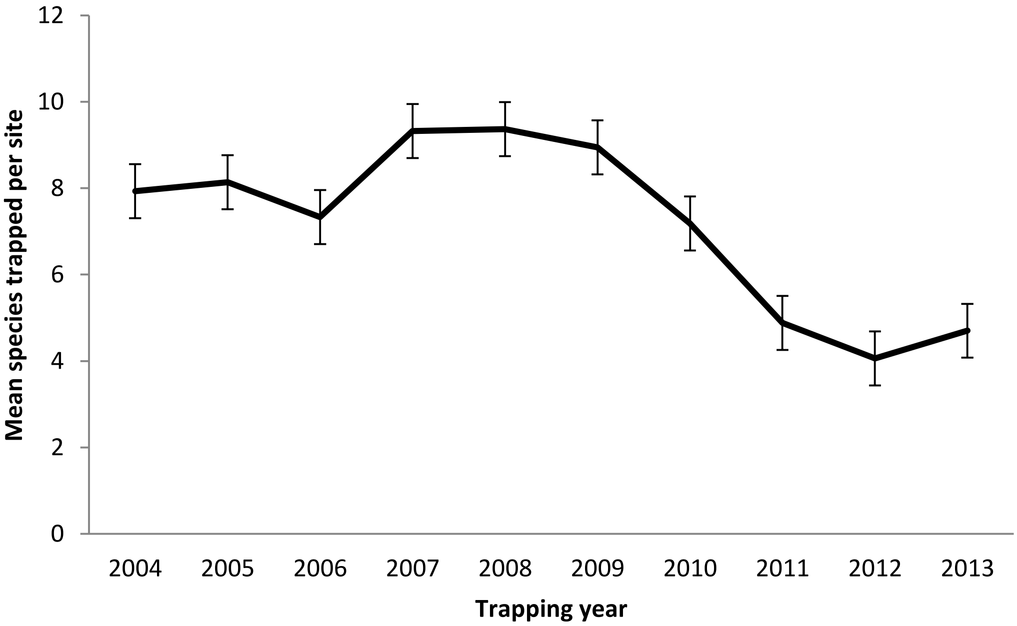

Figure 3.2: Mean moth species trapped per trap location in Northamptonshire since 2004 with standard error bars (Data collated from Northamptonshire's historic moth records).

3.3 Seasonal and daily variations

3.3.1 The influence of local weather conditions on trapping

As well as annual and seasonal weather fluctuations, Lepidoptera activity is known to be affected by smaller scale changes in weather conditions. Factors known to impact on moth trapping yields are: temperature, wind speed, moon luminance and air pressure (Dent and Pawar, 1988; McGeachie, 1989; Williams and Liebhold, 1995; Raimondo *et al.,* 2004; Yela and Holyoak, 1997). All of these variables can change in a very short time scale and could impact on catch rates or observations. Weather data from Pitsford weather stations (wind speeds, temperatures, precipitation [this weather station is located 2.1 miles from Moulton site and 5 miles from the Kelmarsh site]), and moth trapping data were used to determine any relationships between weather and moth abundance or species richness.

Stepwise multiple regression was used to investigate the relationships between moth abundance and richness and local weather conditions. Once all insignificant variables were removed from the model only localised pressure was found as having a significant relationship with the mean numbers of moths trapped per night (R=0.137, R^2=0.019, p=0.028). The relationship was not very strong, however it was still likely to be having some influence on the abundance of moths trapped within the study. When this analysis was run again using mean species numbers, no significant relationship was found, suggesting that air pressure was not significantly influencing the species richness in the study.

Wind speed and low temperatures are usually shown to have a negative effect on the numbers of moths trapped on any occasion due to the adverse effects on flight behaviour

(McGeachie, 1989; Yela and Holyoak, 1997). Trapping within this study was only carried out on stiller, low precipitation, warm nights, so this likely explains the lack of effect found for these variables.

Wind speed may have been influencing the movements of moths along hedgerows in the moth movement study as the benefits of hedgerows as wildlife corridors for invertebrates may be dependent on their shelter effects (Merckx, 2010). This is explored further in Chapter Six.

During 2013 the trapping was carried out over nine days in a much more intensive manner to reduce the effects of poor weather and moth species emergence. The results of the 2013 moth trapping revealed no significant relationships with weather conditions. This suggests that the short, intensive period of trapping during good weather was successful in mitigating against the influence of weather.

3.3.2 Phenology

Moths are in flight all year round in the UK; however the highest numbers and richness are found in the summer months between May and September (Figure 2.7, Waring *et al.,* 2009). Moth life cycles, like many invertebrates, involve stages of egg, larvae, pupae and adult form (Waring *et al.,* 2009). Due to this, varying of brood numbers, feeding habits and host-plant preferences, moth species in flight change throughout the year on a regular basis (Waring *et al.,* 2009). This can have an effect on any moth trapping data collected as there may be underlying effects of moth phenology (Raimondo *et al.,* 2004). Additional to these seasonal changes in diversity, Lepidoptera are usually either single brooded (univoltine), or double brooded (bivoltine) (Waring *et al.,* 2009). The majority of UK moths are single brooded, meaning that weather conditions of the year prior to emergence are just as influential as the emergence year (Waring *et al.,* 2009).

As the summer continued in both 2011 and 2012, more individual moths and moth species were trapped (Figures 3.3 and 3.4). This seasonal increase was as expected from cursory analysis of the historic moth trap data (Figure 2.7) and information from various field guides, which suggested that moth numbers and species emergences increased through the summer till a peak around July (Chapter 2: Figure 2.7; Waring *et al.,* 2009). The strength of these relationships was much stronger in 2012 than 2011 (Figures 3.3 and 3.4). Ideally with good weather, data could be broken down into weekly segments and analysed separately to reveal other environmental factors, however due poor weather conditions which resulted in a patchy data set, this was not possible.

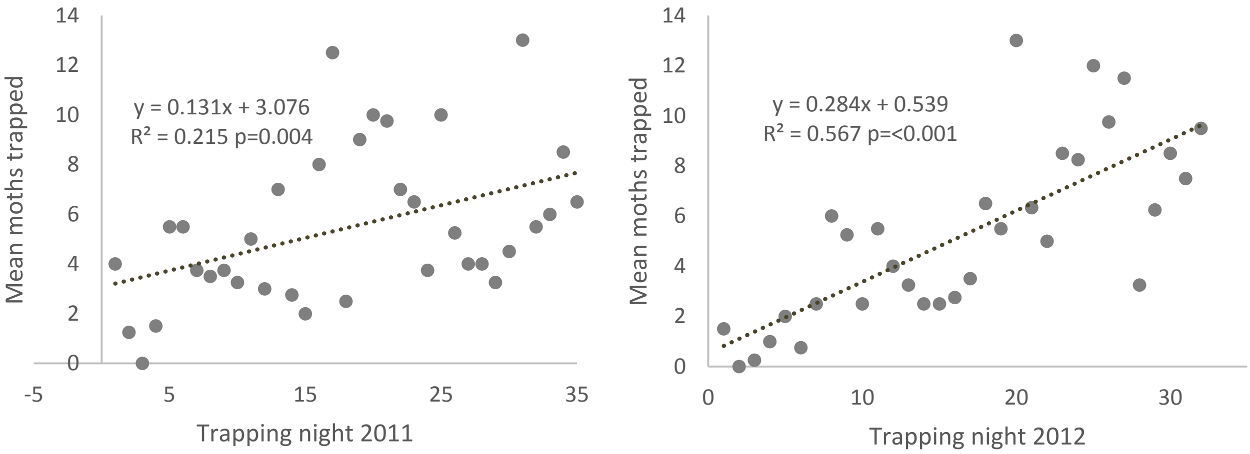

Figure 3.3: Numbers of moths trapped according to trap night (day number in the trapping period) in 2011 and 2012.

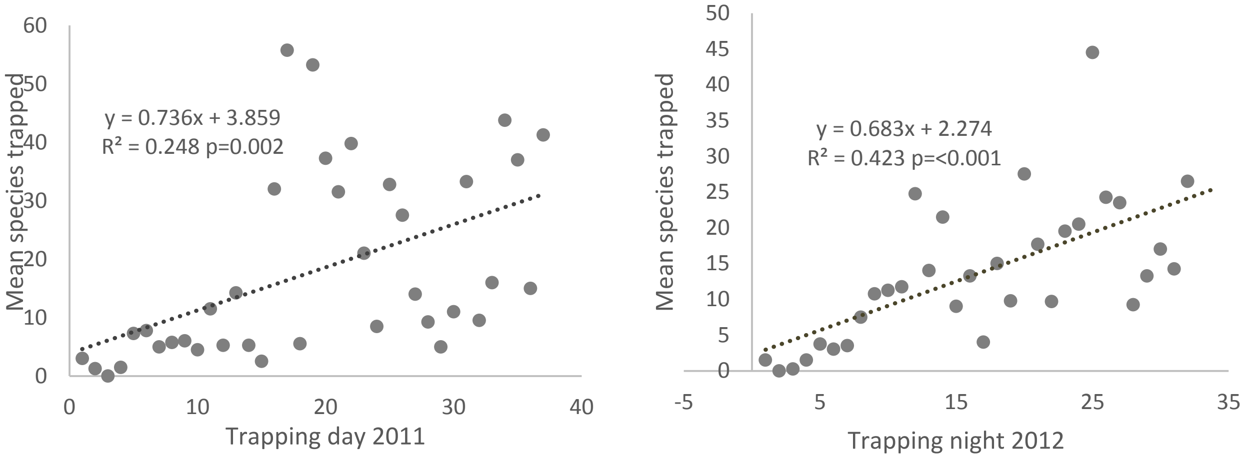

Figure 3.4: Numbers of species trapped according to trap night (day number in the trapping period) in 2011 and 2012.

3.4 Summary

Moth numbers and species richness are generally influenced by weather conditions and seasonal phenology. As such, these external factors were taken into consideration when the data was analysed for each of the studies in the subsequent chapters. Through analysis of the moth abundance and species richness for the 2011 and 2012 trapping periods, a significant positive relationship was found between moth abundance and local air pressure. No significant relationships were found between any weather variables and moth data in 2013. Moth phenology was likely to having an impact on the richness and abundance of the 2011 and 2012, however this was considered during the analysis. The 2013 research was confined to a smaller and more intensive study, which would have reduced the influence of phenology on the results.

Chapter Four: The Influence of Land-Use on the Diversity and Abundance of Moths in Northamptonshire

4.1 Introduction

Declines have been reported in the UK for a number of invertebrate groups including bumblebees, butterflies and dragonflies (Clausnitzer *et al.,* 2009; Goulson *et al.,* 2008; Smart *et al.,* 2000). Recent studies have found that these worrying trends have been mirrored for macro-moth species, a diverse yet understudied insect group (Conrad *et al.,* 2006; Fox *et al.,* 2011b; Fox *et al*., 2013). The latest report on UK macro-moths showed that overall moth abundance had declined by 28% since 1968. These declines are thought to be especially prominent in the south of the UK, where 44% of overall moth abundance has declined (Fox *et al*., 2013). The 2013 'State of the UK's Larger Moths' report also listed 62 moth species revealed as declining by more than 75% over this period and therefore requiring further research (Fox *et al*., 2013). Emerging evidence of such widespread declines has spurred an increase in studies on moth populations and ecology, with a hope to mitigate against further losses, by understanding the mechanisms of declines (Fox *et al*., 2013). A 2013 review based on long-term moth trap data from Rothamsted Research, found that there was a negative correlation between agricultural intensification and moth abundance in the UK landscape ([between 1968 and 2002] Fox *et al*., 2013; Woiwood and Gould, 2008). Both abundance and diversity of moths in agricultural landscapes have been shown to increase under organic as opposed to conventional farming, suggesting that a reduction of chemical applications and the use of arable field margins as buffer zones, may increase invertebrate numbers (Chiverton and Sotherton, 1991; Dover, 1989; Dover *et al.,* 1990; Hassall *et al.,* 1992; Sotherton, 1984; Sotherton, 1985; Taylor and Morecroft, 2009; Wickramasinghe *et al.,* 2004). Further, Pocock and Jennings (2008) found that moth abundance was positively associated with the presence of field boundaries within agricultural areas.

As well as the known impacts of agricultural intensification on moth abundance, specific the benefits of semi-natural habitats have been investigated. High grassland and scrub coverage in the British landscape have been recognised as positively associated with moth abundance (Fuentes-Montemayor, 2012). Woodlands are also known to be important for moth populations, and it has been suggested that open woodlands such as coppice, are key habitats for both macro-moths and butterflies (Broome, 2011; Usher and Keiller, 1998). Woodland in the UK only accounts for 12% of land cover compared with 45% of the total area of the EU, so confirming that the necessity of woodland for priority research species should be considered of high importance (DEFRA, 2012; FAO, 2011). This study aims to determine the relationship between county-wide Northamptonshire moth populations and landscape features including the coverage of semi-natural habitats, agricultural land and urban areas.

4.2 Methods

See Chapter Two section 2.1 for the methods used to gather, select and analyse the historic moth trapping records and landscape data. See Figure 2.1 for trapping locations

4.3 Results

4.3.1 Land Cover Map Data

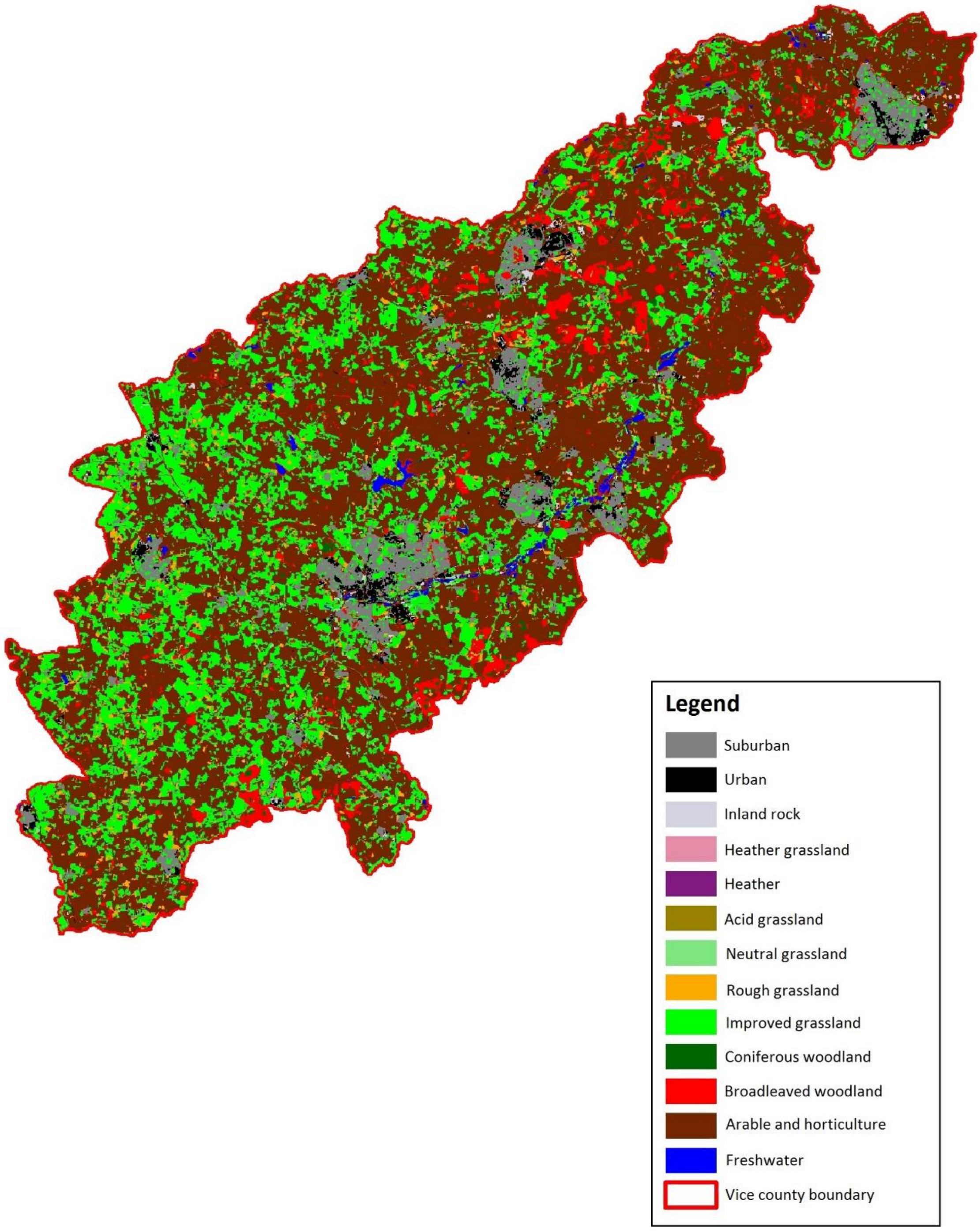

Figure 4.1: Land cover mapping for Northamptonshire in 2007 (Centre for Ecology and Hydrology, 2007).

Table 4.1: Trap point land use coverage at 250m radius (Derived from land cover map data. Habitats not listed have 0% coverage adjacent to trap locations.)

		Percentage habitat coverage (at 250m radius)											
Trap Location No.	**Trap location immediate habitat**	**Broadleaved woodland**	**Coniferous woodland**	**Total woodland**	**Inland rock**	**Improved grassland**	**Rough grassland**	**Total grassland**	**Arable/Horti cultural**	**Urban**	**Suburban**	**Total anthropogenic**	**Total semi-natural**
1	Improved grassland	1%	0%	1%	0%	75%	2%	77%	18%	0%	5%	22%	78%
2	Broadleaved woodland	72%	0%	72%	0%	23%	0%	23%	5%	0%	0%	5%	95%
3	Suburban	5%	0%	5%	0%	37%	16%	53%	19%	0%	22%	42%	58%
4	Improved grassland	0%	0%	0%	0%	95%	0%	95%	4%	0%	1%	5%	95%
5	Broadleaved woodland	73%	12%	85%	0%	13%	0%	13%	2%	0%	0%	2%	98%
6	Suburban	0%	0%	0%	0%	42%	5%	46%	19%	12%	22%	54%	46%
7	Broadleaved woodland	58%	8%	66%	0%	0%	30%	30%	4%	0%	0%	4%	96%
8	Broadleaved woodland	94%	0%	94%	0%	3%	0%	3%	0%	0%	3%	3%	97%
9	Improved grassland	31%	11%	42%	0%	49%	3%	52%	6%	0%	0%	6%	94%
10	Arable	13%	0%	13%	0%	0%	5%	5%	82%	0%	0%	82%	18%
11	Suburban	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	0%
12	Suburban	0%	0%	0%	5%	0%	0%	0%	21%	9%	64%	95%	5%
13	Suburban	0%	0%	0%	0%	22%	0%	22%	14%	0%	64%	78%	22%
14	Arable	0%	0%	0%	10%	0%	10%	10%	79%	0%	0%	79%	21%
15	Broadleaved woodland	80%	20%	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%
16	Broadleaved woodland	30%	5%	35%	0%	1%	10%	12%	53%	0%	0%	53%	47%
17	Suburban	0%	0%	0%	0%	0%	0%	0%	0%	4%	96%	100%	0%
18	Arable	0%	0%	0%	0%	45%	0%	45%	55%	0%	0%	55%	45%
19	Broadleaved woodland	87%	0%	87%	0%	8%	0%	8%	5%	0%	0%	5%	95%
20	Coniferous woodland	86%	8%	94%	0%	0%	0%	0%	5%	0%	1%	6%	94%
21	Arable	3%	0%	3%	0%	4%	0%	4%	82%	11%	0%	93%	7%
22	Suburban	0%	0%	0%	0%	2%	0%	2%	0%	6%	92%	98%	2%
23	Suburban	0%	0%	0%	0%	18%	0%	18%	19%	0%	63%	82%	18%
24	Broadleaved woodland	68%	0%	68%	0%	0%	0%	0%	32%	0%	0%	32%	68%
25	Improved grassland	0%	0%	0%	0%	66%	0%	66%	30%	0%	4%	34%	66%
26	Broadleaved woodland	5%	0%	5%	0%	42%	37%	79%	16%	0%	0%	16%	84%
27	Broadleaved woodland	13%	0%	13%	0%	26%	3%	29%	58%	0%	0%	58%	42%
28	Suburban	0%	0%	0%	0%	24%	0%	24%	20%	0%	56%	76%	24%

Over the selected dates (See Chapter Two; 2.1) for the four years included in the study a total of 16,162 macro-moths from 272 species were trapped across the 28 selected sites over the first two weeks of July 2004-2007. Of these species, 97% were generalist moth species and the remaining 3% were habitat specialists with a preference for a particular habitat type, or indeed specific host plant (generalist species were those found in at least three different habitats, specialist those found in fewer, or only where food-plant is available [discretion was used when habitats used were of a similar type i.e. scrub, woodland and forest]). Of the 272 species, two trapped at these sites were BAP priority species (Concolorous [*Chortodes extrema*] and Heart Moth [*Dicycla oo*]; Fox *et al*., 2013), and 27 were Research Priority species (See Figure 4.2 for full list and more information; Fox *et al*., 2013). As well as these BAP species, four of the species trapped have no designation, but are known to have declined in abundance by over 75% nationally since 1968 (See Figure 4.2; Fox *et al*., 2013).

Table 4.2: Macro-moths trapped over the study period, which are known to be in decline across the UK (Fox *et al*., 2013; JNCC, 2007).

Common Name	**Scientific Name**	**Designation**	**Population Status**
Concolorous	*Chortodes extrema*	BAP priority species	Status unknown.
Heart moth	*Dicycla oo*	BAP priority species	74% decline over 24 years
Blood-vein	*Timandra comae*	Research only priority species	79% over 35 years
Buff Ermine	*Spilosoma luteum*	Research only priority species	68% over 40 years
Cinnabar	*Tyria jacobaeae*	Research only priority species	67% over 40 years
Dark-barred twin-spot carpet	*Xanthorhoe ferrugata*	Research only priority species	91% over 40 years
Dot moth	*Melanchra persicariae*	Research only priority species	91% over 40 years
Double dart	*Graphiphora augur*	Research only priority species	98% over 40 years
Dusky brocade	*Apamea remissa*	Research only priority species	76% over 35 years
Garden dart	*Euxoa nigricans*	Research only priority species	98% over 40 years
Garden tiger	*Arctia caja*	Research only priority species	92% over 40 years
Ghost moth	*Hepialus humuli*	Research only priority species	62% over 40 years
Grey dagger	*Acronicta psi*	Research only priority species	77% over 35 years
Knot grass	*Acronicta rumicis*	Research only priority species	75% over 40 years
Lackey	*Malacosoma neustria*	Research only priority species	93% over 40 years
Large nutmeg	*Apamea anceps*	Research only priority species	93% over 40 years
Latticed heath	*Chiasmia clathrata*	Research only priority species	85% over 40 years
Minor shoulder-knot	*Brachylomia viminalis*	Research only priority species	82% over 40 years
Mottled rustic	*Caradrina morpheus*	Research only priority species	84% over 40 years
Oak hook-tip	*Watsonalla binaria*	Research only priority species	78% over 40 years
Pretty chalk carpet	*Melanthia procellata*	Research only priority species	88% over 40 years
Rosy minor	*Mesoligia literosa*	Research only priority species	93% over 40 years
Rustic	*Hoplodrina blanda*	Research only priority species	78% over 40 years
September thorn	*Ennomos erosaria*	Research only priority species	87% over 40 years
Shaded broad-bar	*Scotopteryx chenopodiata*	Research only priority species	73% over 35 years
Shoulder-striped wainscot	*Mythimna comma*	Research only priority species	72% over 35 years
Small emerald	*Hemistola chrysoprasaria*	Research only priority species	64% over 40 years
Small phoenix	*Ecliptopera silaceata*	Research only priority species	77% over 35 years
Small square-spot	*Diarsia rubi*	Research only priority species	87% over 40 years
Spinach	*Eulithis mellinata*	Research only priority species	96% over 40 years
White Ermine	*Spilosoma lubricipeda*	Research only priority species	70% over 40 years
Buff arches	*Habrosyne pyritoides*	No designation	80% over 40 years
Garden carpet	*Xanthorhoe fluctuata*	No designation	75% over 40 years
Gothic	*Naenia typica*	No designation	76% over 40 years
Heart and dart	*Agrotis exclamationis*	No designation	76% over 40 years

The mean individuals and species trapped was calculated for each of the trap sites, as well as the Shannon’s and Simpson’s Diversity (Table 4.3). Trap location eight had the highest Shannon’s Diversity. Trap point 17 had the highest Simpson’s Diversity. Trap point 12 had the lowest Shannon’s and Simpson’s Diversity.

Table 4.3: Trap points across the county and summary statistics (Mean and standard deviation [SD] for moth and species totals [See Figure 2.1 for locations]).

Location	Mean Moths Trapped	SD Moths	Mean Species Trapped	SD Species	Shannon's Diversity Index	Simpson's Diversity Index
1	**60.0**	**23.2**	**13.0**	**1.5**	**3.014**	**0.932**
2	**320.0**	**60.8**	**48.0**	**8.5**	**2.772**	**0.866**
3	46.8	28.9	8.8	4.2	2.840	0.871
4	58.8	41.6	10.2	12.0	2.888	0.902
5	104.7	149.5	26.7	30.3	3.806	0.966
6	32.1	22.4	4.7	5.1	2.927	0.915
7	10.7	7.4	6.3	3.5	2.713	0.946
8	110.1	321.0	13.1	37.7	4.265	0.980
9	114.2	67.4	9.5	11.9	3.334	0.922
10	78.3	133.9	13.7	23.1	2.844	0.899
11	71.0	32.1	12.5	5.0	2.917	0.900
12	1.1	0.0	0.4	0.0	0.940	0.533
13	93.5	22.1	17.5	7.8	3.666	0.964
14	78.0	31.1	24.0	0.7	2.769	0.925
15	209.0	253.9	47.0	53.7	3.448	0.960
16	338.0	215.0	55.0	31.8	3.554	0.962
17	21.0	6.4	21.0	6.4	3.045	1.000
18	6.9	7.0	6.0	7.0	3.698	0.995
19	439.0	292.0	38.0	50.9	3.681	0.952
20	315.0	1045.9	50.0	21.0	2.987	0.904
21	5.3	3.9	1.0	1.1	1.492	0.745
22	84.2	91.2	12.8	19.2	3.338	0.936
23	188.9	120.0	7.7	16.1	3.426	0.933
24	612.0	81.3	72.0	9.9	3.342	0.929
25	195.1	112.3	8.8	15.1	3.515	0.945
26	283.4	94.8	24.2	6.4	3.988	0.969
27	608.0	577.7	92.0	99.0	3.943	0.972
28	29.1	38.4	7.0	14.3	3.298	0.940

4.3.2 Relationships between Land-Cover and Moth Abundance and Diversity

The distribution of moth abundance over the county was analysed using the Natural England 'Natural Areas' mapping. A one-way ANOVA revealed no significant difference between the four different Natural Areas within Northamptonshire with regards to diversity or moth abundance. In order to analyse the effect of land cover on richness and abundance, the trap locations were coded according to their habitat location. A one-way ANOVA revealed that there were differences in some of the trapping statistics across the different habitats (Table 4.4).

Table 4.4: Results of one way ANOVA comparing the trapping statistic means by habitat area (F statistic and significance [p]) (See Table 4.1 for trapping location habitats).

Trapping statistic	F	p
Mean moths	6.677	0.003
Mean species	7.589	0.001
Mean scrub species	6.750	0.002
Mean open woodland species	6.008	0.004
Mean woodland species	5.775	0.004
Mean shrub feeders	10.730	<0.001
Mean specialist feeders	8.841	<0.001

Post-hoc Least Significant Difference (LSD) tests revealed where the differences were for these results. Trap point 20 had to be removed from this analysis as it was the only one located in coniferous woodland. In all included cases, there was a significant difference between the means for suburban and broadleaved woodland, with traps based within woodland having higher moth numbers (See Table 4.5).

Table 4.5: Results of the LSD tests for differences in trapping statistic means between habitat types (habitats where differences occur, mean difference and significance [p]). Habitat with highest mean is listed first in pair.

Trapping statistic	Habitats	Mean difference	p
Mean moths	Broadleaved woodland and suburban	9.017	0.001
	Broadleaved woodland and arable	10.540	0.001
Mean species	Broadleaved woodland and suburban	3.156	<0.001
	Broadleaved woodland and arable	3.155	0.003
	Broadleaved woodland and improved grassland	2.955	0.006
Mean scrub species	Broadleaved woodland and suburban	6.804	0.001
	Broadleaved woodland and arable	9.037	0.001
Mean open woodland species	Broadleaved woodland and suburban	6.264	0.006
	Broadleaved woodland and arable	8.605	0.004
Mean woodland species	Broadleaved woodland and suburban	1.847	0.008
	Broadleaved woodland and arable	3.132	0.001
Mean shrub feeders	Broadleaved woodland and suburban	3.849	0.002
Mean specialist feeders	Broadleaved woodland and suburban	9.716	<0.001
	Broadleaved woodland and arable	1.120	0.001

Multivariate analysis was used to examine the effect of land cover on the moth communities in more detail. CCA results suggested that the raw abundance data of the moths trapped across the county were most likely being affected by the land-use cover at different spatial scales (See Figures 4.2 and 4.3, and Table 4.6). See Appendices for CCA bi-plots for 500, 1000, 1500 and 2000m (Appendix 1 through 4). The landscape-variables which appeared to be having an opposing influence at all spatial scales were anthropogenic land use and woodland and semi-natural cover statistics. Agricultural/horticultural land use and grassland habitat cover was also exerting an influence on the moth abundance data.

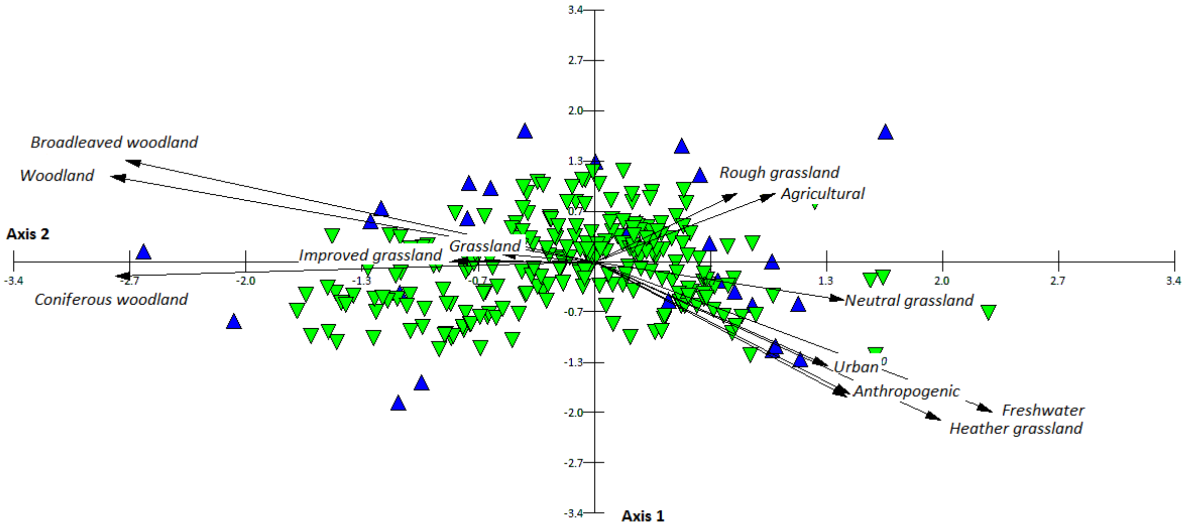

Figure 4.2: CCA biplot of trap sites (blue) and moth abundance (green) and their relationship with land-use cover at 250m (produced in MVSP).

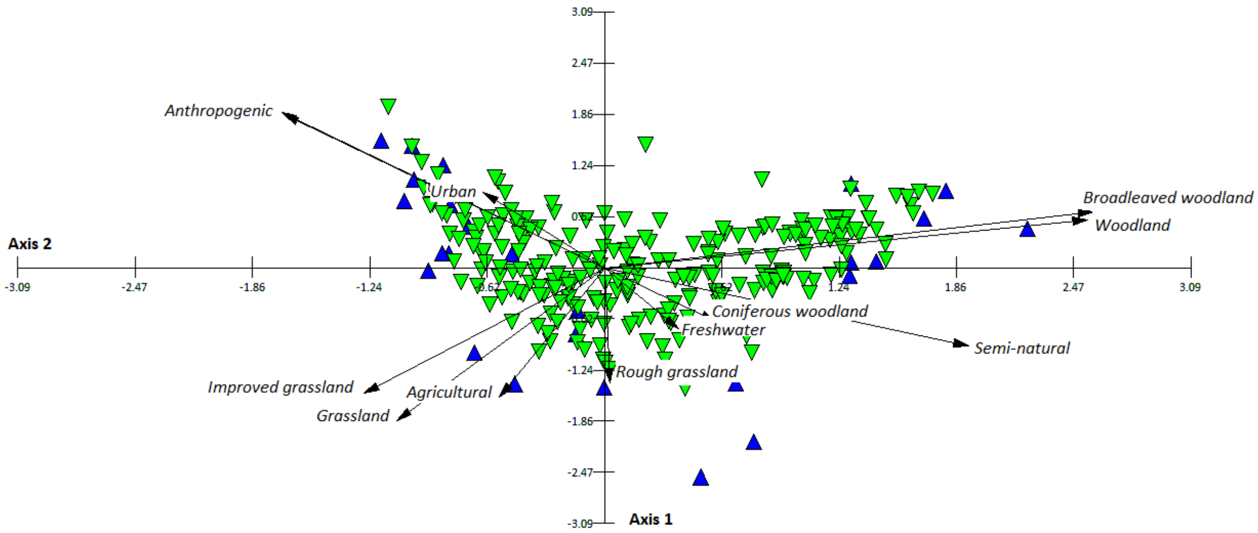

Figure 4.3: CCA bi-plot of trap sites (blue) and moth abundance (green) and their relationship with land-use cover at 3000m (produced in MVSP).

Table 4.6: CCA output statistics for the first four axes extracted from the moth abundance and land-cover map data at 250-3000m scales. (Eigenvalues: Variance value within the produced matrix, Percentage: % variance explained by the given axis, Cum. Percentage: cumulative percentage explained by axes. Spec.-env. Correlations: Percentage of variance in species data which is explained by environmental variables.)

Spatial Scale	**Output Value**	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**
All scales	Eigenvalues	0.439	0.289	0.235	0.2
	Percentage	15.643	10.291	8.38	7.135
	Cum. Percentage	15.643	25.1034	34.314	41.449
	Cum.Constr.Percentage	15.503	25.701	34.006	41.078
	Spec.-env. Correlations	1	1	1	1
250m	Eigenvalues	0.406	0.168	0.122	0.099
	Percentage	14.487	5.1094	4.339	3.515
	Cum. Percentage	14.487	20.481	24.821	28.336
	Cum.Constr.Percentage	39.702	56.129	68.021	77.654
	Spec.-env. correlations	0.978	0.905	0.823	0.901
500m	Eigenvalues	0.391	0.181	0.163	0.104
	Percentage	13.948	6.453	5.906	3.705
	Cum. Percentage	13.948	20.401	26.207	29.911
	Cum.Constr.Percentage	33.548	49.07	63.034	71.945
	Spec.-env. correlations	0.967	0.925	0.875	0.939
1000m	Eigenvalues	0.398	0.203	0.15	0.125
	Percentage	14.196	7.255	5.361	4.442
	Cum. Percentage	14.196	21.45	26.812	31.254
	Cum.Constr.Percentage	30.523	46.122	57.65	67.202
	Spec.-env. correlations	0.969	0.963	0.88	0.884
1500m	Eigenvalues	0.375	0.191	0.151	0.114
	Percentage	13.392	6.828	5.381	4.074
	Cum. Percentage	13.392	20.22	25.601	29.675
	Cum.Constr.Percentage	30.799	4502	58.878	68.248
	Spec.-env. correlations	0.948	0.951	0.91	0.85
2000m	Eigenvalues	0.36	0.164	0.138	0.109
	Percentage	12.857	5.943	4.923	3.878
	Cum. Percentage	12.857	18.7	23.623	27.501
	Cum.Constr.Percentage	31.532	45.964	57.938	67.45
	Spec.-env. correlations	0.933	0.919	0.857	0.869
3000m	Eigenvalues	0.388	0.176	0.171	0.116
	Percentage	13.834	6.266	6.084	4.138
	Cum. Percentage	13.834	20.099	26.183	30.322
	Cum.Constr.Percentage	30.716	44.629	58.137	67.326
	Spec.-env. correlations	0.953	0.943	0.925	0.906

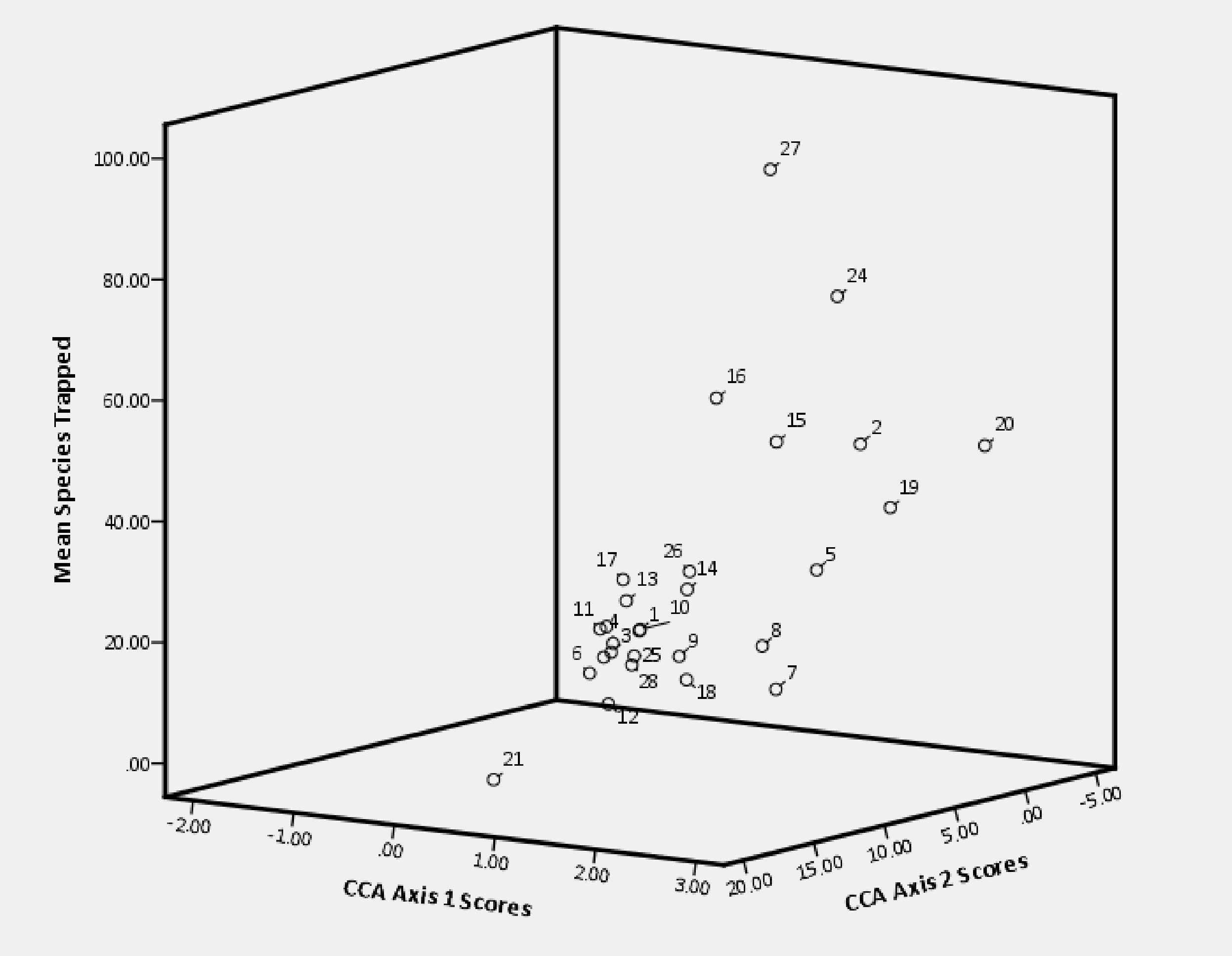

Figure 4.4: 3D scatterplot of CCA axis scores (all scales) and species richness (mean species trapped) for each of the 28 trap points (created in SPSS).

Species richness was correlated with the first two CCA axis scores (relationship between species richness and Axis 1 scores: *R*= 0.641, R^2= 0.411, p= >0.001), as shown in Figure 4.4, suggesting a relationship between the landscape variables and moth abundance in the county. The CCA output for moth abundance data and land-use cover data for all the spatial scales combined produced the highest percentage variance explained (See Table 4.6). These data could not be represented well on a bi-plot, due to the number of landscape variables included. The CCA was re-run for all the different spatial scales (250, 500, 1000, 1500, 2000 and 3000m) and again showed that the environmental variables included were most likely influencing the spread of the moth abundance data (See Table 4.6 and Figures 4.2 and 4.3). The CCA bi-plots revealed that woodland and anthropogenic landscape cover were having opposing influences on the spread of the moth abundance data.

Correlation analysis of the landscape metrics and transformed moth summary data revealed a number of positive and negative correlations. Multiple linear regressions were carried out where a number of variables were found to be influencing the moth data (Table 4.7 and 4.8).

Table 4.7: Significant predictors of the mean numbers of grass feeders derived from a multiple regression model. The *F*-value and the associated *p*-value, degrees of freedom, R^2, and adjusted R^2 are shown (* $p= < 0.05$, ** $p= < 0.01$, *** $p= < 0.001$). For each variable retained in the model, the *p*-value derived from *t*-tests, parameter estimates and standard errors are shown.

Model summary	**Variable**	**t**	***p***	**Standard error**
F= 13.205, P= ***, d.f.= 27	Grassland at 1500m	3.062	0.005	0.00
R^2 = 0.514, *R*= 0.717, Adj.R^2= *0.475*	Urban at 250m	-3.481	0.002	0.00

Table 4.8: Significant predictors of the mean numbers of specialist feeders derived from a multiple regression model. The *F*-value and the associated *p*-value, degrees of freedom, R^2, and adjusted R^2 are shown (*$p= < 0.05$, ** $p= < 0.01$, *** $p= < 0.001$). For each variable retained in the model, the *p*-value derived from *t*-tests, parameter estimates and standard errors are shown.

Model summary	**Variable**	**t**	***p***	**Standard error**
F= 8.849, P= ***, d.f.= 26	Broadleaved woodland at 250m	2.361	0.027	0.00
R^2 = 0.424, *R*= 0.651, Adj.R^2= 0.376	Suburban at 2000m	-2.286	0.031	0.00

Where only one independent variable was found to be influencing the moth data, singular linear regression was carried out and the results are presented below (Table 4.9).

Table 4.9: Results of singular linear regressions (regression co-efficient [*R*], R^2 and significance [*p*]).

Dependent variable (mean numbers)	**Independent landscape variable**	**Spatial scale (m)**	**B**	**R^2**	**P**
Grassland species	Rough grassland cover	1500	0.482	0.232	0.009
Moorland species	Freshwater cover	500	0.504	0.254	0.006
Number of moths	Broadleaved woodland cover	250	0.486	0.236	0.009
Number of species	Broadleaved woodland cover	250	0.52	0.27	0.005
Reedbed species	Urban cover	250	-0.497	0.247	0.007
Shannon's diversity	Urban cover	250	-0.554	0.307	0.002
Shrub feeders	Broadleaved woodland cover	500	0.524	0.275	0.004
Wetland species	Urban cover	250	-0.51	0.26	0.006
Woodland species	Urban cover	250	-0.609	0.371	0.001

4.4 Discussion

4.4.1 Summary Statistics and Species of Interest

The summary statistics showed that 272 moth species were trapped across the 28 selected locations. Of these species 35 are either designated or known to be in serious decline nationally (by 75% or more since 1968). The occurrence of these species across Northamptonshire is promising and suggests that the county provides habitat resources for at least some threatened moth species (Butterfly Conservation, 2007; Fox *et al.*, 2013).

4.4.2 Moth Abundance and Land-Use Cover

One-way ANOVA and post-hoc LSD tests revealed that for both mean moths and species trapped, significant differences were found between the statistics for broadleaved woodland trap locations and suburban, as well as those for broadleaved and arable. These same differences were also found when the mean numbers of scrub and specialist feeder species, as well as both the woodland and open woodland habitat species. These differences are unsurprising due to the high numbers of moth species which are known to prefer woodland and semi-natural habitats (Waring *et al.,* 2009). A recent report by leading experts revealed that land use change in the UK is having a significant negative impact on the abundance and species richness of moths (Fox *et al.,* 2014). Increasing anthropogenic areas such as urban, suburban and agricultural land use are replacing semi-natural habitat coverage, but also negatively impacting on moth abundance and diversity through their reduced floral resources, unnatural temperature fluctuations, as well as both light and air pollution (Fox *et al.,* 2014). When the literature is consulted, very few moth species are found which listed as found in agricultural or urban areas, however gardens and other areas with high concentrations of floral resources may help to improve richness and abundance in anthropogenic areas across the UK (Fox *et al.,* 2014). Projects such as BUGS (Biodiversity in Urban Gardens [Gaston, 2007]) aim to provide guidance on planting for invertebrate biodiversity, as well as increasing public awareness of the benefits of providing good floral resources for wildlife. Recommendations were that providing nectar resources, dead wood, artificial nesting sites for bees and patches of weeds such as nettles all contributed to increases in the abundance of invertebrates in gardens (Gaston *et al.,* 2005). Further research on a coarser spatial scale suggests that collected management of groups of gardens across urban areas can improve urban invertebrate diversity on a greater scale (Goddard *et al.,* 2010).

The results of the CCA suggested that environmental variables were influencing the distribution of the moth abundance data across the 28 trap points. CCA bi-plots for the various spatial scales, showed that woodland and urban land cover were exerting an opposing influence on the moth abundance across the county (Figure 4.2 and 4.3, Appendices 1 through 4). This is not surprising after consultation of the literature, as it is shown that semi-natural habitats, particularly woodland, are positively associated with moth abundance and species richness, whereas anthropogenic cover is shown to be negatively associated (Conrad *et al.,* 2006; Fox *et al.,* 2011b, 2014; Fuller and Warren, 1993; Fuentes-Montemayor *et al.,* 2010; Merckx *et al.,* 2012; Usher and Keiller, 1998). When each of the woodland cover statistics (broadleaved, coniferous and combined [total woodland]) were considered separately, it was broadleaved woodland which was found to be exhibiting the strongest relationship with moth abundance variables. Coniferous woodland cover across the area of the trap locations is fairly low (total combined cover of 2% land use across all 3000m buffer zones), so it is possible that very few coniferous woodland moths are found within Northamptonshire. Indeed, only one species of coniferous woodland specialists was trapped (Bordered white *Bupalus piniaria*). Broadleaved woodland cover across the area was comparatively high (total combined cover of 24% across all 3000m buffer zones). Relatively low numbers of woodland specialists were trapped throughout the entire study (7 species, 1.8%). Despite this, the majority of species trapped are listed as being found in woodland habitats, amongst others (181 species, 67% of 272 total). As well as the influence from woodland and urban land use, the land-cover of arable and horticulture, as well as grassland and freshwater were also shown as influencing the data to varying degrees at each of the spatial scales. These results support those put forward by Fox *et al.* (2014), who suggest that the significant declines of UK moths are a result of both climate and land use change.

One-way ANOVA showed a significant difference between the moth trapping statistics at the different habitat areas (Table 4.5). Post-hoc LSD testing revealed that these differences were for the most part between trapping locations located within broadleaved woodland and those located in suburban areas, with broadleaved woodland having more moths and higher diversity than in suburban areas (Table 4.6). This result suggests that moth species richness and abundance are different between these two habitat types, something with was also reflected in the results of the CCA and later regression analysis.

Initial correlations suggested a relationship between a number of the summary statistics and the land-cover totals for the different scales. Further multiple regression analysis confirmed that many of the landscape variables had a relationship with moth species richness and abundance statistics. Many of these variables were inter-correlated due to their spatial nature, so less influential, inter-correlated variables were removed and multiple regression was run with only the optimum spatial scales (See Tables 4.7, 4.8 and 4.9). Broadleaved woodland was significantly associated with the overall abundance of moths trapped, as well as the species richness, numbers of shrub and specialist feeders. The optimum spatial scales were 250 and 500m for the influence of broadleaved woodland cover on moth abundance and species richness. These findings reinforce those of Fuentes-Montemayor *et al.* (2012), who found that at both 250 and 500m buffer zones, moth abundance was strongly influenced by woodland cover in the landscape. This research could not however confirm the findings of these authors that woodland cover at coarser spatial scales is linked with woodland specialist species, however as mentioned previously, only very small numbers of specialist habitat moths were trapped in this study. The analysis did reveal a significant negative relationship between the numbers of moths found in woodlands and urban cover at the 250m scales.

Urban and suburban, as well as their combined total (Table 4.9: Anthropogenic), had a negative relationship with a number of moth abundance variables. Urban and suburban cover were negatively associated with the numbers of grass, shrub and specialist feeders, reedbed, wetland and woodland species, as well as the Shannon's diversity index. The optimum spatial scale for the influence of these land cover statistics was revealed as 250m for the majority of factors, however for the numbers of specialist and shrub feeding species the scales were larger (3000m anthropogenic [shrub feeders and 2000m suburban [specialist feeders]).

These results support the output of the CCA and suggest that the cover of urban and suburban areas within the landscape may be having a detrimental effect on the species richness and diversity of moths from a variety of guilds. Recent research by Fox *et al.* (2014) has suggested that the two most important influences on moth abundance in the UK are climate change and land use. The researchers found that as overall semi-natural habitat areas decreased, so too did moth abundance across the south of the UK. It was suggested that land use change is the single most influential factor for moths in southern Britain, which ties with findings of this study (Fox *et al.*, 2014). The findings of this research support this, but also give clearer data as to the influences of land cover and the spatial scales at which these influences are optimal.

Other than broadleaved woodland cover, the two landscape variables positively influencing the abundance of difference moth guilds were freshwater and rough grassland cover at 500m and 1500m respectively (Table 4.9). Rough grassland was unsurprisingly linked with the abundance of grassland moths, however freshwater cover was positively associated with moorland species. This could not be explained by the available literature as moths are not generally associated with open water; however it is possible that the freshwater habitat areas themselves are associated with areas of semi-natural habitat along their edge, which provide valuable shelter and feeding resources for moths.

4.5 Summary

The results of the analysis of the historic moth trapping data for Northamptonshire suggest that land use across the county is having a significant impact on the abundance and species richness of moths. This study found that the two most significant and opposing landscape variables were urban and broadleaved woodland coverage. Broadleaved woodland cover was positively associated with the abundance of a number of moth guilds, whereas urban and suburban cover had a negative relationship. The optimum scales at which these influences were having an effect were 250 and 500m, however for some moth guilds, large scales were significantly affecting abundance. Freshwater coverage in the landscape also had a positive relationship on the abundance of moorland moths, possibly due to the associated presence of semi-natural habitats. Conservation of moths in the UK should consider landscape-scale approaches and focus on the resource-based habitat connectivity and improvement works in order to protect and increase moth populations in farmland landscapes. Further research on specialist moth species could reveal further influences from land use and habitat cover.

Chapter Five: Hedgerow Characteristics and Farm-Scale Variations in Relation to Moth Abundance and Diversity in Intensive Northamptonshire Farmland

5.1 Introduction

The latest UK land-use statistics from the DEFRA suggests that approximately 77% of the UK is either built up or in agricultural use, leaving a relatively small percentage left over for semi-natural habitats (DEFRA, 2012a). With the necessity to increase housing and improve food production for growing populations, taking land out of agriculture or residential areas to create habitat areas is not a viable large-scale option (Godfray *et al.,* 2010; Pretty *et al.,* 2010). Recent projects and research have been focused on the improvement and connection of existing habitat areas to help create sustainable and robust ecological systems for wildlife (Evans *et al.,* 2013; Lawton, 2010; Pocock *et al.,* 2012). It is clear that in order to protect threatened species in the long-term, functional ecological networks are essential, particularly those which are future-proofed against problems such as climate change and increased chemical applications (Holker *et al.,* 2010; Lawton, 2010; Opdam and Wascher, 2004; Rands *et al.,* 2010; Vos *et al.,* 2008; Walther, 2010). Landscape ecology is not a new field, however it has seen a renewed emphasis across Europe with studies into Agri-Environment Schemes and larger scale habitat conservation projects (Bates and Harris, 2009; Donald and Evans, 2006; Kleijn and Sutherland, 2003; Kleijn *et al.,* 2006). A number of ongoing projects across the UK are focused on connecting and improving large areas of habitat. The Great Fen Project, Nene Valley Nature Improvement Area (NIA) and Revital-ISE are three such East Midlands projects which focus on landscape-scale regeneration of habitats and the creation of new 'corridor' habitat areas (Great Fen Team, no date; Natural England, no date; River Nene Regional Park, 2007).

Since the first research into ‘island biogeography’ and habitat fragmentation, landscape ecology and landscape-scale approaches to conservation have increased in popularity (Dueilli, 1997; Haila, 2002; Simberloff and Abele, 1976; Simberloff and Cox, 1987). The importance of linear habitats has been established and it is clear that not only the spatial but functional connectivity is essential for the effective creation and sustainability of ecological networks such as hedgerow-woodland systems (Debinski and Holt, 2000; Hendrickx *et al.,* 2007; Ludwig *et al.,* 2009; Robinson and Sutherland, 2002; Tischendorf and Fahrig, 2000). Relatively few studies have investigated functional connectivity, however two such studies on invertebrates revealed the importance of a network of semi-natural habitat areas for species dispersal (Petit and Burel, 1998; Pither and Taylor, 1998).

Overall moth numbers in the UK had decreased by 28% between 1968 and 2007 and 62 species of moth became extinct in the UK in the 20th century (Fox *et al*., 2013). Furthermore the improvement of urban and agricultural areas for biodiversity is highlighted as essential to the sustainable recovery of UK moth numbers (Fox *et al*., 2013). Butterfly Conservation have focused on landscape-scale approaches to the conservation of a number of threatened butterfly and moth species in the UK and have had promising results to date (Ellis *et al.,* 2012). The charity’s projects so far have mainly focused on butterflies, however targeted restoration projects to help groups of moth and butterfly species have also been carried out and have been successful in the stabilization of threatened populations (Ellis *et al.,* 2012).

A moth trapping study was carried out on two Northamptonshire farms to determine the diversity and abundance of macro-moth species on each of the sites. This study aimed to determine the macro-moths across the hedgerows of each site and investigate the proportions of generalist or specialist species, numbers of different moth guilds and comparative diversity statistics for each trap site.

5.2 Methods

All methods and study site details for this study can be found in Chapter Two. Refer specifically to sections 2.3.1 for details of timing, 2.3.3 for moth trapping methods and 2.4 for information on the statistical analysis and specific packages used throughout.

5.3 Results

5.3.1 Hedgerow Management and Diversity

The results of a one-way ANOVA using site as the independent factor showed that the hedgerows across the two sites were significantly different with regards to two of the factors included in the hedgerow surveys (hedgerow height and margin width). The means for all hedgerow features across the two study sites are displayed below (Table 5.1). Full plant and moth species lists for the two study sites can be found in the Appendices (Appendix 5, 6 and 7).

Table 5.1: Mean scores and standard deviation (St. dev) of hedgerow features across the two study sites, as well as results of one-way ANOVA (F value [F] and significance [p]).

	Moulton site		**Kelmarsh site**		**ANOVA statistics**	
Hedgerow feature	**Mean**	**St.dev**	**Mean**	**St.dev**	**F**	**p**
Hedgerow height	3.530	0.970	2.440	0.920	10.077	0.004
Hedgerow width	2.580	0.780	2.750	0.560	0.494	ns
Hedgerow cross-section dimension	9.650	5.250	7.130	4.000	2.244	ns
Number of standard trees	2.940	2.520	2.330	1.950	0.553	ns
Margin width	4.470	3.620	8.600	4.630	7.720	0.009
Number of hedgerow gaps	3.500	3.290	1.130	1.640	6.296	ns
Total length of hedgerow gaps	12.720	15.410	3.790	4.830	4.605	ns
Number of arable adjacent fields	14.000	N/A	11.000	N/A	0.962	ns
Number of pasture adjacent fields	2.000	N/A	4.000	N/A	0.962	ns
Number of woody plant species	5.104	2.170	4.670	1.590	3.412	ns
Number of herbaceous plant species	8.000	4.720	10.730	3.310	3.445	ns
Total vegetative species richness	13.940	5.090	15.400	4.320	0.738	ns

Moulton had a trend towards larger hedgerows in terms of height and cross-sectional dimensions, whereas Kelmarsh had shorter, but wider hedgerows. Moulton also had more standard trees on average along the hedgerow lengths. Kelmarsh however had a lower score for numbers of gaps and total length of gaps, and a higher mean vegetative species richness and margin width. When entered into one-way ANOVA, only margin width and hedgerow height were statistically significantly different between the two study sites. The standard deviation for linear boundary features was higher at Moulton for all factors except margin width.

CCA revealed that the 31 different hedgerows which were included in the initial study varied in terms of local-scale features, but that Moulton hedgerows were associated with gappiness and

Kelmarsh with wider margins and higher vegetative species richness (Figure 5.1; Table 5.1). There was more hedgerow heterogeneity amongst the trap points at Moulton than those at Kelmarsh (standard deviations Table 5.1, Figure 5.1). The CCA biplot shows that for the most part the locations from Kelmarsh (17-31) were bunched together and those for Moulton (1-16), more spread out. This is likely due to the comparative heterogeneity at Moulton and homogeneity at Kelmarsh.

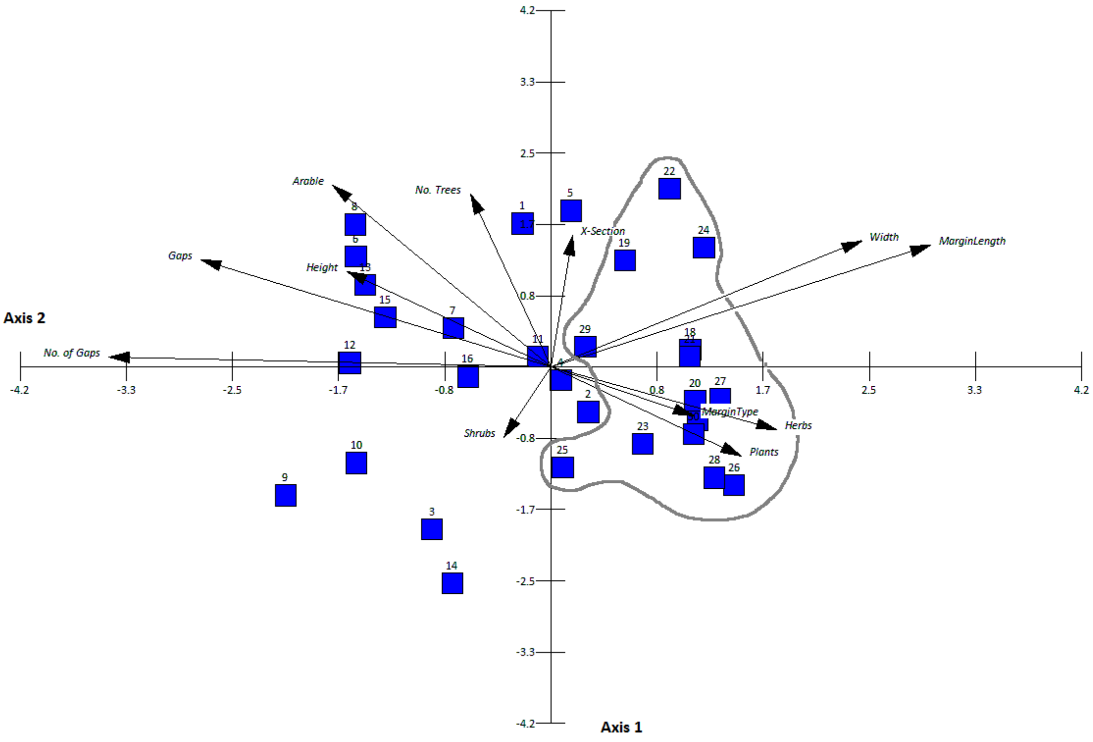

Figure 5.1: CCA plot of 2011/12 hedgerow trap points using hedgerow features as variables, produced in MVSP (Moulton: 1-16, Kelmarsh: 17-31; See Figures 2.3 and 2.5 for trap locations).

5.3.2 Moth Trapping Summary

Over the three summers a total of 6,595 moths were trapped (3196 at Moulton and 3399 at Kelmarsh: See Table 5.2). A total of 121 macro-moth species were identified (Table 5.3, see Appendices for species lists). Only 24 individual moths could not be identified successfully in 2011 and 2012 due to age and wing damage. No moths were unsuccessfully identified in 2013.

Table 5.2: Yearly moth totals and site breakdown for trapping over the three years results from chi-squared test significance (p).

	Total	Moulton	Kelmarsh	p
2011	2570	1453	1117	0.056
2012	1437	583	854	0.019
2013	2588	1160	1428	0.066
Total	6595	3196	3399	0.020

Table 5.3: Yearly species totals and site breakdown for trapping over the three years, with results from chi-squared test significance (p)

	Total	Moulton	Kelmarsh	p
2011	80	68	57	0.056
2012	85	63	70	0.033
2013	83	64	71	0.033
Overall total	121	95	97	0.007

5.3.3 Combined 2011 and 2012 Moth Trapping Data

5.3.3.1 Trapping Summary Statistics and Initial Explorations

Over the course of the summers of 2011 and 2012 a total of 4007 moths were trapped at the two sites composed of a total of 109 moth species. The total moths trapped at each of the two sites were very close, though the yearly totals varied (See Table 5.2). The trapped moths were from a total of nine families and 21 genera. In terms of species richness, the two sites also varied, with Kelmarsh revealing 23% fewer species of the two sites in 2011, but 32% more in 2012 (Table 5.2). The trap points across the site varied in terms of the average number of moths and species, their diversity indices and their taxonomic distinctiveness (Table 5.4). Of the 109 moth species trapped in 2011 and 2012, six species were highly significant in terms of the differences in abundance at the two study sites (Table 5.5). No significant differences were found when moth data was compared between differently managed hedgerows or between the two sites (p>0.05).

Table 5.4: Trap point summary statistics (Average moths and species trapped with mean and standard deviation [SD], Shannon’s and Simpson’s diversity indices for 2011 and 2012 [Shannon’s and Simpson’s] and taxonomic distinctiveness [Td]).

Trap	**No. of moths trapped**			**No. species trapped**			**Diversity indices**		**Td**
point	**Total**	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Shannon’s**	**Simpsons**	
Moulton site (trap points 1-16)									
1	158	13.167	16.602	76	6.333	3.927	2.986	0.931	1.584
2	121	15.125	18.263	29	3.625	4.121	2.690	0.872	2.326
3	180	22.500	23.040	44	5.500	5.372	3.173	0.936	2.097
4	95	13.571	20.149	24	3.429	4.389	2.402	0.829	2.308
5	70	11.667	15.336	14	2.333	2.490	2.178	0.853	4.281
6	84	9.333	13.729	26	2.889	3.403	2.968	0.949	1.051
7	178	17.800	21.984	38	3.800	4.946	3.046	0.932	2.245
8	89	12.714	21.538	19	2.714	2.747	2.598	0.920	2.82
9	65	9.286	14.807	24	3.429	4.525	2.883	0.941	1.012
10	92	15.333	23.305	21	3.500	4.506	2.613	0.912	3.017
11	146	16.222	21.719	37	4.111	5.259	2.998	0.919	1.805
12	183	16.636	24.290	35	3.182	5.710	3.096	0.946	2.233
13	198	16.500	20.096	38	3.167	4.414	2.945	0.911	2.131
14	91	10.111	10.886	27	3.000	4.093	2.669	0.887	1.115
15	193	24.125	36.370	23	2.875	6.040	2.595	0.907	8.904
16	162	18.000	21.249	35	3.889	4.508	3.038	0.932	2.484
Kelmarsh site (trap points 17-31)									
17	126	12.600	17.437	27	2.700	4.067	2.340	0.811	2.175
18	145	24.167	34.719	20	3.333	4.457	1.876	0.718	8.063
19	185	23.125	29.833	30	3.750	4.826	2.687	0.895	4.714
20	110	11.000	12.988	29	2.900	3.962	2.425	0.799	1.468
21	186	18.600	20.702	39	3.900	4.175	2.727	0.856	2.291
22	112	14.000	15.993	26	3.250	3.012	2.764	0.914	2.415
23	92	10.222	13.692	21	2.333	3.553	2.273	0.822	2.182
24	198	24.750	29.767	33	4.125	4.211	2.449	0.830	4.646
25	130	13.000	20.366	33	1.300	5.786	2.865	0.916	1.362
26	121	12.100	13.650	31	3.100	4.012	2.950	0.925	1.588
27	81	20.250	31.236	18	4.500	3.000	1.763	0.654	4.529
28	133	33.250	40.154	16	4.000	2.944	1.347	0.588	13.885
29	196	19.600	24.144	37	3.700	5.982	2.901	0.893	2.872
30	184	23.000	25.871	37	4.625	5.156	2.778	0.871	3.129
31	38	9.500	9.260	13	3.250	4.856	2.279	0.898	1.994

Table 5.5: Individual moth species with very highly significant different abundance between the two study sites (combined 2011 and 2012 data). Results of one-way ANOVA (variance [F value], significance [p], standard deviation [SD] and standard error [SE]).

Common name	**Scientific name**	**F value**	**p**	**Moulton**		**Kelmarsh**	
				Mean	**SD**	**Mean**	**SD**
Common Swift	*Hepialus lupulinus*	11.910	0.002	4.317	1.608	6.533	1.560
Hebrew Character	*Orthosia gothica*	18.031	<0.001	1.070	0.716	0.160	0.432
Magpie	*Abraxas grossulariata*	12.422	0.001	0.063	0.250	0.790	0.785
Setaceous Hebrew Character	*Xestia c-nigrum*	11.797	0.002	1.615	1.218	0.352	0.763
Silver Y	*Autographa gamma*	18.837	<0.001	0.977	0.670	0.133	0.352
Turnip Moth	*Agrotis segetum*	37.555	<0.001	1.628	0.860	0.133	0.352

5.3.4 2013 Moth Trapping Data

5.3.4.1 Trapping Summary Statistics and Initial Exploration

A total of 2588 moths were trapped over the 2013 nine day trapping period from a total of 83 species. The moths trapped were from eight families and 20 genera. A total of 1160 moths were trapped at Moulton and 1428 at Kelmarsh (18% difference). Trap point summary statistics revealed that the 16 trapping locations varied in terms of the number of moths and species trapped, their diversity indices and their taxonomic distinctiveness (Table 5.7). No significant differences were found for the moth summary data with regards hedgerow management or between sites.

Table 5.7: 2013 Trap point summary statistics (Number of moths and species trapped with mean and standard deviation [SD], diversity indices [Shannon's and Simpsons] and taxonomic distinctiveness [Td]).

Trap point	No. moths trapped			No. species trapped			Diversity Indices		Td
	Total	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Shannon's**	**Simpson's**	
Moulton site (trap points 1-8)									
1	144	16.000	16.348	38	9.000	7.778	3.147	0.946	12.430
2	108	12.000	13.551	28	7.700	5.626	2.854	0.925	13.239
3	156	17.333	12.845	32	9.000	4.416	2.939	0.928	19.977
4	168	18.667	12.135	33	10.333	5.123	2.922	0.929	22.912
5	94	10.444	5.434	27	6.667	3.082	2.795	0.921	10.530
6	113	12.556	8.791	28	7.778	3.734	2.941	0.940	15.382
7	156	17.333	6.856	35	9.333	2.739	2.935	0.921	17.820
8	221	24.556	8.487	41	13.222	3.073	3.182	0.947	26.282
Kelmarsh site (trap points 9-16)									
9	200	22.222	11.432	44	12.222	5.191	3.157	0.942	19.405
10	85	9.333	6.633	28	6.222	3.667	2.862	0.923	8.328
11	186	20.667	12.359	35	9.778	6.220	2.742	0.881	24.227
12	92	10.222	9.230	31	7.000	5.196	3.057	0.945	8.636
13	196	21.778	16.672	39	10.778	6.553	3.106	0.938	22.011
14	288	32.000	17.073	38	14.667	4.770	3.013	0.933	50.914
15	227	25.222	29.325	39	8.667	8.322	2.913	0.914	31.164
16	154	17.111	5.465	29	8.444	2.068	2.831	0.922	30.202

A total of 64 different macro-moth species were trapped at Moulton and 71 at Kelmarsh. A total of 11 of the 83 species were significantly different in abundance at the two study sites (See Table 5.8).

Table 5.8: Species with significantly different abundance across the two study sites in 2013. Results of one-way ANOVA (variance [F value] and significance [p], mean and standard deviation [SD]).

Common Name	**Scientific Name**	**F Value**	**p**	**Moulton**		**Kelmarsh**	
				Mean	**SD**	**Mean**	**SD**
Barred Straw	*Eulithis pyraliata*	17.57	<0.001	8.500	1.320	1.875	0.691
Blood Vein	*Timandra comae*	26.355	<0.001	0.500	0.231	6.375	1.054
Brown-Line Bright Eye	*Rusina ferruginea*	10.143	0.002	0.000	0.000	1.125	1.138
Buff Arches	*Habrosyne pyritoides*	6.927	0.009	0.000	0.000	1.000	0.358
Common Swift	*Hepialus lupulinus*	11.887	0.001	1.375	0.399	9.250	2.116
Common Wainscot	*Mythimna pallens*	10.327	0.002	2.000	0.587	0.000	0.000
Double Dart	*Graphiphora augur*	38.508	<0.001	0.000	0.000	12.000	1.823
Green Carpet	*Colostygia pectinataria*	7.025	0.009	1.500	0.475	0.125	0.118
Smoky Wainscot	*Mythimna impura*	12.91	<0.001	5.875	1.115	21.000	3.809
The Snout	*Hypena proboscidalis*	14.546	<0.001	10.000	1.700	2.625	0.659
White Ermine	*Spilosoma lubricipeda*	7.741	0.006	1.000	0.358	3.375	0.721

5.4 Discussion

5.4.1 Hedgerow Management and Diversity

The hedgerow survey data revealed significant differences between the hedgerows across the two study sites (Table 5.1) The Moulton site had higher mean values for all dimensional variables compared with Kelmarsh. The Moulton hedgerows also had a slightly higher mean number of hedgerow standard trees, but also a much higher mean value for the lengths of gaps per hedgerow. All of these features are likely to be a result of the differing management practices being implemented across the two sites. At the Moulton site, hedgerows are flailed on an annual basis, but for the most part have not been laid or planted up in many years. Many hedgerows across the site were also tending towards dereliction or damage due to over or under management (See Plates 5.1-5.4). The influence of hedgerow management on bird, small mammal and invertebrate populations has been discussed, with authors stressing the importance of protecting hedgerow resources and mitigation against dereliction (Bates and Harris, 2004; Croxton and Sparks, 2002; Hinsley and Bellamy, 2000; Maudsley, 2000). DEFRA commissioned a report in 2009, which noted the importance of staggered management and reduced flailing for hedgerow health and fruit cropping, as well as increased planting to protect hedgerow tree loss across the UK (Barr *et al.,* 2009). This information has since been incorporated into the most recent ELS and HLS prescriptions, with notes on cutting to take place in the winter every other year (Natural England, 2013a; Natural England, 2013b). In comparison to the gappy hedgerows of Moulton, the Kelmarsh site was using regular hedge-laying in line with the advice from Natural England under HLS (Natural England, 2013b). As a result, it appears that this management has left the hedgerows of Kelmarsh much more compact and less gappy.

The Moulton site had more woody diversity in its hedgerows, however Kelmarsh had higher herbaceous floral diversity. Neither of these was statistically significant, however there was a trend towards higher floral diversity at the Kelmarsh site than Moulton. The woody diversity of Moulton is most likely due to differing planting of the initial hedgerows, as many appeared to have been planted up with non-native ornamental species, however the lower vegetative diversity may also have been due to neglect in some cases. It was unsurprising that the herbaceous diversity was lower at Moulton, as the site had much smaller margins and less hedge-bottom flora due to the relative intensity of the management practices. Both these aspects should be considered when managing hedgerows and a focus on both margins and diverse woody plant may be beneficial for the overall vegetative diversity of linear boundary features. The implications of the local-scale hedgerow features for macro-moth abundance are considered under Chapter Six.

5.4.2 Moth Trapping Summary Data

Over the course of the two summers of moth trapping, a total of 6,595 moths from 121 species were trapped. Of these species, 97% were common and widespread moths. Due to the differences in the trapping periods of the 2011/12 and 2013, these two data sets could not directly be compared, however the results are discussed separately below.

5.4.3 2011 and 2012 Moth Trapping Data

5.4.3.1 Summary Data

A total of 109 moth species were trapped over the summer trapping periods of 2011 and 2012. All but one of the moth species trapped were considered to be 'common and widespread' in terms of their national status. Only the Rustic (*Hoplodrina blanda*) is considered to be a research priority species. No specific BAP species were trapped. The numbers of over 90% of the moth species trapped are relatively stable, but less than 10% have been declining over the last 40 years (Fox *et al*., 2013). In contrast, six species have shown significant increases over this period, particularly for the Dingy Footman (*Eilema griseola*), which has increased by 1851% since records began in the UK (Fox *et al*., 2013).

Of the 109 species trapped over the two summers, 88 (79%) were from species with either a generalised or open habitat preference. Of the 4142 individuals trapped, 4036 (97%) were of this type of species, leaving only a relatively small number from woodland or other specialist habitat species. This data suggests that the two intensive areas of farmland used in this study are supporting mainly generalist species, rather than those which rely on specific semi-natural habitat areas, but that at least some of these generalist species still rely on woodland habitats. These findings also mirror the summary results from the county-scale analysis which revealed that the majority of moth species trapped were generalists, but had associations with woodland cover (See Chapter Four). It is clear that the intensive farmland of Northamptonshire provides a habitat for a range of generalist, common and widespread moth species; however habitat creation and ecological networking could help to improve conditions for specialist and threatened species. Woodland cover particularly should be extended and connected where possible to increase moth abundance and diversity.

One way ANOVA results showed that six of the 109 species trapped had a significantly different abundance at both of the study sites. As none of these species were specialist habitat species, the variation in abundance could be explained by local abundance of food plants at one of the sites or a mass emergence. The Common Swift, Hebrew Character, Setaceous Hebrew Character and the Silver Y (migrant species) are all known to be very variable in their abundance across Northamptonshire, so for these four species the results of the ANOVA may simply have been due to fluctuations in emergence (Blincow and Ward, 2002). The variation of the Magpie and Turnip moth are discussed further under section 5.4.1.3.

5.4.4 2013 Moth Trapping Data

5.4.4.1 Summary Data

None of the moth species trapped in 2013 (or indeed 2011 and 2012) are currently considered to be uncommon or rare species. These results pose questions as to the value of farmland for rarer species of moth. It is known that areas such as woodland and heathland support a high diversity of moths and should be conserved and connected where possible (Fox *et al*., 2013; Fuentes-Montemayor, 2012; Waring *et al.*, 2009). Despite their national status, 12 of the species trapped in 2013 have been declining over the last 40 years, although seven are known to be increasing in numbers. The Scarce Footman (*Eilema complana*), has increased its abundance by a surprising 3590% and the other six have increased by at least 100% (Fox *et al*., 2013). This represents a mixed picture of abundance for these ‘common and widespread’ moths, and highlights the importance of research into the ecology of those species in decline.

Of the 83 moth species trapped over the course of the 2013 study, 91% of these were either generalist species, or species with a preference for open habitats such as grassland (Waring *et al.,* 2008). Of the 2588 individuals, these open habitat species made up 98% (2543) of the trapping yield. This statistic alone suggests that intensive farmland areas may be suitable habitat for generalist or open habitat species due to the availability of arable weeds and grassland, but probably not for specialist woodland or scrub species, and likely explains why many of these species are currently considered threatened in the UK (Bates *et al.,* 2014; Fox *et al.,* 2014).

5.5 Summary

The two farm sites used for the moth trapping study were under differing management (one ELS and one HLS). Although the majority of hedgerow features sampled were not significantly different, the HLS Kelmarsh site did have significantly wider margins, but shorter hedgerows. The other factors were not statistically different, however there was a trend towards higher vegetative diversity and fewer gaps at the HLS Kelmarsh site.

Over the course of the trapping, the majority of moths trapped were generalist and open habitat species. Only one research-priority BAP species was trapped and no BAP species. This likely reflects the low semi-natural habitat coverage surrounding the trap sites. Results of ANOVA showed that some species varied in terms of their abundance across the two sites, however this variation was most likely due to localised emergences or food plant availability.

Plate 5.1: Defunct, gappy hedgerow at Moulton site (Trap point 7 [2011/12]).

Plate 5.2: Hedgerow with 1m enriched and weedy margin (Trap point 1 [2011/12])

Plate 5.3: Hedgerow at Moulton site with a high number of hedgerow trees (Trap point 14 [2011/12].

Plate 5.4: Hedgerow at Moulton site with a 10m gap and enriched margins (Trap point 13 [2011/12].

Plate 5.5: Hedgerow at Kelmarsh with a 6m grass margin (Trap point 21 [2011/12]).

Although few photographs were taken of the Kelmarsh site, the majority of hegerows were much thicker, less gappy and showed less indicators of enrichement, possibly due to the larger margins (Table 5.1).

Chapter Six: Local-Scale Factors Influencing the Diversity and Abundance of Macro-Moths in Intensive Farmland Landscapes

6.1 Introduction

As stated in Chapter One, research has indicated that the specific influences on hedgerow flora and fauna diversity are management level, eutrophication and connectivity or proximity to other habitats (Aude *et al.,* 2003; Le Coeur *et al.,* 2002; McCollin *et al.,* 2000a; Staley *et al.,* 2013). A long-term study published by Staley *et al.* in 2013 revealed that changes in management and agricultural practice were resulting in homogenisation of hedgerows at a landscape-scale. The findings indicated that reinstatement of traditional hedge management practices such as hedge-laying or coppicing, along with a considered and diverse approach would help to mitigate against this.

A review of hedgerow features and invertebrate diversity showed that different aspects of hedgerows were important for different species and suggested that hedge-bottom vegetation was also a key feature (Maudsley, 2000). Additionally, field margins associated with hedgerows can reduce spray drift to other areas and provide essential resources for wildlife in what can otherwise be a homogenous and resource-poor landscape (De Snoo and Wit, 1998; Game and Wildlife Conservation Trust, 2014; Kleijn and van der Voort., 1997; Longley *et al.,* 2009; Meek *et al.,* 2002).

This chapter focuses on the influence of local-scale hedgerow and margin features on macro-moth diversity and abundance. Factors explored in this study are: hedgerow width, height and overall cross-sectional area, vegetative diversity (numbers of standard hedgerow trees, herbaceous, woody and total plant species), hedgerow gaps, adjacent field margin width, recent management and adjacent field usage (arable or pasture). The diversity and abundance of macro-moths is compared at the two study sites and taxonomic groups and individual species trends are explored in the analysis to determine the overall importance of aspects of linear boundary feature management.

6.2 Methods

All methods and study site details for this study can be found in Chapter Two. Refer specifically to sections 2.3.1 for details of timing, 2.3.2 for hedgerow and vegetation surveys, 2.3.3 for moth trapping methods and 2.4.1 for information on the statistical analysis and specific packages used throughout.

Table 6.1: Local landscape variables being investigated throughout this chapter.

	Independent hedgerow variable
1	Hedgerow height
2	Hedgerow width
3	Cross-sectional area
4	Number of standard trees
5	Margin width
6	Number of gaps
7	Total length of gaps
8	Number of shrub species
9	Number of herbaceous species
10	Total vegetative diversity
11	Total hedgerow length
12	Number of nodes
13	Number of connections to woodland

6.3 Results

6.3.1 2011 and 2012 Data

Analysis of the abundance, species richness and taxonomic distinctiveness scores for each of the trap locations showed no significant relationships with any of the local-scale environmental variables included (See 2.2.2 for hedgerow and margin variables). Although moths were also grouped based on their habitat and feeding preferences, no significant relationships were found between these groups and any of the local-scale variables. Any site differences in moth numbers or site trapping statistics were included in Chapter Five due to the relationships with landscape-scale variables.

6.3.1.1 Local-Scale Influences on Families

Taxonomic distinctiveness indices for 2011 and 2012 varied between trap points, however no significant difference was found between the two sites. When abundance data was broken down into macro-moth families, regression analysis revealed that only one of the trapped moth families had a significant relationship with features of the hedgerow and woodland network. Linear regression was carried out to predict the numbers of Hepalidae trapped from total hedgerow length. Hedgerow length significantly predicted numbers of Hepalidae moths (β=0.526, R^2=0.277, p=0.002, Standard error=0.002).

6.3.1.2 Local-scale Influences on Sub-Families

No sub-families were found to have significant relationships with local hedgerow factors in this data set.

6.3.1.3 Local-Scale Influences on Moth Species

Of the 109 moth species trapped in 2011 and 2012, four of the species had a highly significant relationship with one or more local-scale variable (Table 6.2). The only local-scale features of hedgerows which appeared to be impacting on species abundance were those relating to hedgerow gaps. For each of the species highlighted, multiple regression was carried out (Table 6.2). In instances of multi-collinearity (i.e. for total length of hedgerow gaps and hedgerow gaps, or vegetative and herbaceous diversity), two separate linear regression models were produced and the more significant of the two was included.

Table 6.2: Individual moth species which had highly significant relationships with local-scale variables in 2011/12 (regression co-efficient [*R*], R^2 significance [p] and standard error [S.E.]).

Common Name	**Scientific Name**	**Local-Scale Variable(s)**	***R***	**R^2**	**p**	**S.E.**
Common Wainscot	*Mythimna pallens*	Number of hedgerow gaps	0.456	0.208	0.010	0.528
Flame	*Axylia putris*	Total vegetative diversity	0.538	0.289	0.002	0.015
Middle-Barred Minor	*Oligia fasciuncula*	Total length of hedgerow gaps	0.563	0.317	0.001	0.039
Silver Y	*Autographa gamma*	Number of hedgerow gaps	0.516	0.266	0.003	0.064

6.3.2. 2013 Trapping

A total of 2587 moths were trapped over the 9 day trapping period from a total of 83 species. A total of 1160 moths were trapped at Moulton and 1427 at Kelmarsh. A total of 64 different macro-moth species were trapped at Moulton and 71 at Kelmarsh.

6.3.2.1 Local-Scale Influences and Families

The taxonomic distinctiveness indices varied for each of the trap points in 2013, however no significant relationships were found with any of the landscape variables included in the analysis. No significant difference was found between the two study sites either. No relationships were found for any of the moth families trapped in 2013 and local scale factors.

6.3.2.2 Local-scale Influences on Sub-Families

Of the 20 moth sub-families trapped in 2013, only the Noctuinae were revealed as having highly significant relationships with hedgerow factors. Both hedgerow length and the number of hedgerow nodes were revealed as having a possible relationship with the numbers of Noctuinae trapped. Multiple regression was carried out to predict the numbers of this family from both of the independent variables. The model was highly significant ($p=<0.001$) and revealed that hedgerow nodes did not predict Noctuinae numbers, but that total hedgerow length did ($\beta=0.836$, $R^2=0.699$, $p=0.018$, Standard error=0.012)

6.3.2.3 Local-scale Influences on Moth Species

Of the 83 moth species trapped in 2013, only four species had a significant relationship with any of the local-scale landscape variables investigated (Table 6.3 and 6.4).

Table 6.3: Significant predictors of the mean numbers of Clay moth (*Mythimna ferrago*) derived from a multiple regression model. The *F*-value and the associated *p*-value, degrees of freedom, R^2, and adjusted R^2 are shown (*$p= < 0.05$, ** $p= < 0.01$, *** $p= < 0.001$). For each variable retained in the model, the *p*-value derived from *t*-tests, parameter estimates and standard errors are shown.

Model summary	**Variable**	**t**	***p***	**Standard error**
F= 19.674, P= ***, d.f.= 15	Hedgerow width	-2.024	0.066	0.218
R^2 = 0.831, R= 0.912, Adj.R^2= 0.789	Hedgerow cross-section	4.147	0.001	0.060
	Margin width	-2.286	0.010	0.023

Numbers of the Clay moth (*Mythimna ferrago*) trapped at each location was positively correlated with margin width, hedgerow height, width and cross-sectional area (height x width). The relationship was stronger than that for other relationships, so linear models were produced for these (Figures 6.1 and 6.2).

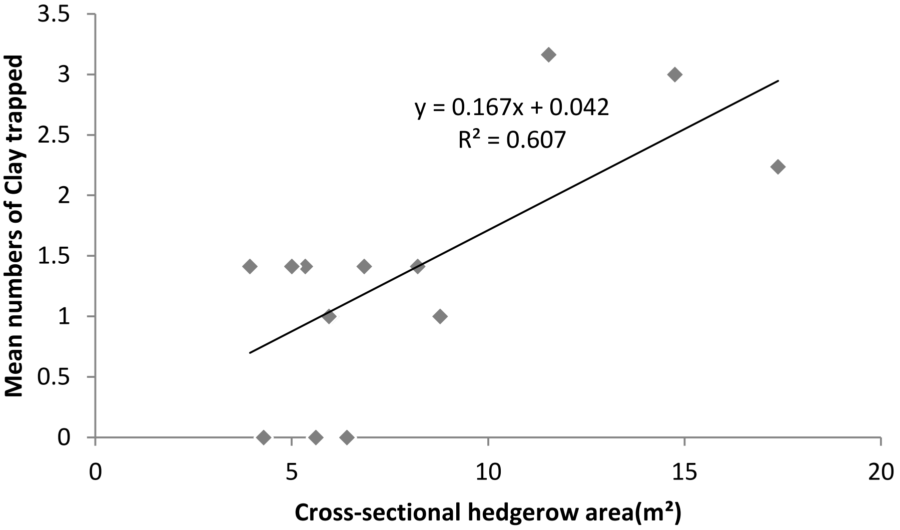

Figure 6.1: Linear models for the mean numbers of the Clay moth (*Mythimna ferrago*) based the cross-sectional area of the hedgerow (width by height in metres).

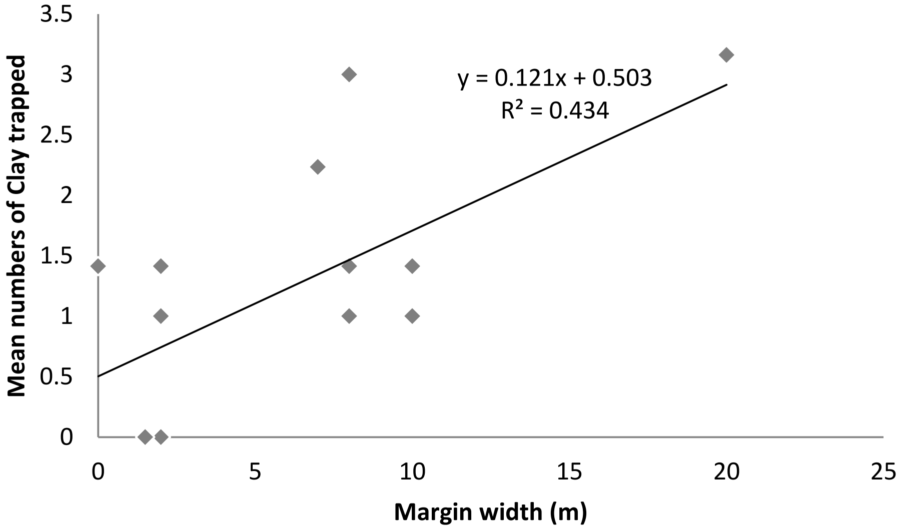

Figure 6.2: Linear models for the mean numbers of the Clay moth (*Mythimna ferrago*) based on the width of the adjacent margin.

Table 6.4: Results of singular linear regression analysis (regression co-efficient [*R*], R^2 and significance [*p*]).

Common Name	**Scientific Name**	**Local-Scale Variable(s)**	***R***	**R^2**	**P**
Double Dart	*Graphiphora augur*	Total hedgerow length	0.705	0.497	0.002
Green Carpet	Colostygia pectinataria	Number of hedgerow gaps	0.660	0.436	0.005
Mottled Beauty	Alcis repandata	Hedgerow width	0.660	0.436	0.005

6.4 Discussion

6.4.1 Local Scale Factors and Moth Abundance

6.4.1.1 Macro-Moth Numbers and Hedgerow Dimensions

Of the variables shown to be influential for some moth species, two that became apparent more than once were hedgerow width and overall cross-sectional dimensions (Table 6.2). These factors were found to have a positive association with one species in 2011/12 (White Ermine) and two in 2013 (the Clay and Mottled Beauty). All three of these species were associated with hedgerow width and the Clay was also found to be associated with the overall cross-sectional dimensions of the hedgerow. The Clay is a generalist open-habitat species known to feed on herbaceous plants, so the relationships with hedgerows and margins may be due to a combination of vegetative resources and shelter effects. The Mottled Beauty in comparison is associated with shrubby or wooded habitats and has woody larval food plants, so an association with hedgerow factors is unsurprising in farmland (Kimber, 2014; Waring *et al.,* 2009). Mottled Beauty was also seen feeding on Bramble plants during the floral visitation study (Chapter Eight). Management to increase the dimensions of hedgerows could help improve both nectar and larval food resources, provided these factors do not encroach on margin width.

6.4.1.2 Macro-Moth Numbers and Hedgerow Gaps

In 2011/12 the number or length of hedgerow gaps was positively associated with three of the species trapped (Common Wainscot, Middle-Barred Minor and Silver Y [Table 6.2]). All these species were positively associated with the total length of gaps throughout the adjacent hedgerow and all but one were positively associated with the number of gaps. In 2013 only the Green Carpet was positively associated with both total and number of hedgerow gaps. All these species are larval feeders of low growing herbaceous plants such as bedstraws, nettles or grasses. Gaps in the hedgerows across Moulton were generally dominated by low-growing ruderal vegetation such as Common Nettle (*Urtica dioica*) or Cleavers (*Galium aparine*). Such gaps may provide ideal egg-laying sites for species feeding on herbaceous plants or grasses, however, hedgerow gaps are not encouraged within current AES. Gapping up of hedgerows as a blanket prescription could be detrimental to some moth species, as well as reducing the farm-scale, and possibly landscape-scale hedgerow heterogeneity. The importance of heterogeneity for biodiversity should not be overlooked, especially when dealing with invertebrates, which are diverse in their habitat preferences (Maudsley, 2000). A more varied and rotational approach to hedgerow management should be encouraged, particularly where a range of management options such as coppicing are included.

6.4.1.3 Macro-Moth Numbers and Hedgerow Length

The only moth found to have a relationship with hedgerow length was the Double Dart. The Double Dart is listed as in serious decline, with numbers reducing by 98% over the last 40 years, and catches reducing specifically in Northamptonshire (Blincow, 2002; Fox *et al*., 2013). The Double Dart is a woodland species described as having a localised distribution over Northamptonshire. The species’ larval food-plants are deciduous woody plants including hawthorn (*Crataegus monogyna*) and blackthorn (*Prunus spinosa)* (Blincow, 2002; Kimber, 2014). The Double Dart is uncommon in Northamptonshire, however 96 individuals were trapped in the 9 day period at Kelmarsh (Blincow and Ward, 2002). The abundance of this moth is known to fluctuate significantly, which may explain the site variation (Blincow and Ward, 2002). Double Dart abundance had a highly significant relationship with the total length of adjacent hedgerows. The hedgerows of both sites were mainly composed of hawthorn and blackthorn, providing ideal egg-laying sites for this and other similar species with preferences for shrubby food plants. Due to this species' declining numbers and its localised distribution, any information regarding the habitat preferences for this species could prove valuable for its conservation.

In addition to the local-scale variables recorded in this study, it is possible that the abundance of vegetative species may be influencing moth abundance and diversity at a local scale. Surveys of vegetation cover in hedgerows and margins would have been very time consuming for two large areas of farmland, however it is an aspect which should not be overlooked in future research. Another key issue with regards the findings of Chapters Four, Five and Six, is the influence of the high proportions of generalist moth species trapped. Without more data on the distribution and abundance of specialist species, it is difficult to make assumptions about these niche species.

6.4.2 Local-Scale Influences and Moth Families and Sub-Families

Macro-moths are very diverse, so grouping them into ecologically meaningful units was not simple. Moths trapped were grouped into feeding guilds, however no significant relationships were apparent from the basic statistical analysis, so moths were grouped into families, then sub-families for regression analysis (Kimber, 2014; Waring *et al.,* 2009). Of the nine families of moth trapped in 2011 and 2012, two were only trapped in very small numbers and were therefore excluded from any statistical analysis (less than ten individuals). The other seven were included and one of them was revealed as having a significant relationship with one of the hedgerow variables.

The numbers of the Hepialidae were positively associated with the total hedgerow length adjacent to trapping sites. This family contained only two trapped species, the Common Swift and the Ghost Swift. These moths are some of the most taxonomically distinct species in the UK, due to their more primitive taxonomy (Waring *et al.,* 2009). Both these species are reportedly found in grassy habitats such as grassland or field margins, so may be associated with long stretches of margin across farmland areas (Waring *et al.,* 2009). These species are thought to have reasonable dispersal abilities, and could be using hedgerows and margins as corridors across agricultural landscapes (Waring *et al.,* 2009).

When the taxonomic distinctiveness and diversity indices were analysed for the 2013 data, no significant relationships were found between these scores and any of the landscape scale variables. It may be that the overall heterogeneity of the landscape may have a bigger impact on the moth diversity, as well as other factors such as urbanisation and proximity to coastal areas (Bates *et al.,* 2014).

In the 2013 data set, the numbers of Noctuinae family moths were positively associated with the total length of adjacent hedgerow and the number of hedgerow nodes. The Noctuinae is a large and diverse sub-family of the Noctuidae (Waring *et al.,* 2008; Kimber, 2014). The sub-family contains the Double Dart, the Large Yellow Underwing (a migratory species) and the Gothic among others (See Appendix 1, 2 and 3 for full species lists). The Noctuinae species are large-bodied moths, often with high dispersal capabilities (Fuentes-Montemayor *et al.,* 2012). These large migratory species are known to fly at high altitudes (200-500m), however there is currently very little understanding of what sensory cues these organisms use to determine flight directions (Wood *et al.,* 2009). It is possible that at low altitudes, landscape features may play a role in their dispersal.

6.5 Summary

Overall moth abundance data was not found to be significantly influenced by local-scale features of hedgerows and margins; features included in the analysis were hedgerow dimensions, margin width and type, hedgerow gaps and vegetative diversity. A small number of the species trapped during the study had a highly significant relationship with one or more local-scale variable. Features shown to be influencing these species were presence of hedgerow gaps, vegetative diversity, and both margin and hedgerow width. Although local-scale factors were found to be less influential on species and taxa abundance, the importance of local habitat management on landscape connectivity and heterogeneity should not be overlooked. The management of linear boundary features to improve hedgerow vegetative and structural diversity, as well as their functional connectivity, are encouraged. Although not investigated in this study, it is possible that food plant availability is a key factor in determining moth abundance, so perhaps should be included in management focus. It is possible that the generalised habits of the majority of species trapped are, at least in part, explaining the lack of associations with localised habitat features.

Chapter Seven: The Use of Linear Boundary Features as Flight Paths by Macro-Moths in Intensive Farmland Landscapes

7.1 Introduction

Hedgerows are known to be important habitats for butterflies in UK landscapes and as many as 39 of the UK's 61 (resident or regular migrant visitors) butterfly species are thought to rely on hedgerow habitats to some extent and many even breed in these habitats (Lewington, 2003; Dover and Sparks, 2000). The 2000 review by Dover and Sparks found that hedgerows were just as good as grass banks for butterfly biodiversity and in fact suggested that these areas were more beneficial due to their sheltering effects, something seconded by further research into farmland moth diversity (Merckx *et al.,* 2010). It is possible that at least some of the thousands of UK resident moth species utilise hedgerows to a similar extent as butterflies, however this is much less researched (Waring *et al.* 2009; Manley, 2008; Butterfly Conservation, 2007; Fox *et al.* 2011b; Fox *et al*., 2013; Kimber, 2014).

The abundance of flying insects in farmland is known to be positively associated with sheltered linear features such as hedgerows and windbreaks, as such features reduce the influence of wind speed on such organisms, or result in an accumulation of insects blown towards them (Bowden and Dean, 1977; Lewis, 1969; Lewis, 1970; Lewis and Dibley, 1970; Pasek, 1988). Research comparing the abundance of airborne insects along artificial windbreaks showed that higher numbers of individuals accumulated against features of lower permeability (Lewis and Dibley, 1970). Similar research on low hedgerows and airborne insects revealed that this accumulation also occurs along hedgerows under windy conditions (Lewis, 1969). Where tree windbreaks are concerned, it was found that wind speed was one factor in the abundance of insects recorded, however the vegetative composition appeared to influence the results too (Lewis, 1970). A later study by Bowden and Dean (1988), found that over a long term study, insect abundance along hedgerows was associated with vegetative species richness rather than wind speed or direction. For shrubby linear features, it is likely that the association with flying invertebrates is due to a combination of factors, but it is clear that such features could provide both shelter and vegetative resource benefits to invertebrates.

A study of sheltered green lanes by Dover *et al.* (2000) found that significantly more butterfly species were recorded within green lanes than outside, and that the species composition was different. The study highlighted the importance of hedgerows for the movement of butterflies. A later study by Dover and Fry (2001) aimed to simulate the effect of hedgerow resource visibility versus physical barriers on three free-flying butterfly species' movements. The authors used sheeting and red and white tape to simulate physical hedgerow structure (sheeting) or visual stimulus of the hedge flowers (tape). The research found that the three species reacted differently to the purely visual stimulus, with the High Brown Fritillary (*Fabriciana adippe)* / Niobe Fritillary (*F. niobe)*complex following the tape, the Heath Fritillary (*Mellicta athalia*) unaffected, but Scarce Copper (*Heodes virgaureae)* responded to the tape stimulus as a barrier. The physical sheeting 'hedgerow' however acted as a partial barrier and as a corridor to all three species, with most individuals flying along the simulated hedgerow. These results suggest that species respond differently according to behavioural ecology, but that the physical structure of a hedgerow can be a barrier to the movements of some butterfly species, as well as a corridor (Dover and Fry, 2001). It is probable that macro-moth species have similar variation in their responses to linear landscape features such as hedgerows and field margins.

A study was carried out to determine the use of linear boundary features as areas for dispersal by macro-moths in intensive farmland. The movements of macro-moths were recorded along lengths of farmland hedgerows and the findings are detailed throughout this chapter.

7.2 Methods

See Chapter Two section 2.3.5 for details of the survey methods used in this study.

7.3 Results

A total of 332 moths were observed in total throughout the study, with moth abundance varying depending on weather conditions. The majority of moths observed were seen at the 1 m observation point; with 68% (225) of all moths seen at this distance, 22% (73) at 5 m and 10% (34) at 10 m (Table 7.1).

Table 7.1: Moth movements at 1m, 5m and 10m observation points. Results from a total of 13 observation occasions across the study site from both the summers of 2010, 2011, 2012 and 2013.

	Parallel	Diagonal	Right-Angle	Irregular	Total
1m	156	19	13	37	225
%	69%	8%	6%	16%	68%
5m	30	11	18	14	73
%	41%	15%	25%	19%	22%
10m	9	10	11	4	34
%	26%	29%	32%	12%	10%

Of the moths seen at 1m, the majority of moths were observed as moving parallel to the hedgerow face (Table 7.1, Figure 7.1). The results of a Kruskal-Wallis testing showed significant differences between moth movements with respect to direction at 1m from the hedgerow (*H* [3] =17.747, p=0.001). This test also revealed that the numbers of moths at 1, 5 and 10m were significantly different as well (*H* [3] =34.541, p=<0.001).

Pairwise comparisons with adjusted p values showed a significant difference between the numbers of moths moving parallel and diagonal (p=0.009), as well as between parallel and right angle (p=0.001), but not between parallel and irregular (p=0.068).

For moths observed at 5m, 30 of the 73 moths were seen moving parallel to the hedgerow face (41%). The results for observations at 5m from the hedgerow were not significantly different (*H* (3) =1.964, p=0.580). At 10m, only 9 of the 34 moths observed were moving parallel to the hedgerow face (26%); the results for the 10m observations were not significant (*H* (3) =0.766, p=0.858).

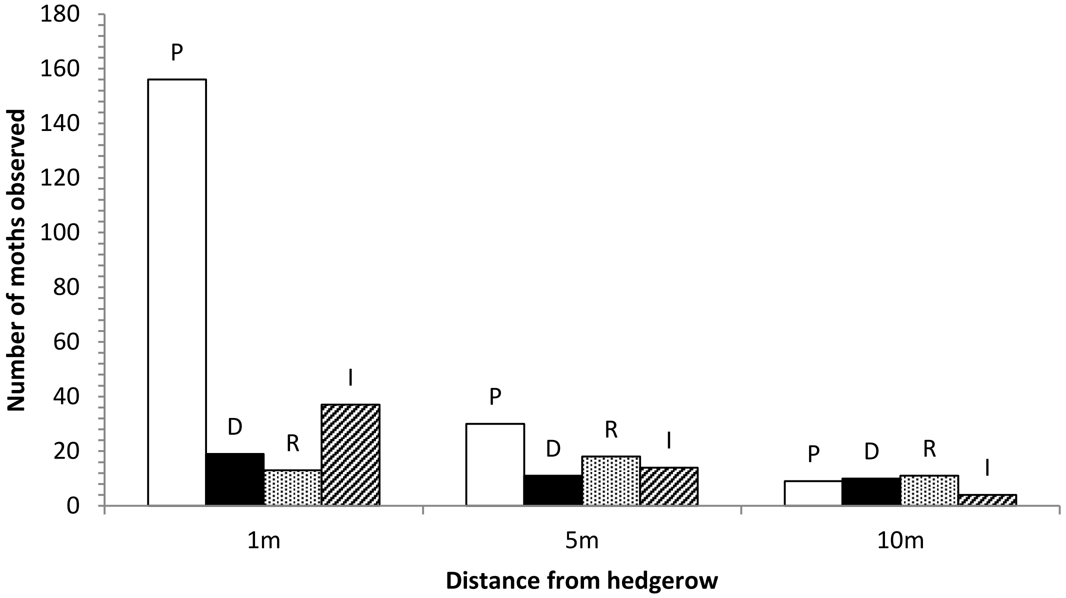

Figure 7.1: Numbers of moths moving at 1, 5 and 10 m from the hedgerow. P: Parallel, D: Diagonal, R: Right-Angle and I: Irregular in relation to the hedgerow face.

7.4 Discussion

7.4.1 Moth abundance and hedgerow proximity

This study only focused on the movements of moths along hedgerows and not within other habitat areas, whereas previous studies have highlighted the importance of woodland areas and grassland for moths (Merckx *et al.,* 2012). The term ‘boundary feature’ has been used within this study to encompass both the hedgerow and the adjacent hedge-bottom and field margin area. The focus of the study was to assess the possible use of linear boundary features as flight paths or ‘wildlife corridors’. For this reason, only moth movements within a 10 metre distance of the hedgerow were investigated.

The majority of moths observed during the course of the study were seen at closer proximity to the hedgerow (68%). These results suggest that there may be more macro-moth activity along hedgerows than further out along margins and within crop fields. The numbers of moths observed were less at 5 and 10m combined than at 1m from the hedgerow (Table 7.1). These figures alone indicate that hedgerows may be key habitat features for macro-moths within agricultural landscapes. This result supports the findings from previous studies that hedgerows are important habitat features for invertebrates within agricultural landscapes and more specifically for butterflies and moths (Maudsley, 2000; Dover, 1990; Merckx *et al.,* 2010). Previous studies have found that butterflies may be using hedgerows as wildlife corridors and these results suggest that moths are also using hedges in a similar manner nocturnally (Dover, 1990). It is of course unclear whether moths are using the hedgerows as corridors for dispersal or simply responding to the physical barrier effect of the hedge and travelling along to find a gap, as with some butterfly species (Dover and Fry, 2001). It is likely that factors such as size, mobility and resource requirements of moth species will have an impact on the behavioural ecology of a species and therefore its response to linear landscape features. Such varied responses have been observed with moth species to hedgerow trees (Merckx *et al.,* 2010).

7.4.2 Moth movement and hedgerow proximity

The results at 1m from the hedgerow showed that most moths within this distance are moving parallel to the hedgerow (69%). The highly significant Kruskal-Wallis results at this observation point support the theory that moths may be using hedgerows as flight paths. Butterflies have been shown to use linear features as corridors around landscapes and it is very probable that many moth species will do the same. Because moths are nocturnal, it is unlikely that they are following the visual stimulus of a hedgerow shadow unless moonlight luminosity is high, but they are possibly responding to the physical structure as a corridor or barrier, or as shelter (Dover and Fry, 2001). Due to moth preferences for white flowers as nectar sources, it is possible that under strong moon luminance, flowers along hedgerows and margins could be acting as a visual stimulus to moths (Waring *et al.,* 2009). There are several influencing factors which make such areas attractive as habitats in their own right, such as nocturnal nectars sources and egg-laying sites (see section 7.4.3 Moth behaviour observations).

The results from the 5m observation points showed no significant difference between directional movements at this distance. Although the results were not significant, the highest percentage of moths were still moving parallel to the hedgerow, which suggests that even further out from the hedgerow, some moths may still be using linear boundary features as flight paths, however it is more infrequent at this distance.

The results for 10m were also not significant, which again supports the hypothesis that moths in closer proximity to hedgerows will be travelling parallel in relation to the hedge. At this distance the highest percentage (32%) was for right-angled movements. Movements of moths at this distance may be of moths travelling towards hedgerows or searching for food sources and egg-laying sites.

The use of hedgerows as flight paths for moths and their predators, such as bats, has implications for their management (Boughey *et al.,* 2011; Entwhistle *et al.*, 2001). In order to maintain the effectiveness of hedgerows as flight paths or ‘corridors’ they may require planting up where gaps have appeared, to avoid the loss of their functionality. Current management prescriptions under HLS suggest that hedgerow gaps should be filled where possible (Natural England, 2008). This finding of this study supports this management policy to some extent, but smaller gaps may provide valuable heterogeneity and allow for movements between populations.

7.4.3 Moth Behaviour Observations

Aside from the moth movement observations, some general notes were taken on moth behaviour along hedgerows. These ‘irregular’ moths were often moving backwards and forwards, up and down, across the hedgerow face. A number of these moths were seen eventually landing on hedgerow or adjacent margin foliage, possibly in search of egg-laying or feeding sites.

Observations made of moth behaviour at hedgerow gaps suggest that large gaps can have an influence on their value as corridors, as moths were seen travelling through larger gaps, rather than continuing along the hedgerow. As suggested previously, the effect of physical structure is likely different for different moth species, and heterogeneity of hedgerows at a wider scale is important to be sure to provide suitable habitats for a wider range of species. Planting of gaps under HLS may disadvantageous for some species, so planting of gaps may be more beneficial for those 1m or over, allowing for some movements between fields and providing structural diversity.

A further behaviour observed during the course of the study was moths feeding on hedgerow flowers and field margin species. This is detailed in the next Chapter (Eight), which is concerned with the visitation of moths to hedgerow flowering species.

7.5 Summary

The method used for observing moth movements was inexpensive, easy to carry out and proved successful as an initial way to gauge the use of hedgerows as dispersal routes by moths. The results of the study and related observations suggest that hedgerows and adjacent field margins are important habitat features for macro-moth species in intensive agricultural landscapes with moths appearing to be using linear boundary features as sheltered flight paths, feeding sources and egg laying sites.

Hedgerow management under environmental stewardship should encourage heterogeneity of farmland habitats to increase biodiversity and localised abundance of invertebrates (Maudsley, 2000). Further research is needed to confirm the effects of gaps on moth dispersal along hedgerows. Along with data collected on moth visitation to hedgerow flowers (see Chapter Eight), this study confirms that hedgerows are important habitat features for moths as well as butterflies, which are already known to depend on hedgerows and other linear features in the UK landscape (Lewington, 2003; Dover and Sparks, 2000; Dover *et al.*2000, Dover, 2001; Ouin and Burel, 2002).

Chapter Eight: The Visitation of Moths (Lepidoptera) to Hedgerow Flowering Plants in Intensive Northamptonshire Farmland

8.1 Introduction

The value of invertebrate diversity to the economy is already well understood, with pollination ecosystem services in the UK alone currently valued at around £400 million (Klein *et al.,* 2007; Losey and Vaughan, 2006; POST, 2010). Global biodiversity declines suggest an uncertain future for many species and wildlife areas, including some important pollinators and their associated habitat areas and associated flora (Biesmeijer *et al.* 2006; Butchart *et al.,* 2010; Goulson, 2003; Kevan and Phillips, 2001). Pollinating insects are of obvious value, yet their numbers are under threat from habitat loss, land use change, chemicals and multiple other influences (Potts *et al.,* 2010).

Pollination studies in the UK are almost completely focused on bees, and to a lesser extent, butterflies (Goulson, 2003; Goulson and Darvill, 2004; Jennerston, 1984; Tudor *et al.* 2004; Woodcock *et al.* 2013). Despite increases in UK insect pollinated crops, honeybee populations are unable to provide sufficient pollination services to meet demands (Breeze *et al.,* 2011). Some researchers even suggest that honeybees are overplayed as pollinators and that other insect groups are being overlooked (Ollerton *et al.,* 2012). UK Lepidoptera studies have focused heavily on the ecology of butterfly species, despite their significantly low diversity comparative to moths (Dover and Sparks, 2000; Tudor *et al.* 2004; Hardy *et al.,* 2007; Waring *et al.,* 2009). Similarly, butterflies are often used as indicators of ecosystem health; however researchers have suggested that some moth species may serve the purpose more effectively due to their comparative diversity (Blair, 1999). Indeed, the pollination of flowering plants by moths is thought to be one of the oldest plant-pollinator relationships, possibly dating back around 40 million years, with even Charles Darwin recognising the likely pollination of orchids by moths (Darwin, 1862; Pellmyr and Leebens-Mack, 1999). There are numerous moth pollinated plants worldwide, from a wide range of taxa, although the majority of studies focus on pollination by hawk moth species (Sphingidae [Levin *et al.,* 2001; Sakai, 2002]). One recent study of UK butterfly-orchids has revealed their pollination by moth species including the Spangle (*Autographa bractea*), Large Yellow Underwing (*Noctua pronuba*) and Beautiful Golden Y (*Autographa pulchrina*) (Noctuidae [Sexton, 2014]).

A study was carried out to investigate the visitation of nocturnal moths to hedgerow flowering plants in intensive farmland areas. This chapter details the findings of this research and the implications for further studies and conservation.

8.2 Methods

See Chapter Two for more information on the two study sites used for this research (2.3.5), and Chapter Three for the possible influences on moth emergence and phenology.

8.3 Results

8.3.1 Results for all flowering hedgerow plants

A total of 333 individual invertebrates were recorded during the study period (15 nights, 26 transects). Of all the plants observed during the study, many species had very few nocturnal visitors and the most visited plant species throughout the study was Bramble (*R. fruticosus* agg.), which had

74% of all nocturnal hedgerow visitors (Figure 8.1). Of the 333 invertebrates seen visiting hedgerow flowers, 178 were Lepidoptera (53%), 58 were Dermaptera (17%), 53 were Diptera (16%), 24 Coleoptera (7%) and the final 7% came from the other orders (Figure 8.1).

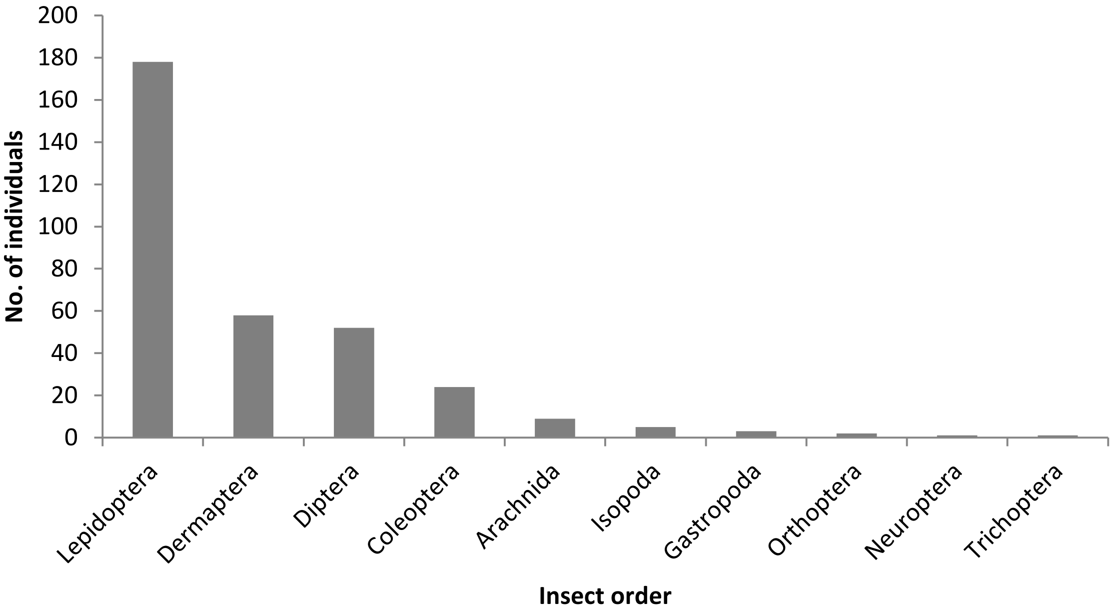

Figure 8.1: Invertebrate visitors to hedgerow flowering plants by order.

Of the total 178 moths seen visiting hedgerow flowers during the study period, 110 (62%) were macro-moth species and the remaining 73 (38%) were micro-moths (Figure 8.1). A total of 21 macro-moth species were recorded feeding on hedgerow flowers, with the most abundant species being the Snout moth (*Hypena proboscidalis*), which was recorded a total of 36 times and Common Wave (*Cabera exanthemata*) which was recorded 30 times. The Snout moths were only ever recorded on *R. fruticosus* agg. (Bramble), however Common Wave moths were also seen on Cow Parsley (*Anthriscus sylvestris*) and Creeping Thistle (*Cirsium arvense*) (see Table 8.1). Some other macro-moth species seen visiting hedgerow flora were Common, Brown and Mottled Rustics (*Rusina* *ferruginea, Mesapamea secalis, Caradrina Morpheus*), Large Yellow Under-Wing (*Noctua pronuba*) and Brimstone Moths (*Opisthograptis luteolata*) (Table 8.1).

Table 8.1: Macro-moth visitors to hedgerow flowering species with total numbers (Species in grey have research priority status due to declining numbers).

Common name	Scientific name	Total	Plants visited
Barred Straw	*Eulithis pyraliata*	1	Bramble
Brimstone Moth	*Opisthograptis luteolata*	3	Bramble
Brown Rustic	*Rusina ferruginea*	1	Cow parsley
Common Carpet	*Epirrhoe alternate*	2	Bramble
Common Emerald	*Hemithea aestivaria*	1	Bramble
Common Footman	*Eilema lurideola*	2	Bramble
Common Pug	*Eupithecia vulgate*	3	Bramble
Common Rustic	*Mesapamea secalis*	5	Bramble
Common Wave	*Cabera exanthemata*	30	Bramble, Cow parsley, Creeping thistle
Dingy Footman	*Eilema griseola*	9	Bramble
Grass Wave	*Perconia strigillaria*	1	Bramble
Green Carpet	*Colostygia pectinataria*	1	Bramble
Large Yellow Underwing	*Noctua pronuba*	1	Bramble
Middle-barred Minor	*Oligia fasciuncula*	1	Cow parsley
Mottled Beauty	*Alcis repandata*	1	Bramble
Rustic	*Hoplodrina blanda*	1	Bramble
Mottled Rustic	*Caradrina Morpheus*	2	Cow parsley
Silver Ground Carpet	*Xanthorhoe montanata*	1	Bramble
Silver Y	*Authographa gamma*	1	Bramble
Single-dotted Wave	*Idaea dimidiate*	1	Bramble
The Snout	*Hypena proboscidalis*	36	Bramble
Yellow Shell	*Camptogramma bilineata*	1	Bramble

A total of 73 micro-moths were observed visiting hedgerow flowers over the course of the study, with the majority (81%) being *Udea* species, recorded as *Udea prunalis* and *Udea olivalis*

(Table 8.2). Other micro-moth species seen visiting flowers along the hedgerows were Small Magpie (*Eurrhypara hortulata*) and the White Plume (*Pterophorus pentadactyla*).

Table 8.2: Micro-moth visitors to hedgerow flowering species with total numbers.

Common name	**Scientific name**	**Total**	**Plants visited**
Bee Moth	*Aphomia sociella*	1	Bramble
Buttoned Snout	*Hypena rostralis*	3	Bramble
N/A	*Emmelina monodactyla*	6	Bramble
Small Magpie	*Eurrhypara hortulata*	1	Bramble
White Plume	*Pterophorus pentadactyla*	2	Bramble
N/A	*Udea prunalis*	33	Bramble
N/A	*Udea olivalis*	26	Bramble
Un-identified spp.	N/A	1	Cow parsley

8.3.2. Visitors to Bramble

The most frequently visited hedgerow flowering plant in the study was Bramble, which accounted for a total of 74% of the invertebrate visitations. As such the results for Bramble were separated from those of the other flowering species and analysed separately as well as with the other plants.

Of the 245 invertebrates found visiting Bramble flowers, a total of 172 (70%) were Lepidoptera, 36 Diptera (15%), 19 Dermaptera (8%) and the final 7% came from the orders Coleoptera, Arachnida, Isopoda and Orthoptera (Figure 8.2).

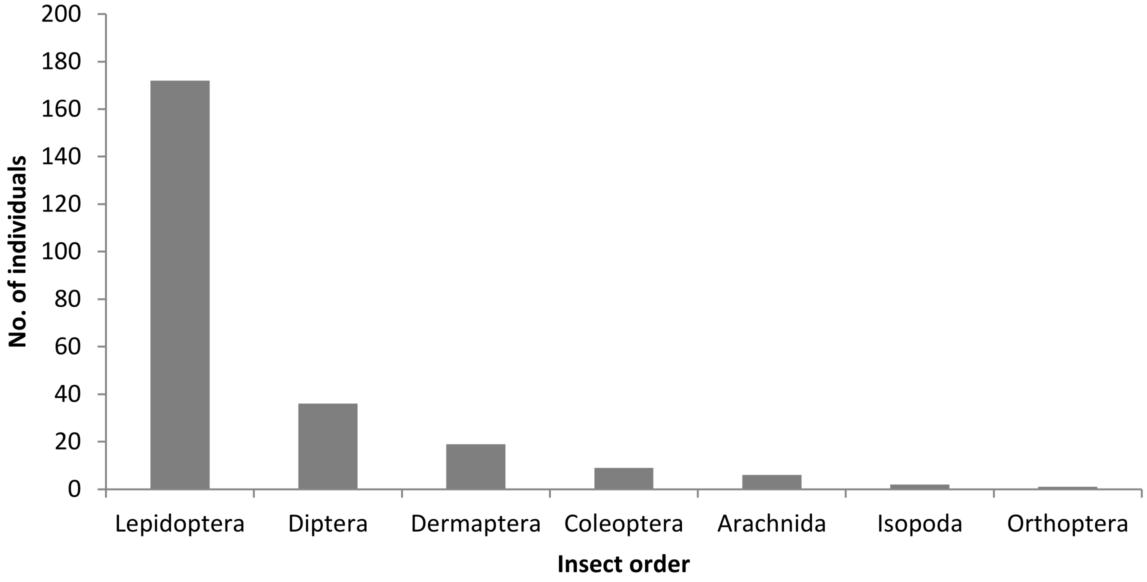

Figure 8.2: Invertebrate visitors to Bramble by order.

Of the 172 moth visitors to bramble flowers, 61% (105) were macro-moth species and 39% (67) micro-moths. A total of 20 macro-moth species were recorded over the course of the study and seven micro-moths. Macro-moth species were from a range of families and genus (Table 8.3). The two most common macro-moths made up a total 62% of the visitors (the Snout [recorded 35 times] and Common Wave [30 times]), with the remainder being moths which were recorded relatively few times. The two micro-moths were both from the same genus and together made up 82% of the total micro-moth visitors (*U. prunalis* [recorded 33 times] and *U. olivalis* [recorded 26 times]).

Table 8.3: Summary statistics for individual hedgerow survey sites; total moths and species observed.

Hedgerow Site	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Total Moths	12	0	1	5	25	60	58	7	3	1
Total Species	8	0	1	4	7	16	11	4	2	1
Number of Bramble Clumps	5	1	3	2	8	15	20	3	2	2

The number of moths observed at each of the hedgerow sites correlated positively with the number of Bramble clumps along the hedgerow (Figure 8.3). The total moth species observed at each of the sites also correlated positively with Bramble clumps (Figure 8.4).

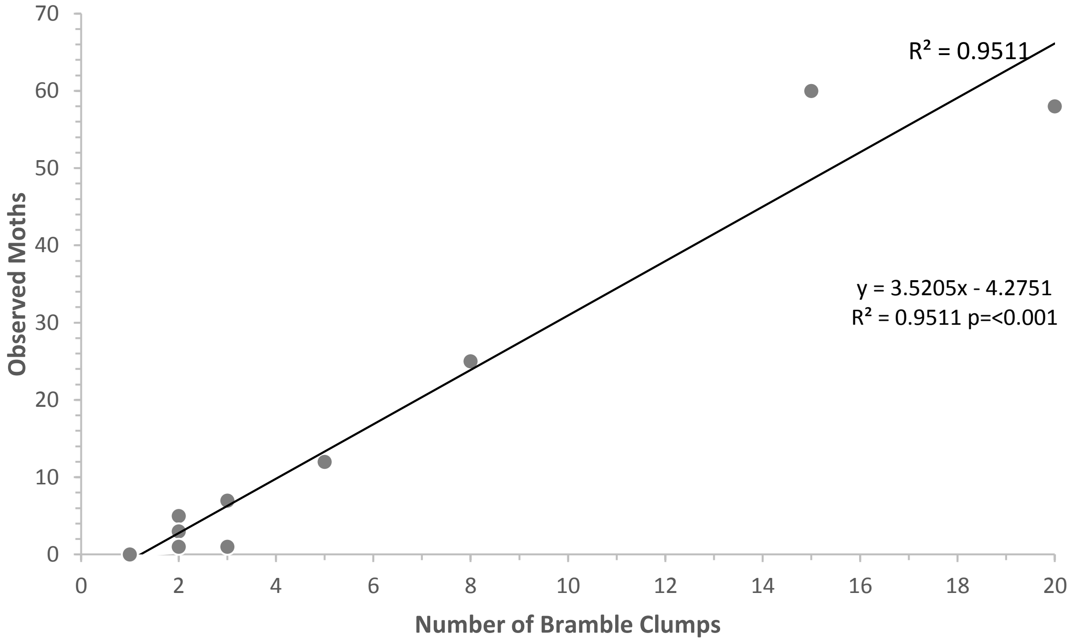

Figure 8.3: Linear regression model for predicting numbers of moths from hedgerow bramble clumps.

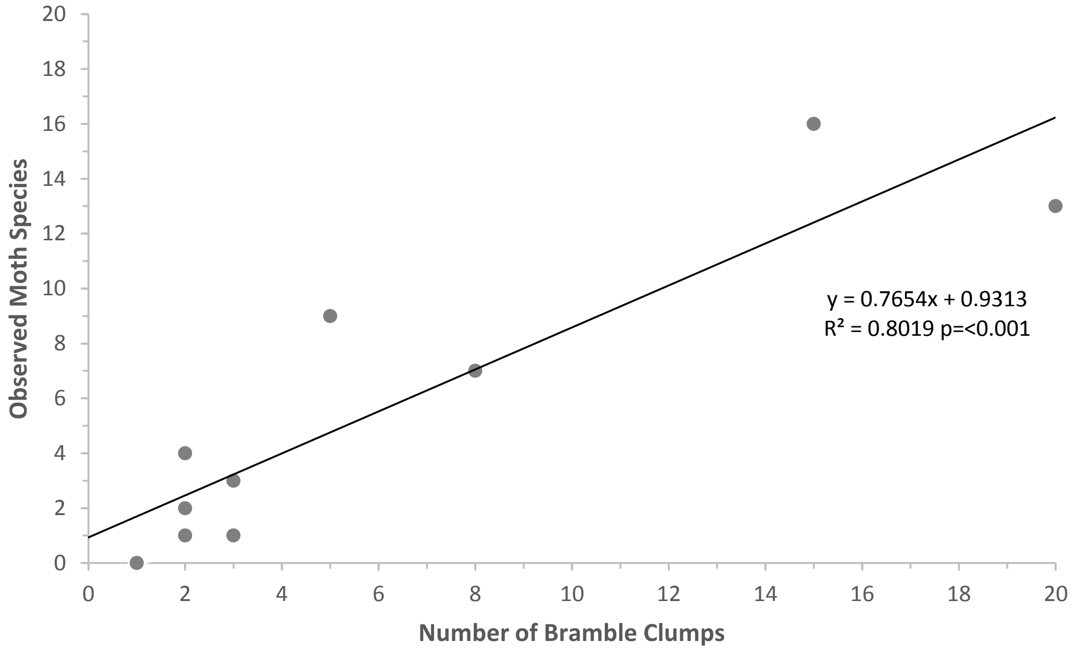

Figure 8.4: Linear regression model for predicting moth species from hedgerow bramble clumps.

8.4 Discussion

The majority of the visitations observed throughout this study were from Lepidoptera, suggesting that moths are nocturnal visitors to hedgerow flowering species such as Bramble, Cow Parsley and Creeping Thistle. Invertebrate visitation to Bramble flowers accounted for 74% of the activity along the hedgerows during the study. This suggests that Bramble could be an important nectar source for nocturnally active invertebrates (this would need further investigation to include pollination studies). Bramble supports a range of macro and micro-moth visitors from a total of seven families (three macro families and four micro families). The most abundant nocturnal visitors to Bramble were members of the order Lepidoptera. These results support the suggestions by previous publications that moths are understudied despite their relative diversity compared with other groups (Fox *et al*., 2013).

8.4.1 Visitation to Bramble Flowers

This study found that UK moth species are visiting Bramble flowers in hedgerows in intensive agricultural areas. A total of 27 moth species were recorded visiting these flowers, including 20 macro species and seven micro-moth species. The species recorded included one species listed as a species of conservation concern due to declining numbers (the Rustic). Three of the species observed have been reported as increasing by over 100% in the last 40 years: Dingy Footman (*Eilema griseola*), Large Yellow Underwing (*Noctua pronuba*) and Yellow Shell (*Camptogramma bilineata*), some by huge numbers.

Of the 172 Lepidoptera visitors to Bramble, there was a mix of both macro and micro moth species observed. Micro-moths in particular are overlooked in the scientific literature, due to the difficulty of identification (Stirling *et al.,* 2012). Four of the moth species were observed in high numbers, two of these macros and two micros (*Cabera exanthemata, Hypena proboscidalis, Udea olivalis* and *U. prunalis*). These results could reflect the relative diversity of moth species in the local area, however they more likely reveal the variation in the feeding habits of the moth species concerned. The two macro-moths recorded as most frequent visitors to Bramble were not the most commonly trapped species over the course of the 2011/12 and 2013 trapping. Both species were trapped in the main study and the Snout in relatively high numbers (Total 109 over the three summers). There were however more common species which were not recorded as visiting hedgerow flowers. With many moth species, adults do not have mouth parts, so are not nectar feeders (Waring *et al.,* 2009). This fact would explain some of the differences in the results, however the visitation study would also reveal species which might not be attracted to light at all, or in high numbers (Fry and Waring, 2001; Waring *et al.,* 2009). The more regular nectar visitors recorded may be regular and possibly specialist visitors to Bramble and those less abundant may be visitors to a variety of flowering species in the surrounding landscape. Further research on moth pollination should include studies into other farmland habitats such as woodland, grassland and field margins or tracks, in order for comparisons to be made. Currently, further research is being carried out to compare the nocturnal and diurnal visitation of Lepidoptera to Bramble flowers across the countryside in order to make direct comparisons to day time pollination systems.

The survey results showed a positive relationship between the number of Bramble clumps along the hedgerow and both the total moths observed and the number of moth species. This strongly suggests that increased Bramble plants in hedgerows and margins increases resources for nectar feeding moths, reinforcing the idea of resource-based conservation to improve habitats for Lepidoptera (Dennis *et al.,* 2003, 2006 & 2013). Hedgerow vegetative diversity could significantly improve the abundance and diversity of invertebrates by means of increasing nectar and food plant resources such as those provided by Bramble. Due to the intensive nature of the farmland surveyed in this research it was not possible to investigate the benefits of a wide range of flowering hedgerow plants, however further targeted research across a range of hedgerows could provide important data on the other floral resources beneficial for farmland moth species.

Bramble is closely related to a number of other commercially grown fruiting plants such as Raspberry (*Rubus idaeus*), Loganberry (*Rubus loganobaccus*) and Cloudberry (*Rubus chamaemorus*) (Stafne and Clark, 2005). These species obviously have similar flowers morphologically and could also be visited by moth species nocturnally. The economic value of diurnal pollination activity is widely commented on, however as yet the value of nocturnal pollination seems to be overlooked. Further valuable studies could include nocturnal surveying of commercially grown fruiting species during their flowering period, to determine the proportions of nocturnal Lepidoptera visitors. Comparisons of diurnal and nocturnal visitation, combined with pollinator effectiveness research would help to clarify the relative economic value of nocturnal visitation.

8.4.2 Environmental factors influencing moth visitation

Hedgerow sites differed in terms of both total observed moths and the number of moth species observed (Table 8.3). Both the total moths and number of species had a positive relationship with the number of bramble clumps located along the hedgerow (Figures 8.3 and 8.4). These results are as expected, since a higher number of floral resources are likely to attract a higher number of nectar feeding invertebrates to habitat areas (Anon, 1995; Maudsley, 2000).

Of the total hedgerows on both the study site farms, only a relatively very small proportion had Bramble flowers present (approximately 20% at Moulton and 10% at Kelmarsh). Kelmarsh had a lower number of hedgerows with Bramble flowers, particularly among those hedgerows laid within the last few years under HLS prescriptions.

Although data was not kept for nights when no invertebrates were recorded, it was clear from notes that visitation to hedgerow flowers varied significantly depending on weather conditions. Some nights had a high abundance of moth visitors to floral resources, whereas other nights revealed very few or none. No significant relationships were found for this data set with any of the weather variables recorded (temperature, wind speed and relative humidity), however as mentioned above, data was not recorded on nights with no visitation activity.

8.4.3 Hedgerow management for improving floral resources

Improved management of hedgerows in intensive agricultural landscapes could help in improving moth numbers on a local scale, by providing resources and habitat patches valuable to such species (Dennis *et al.,* 2003, 2006 & 2013). Recent UK moth research has already suggested both local, targeted management and landscape-scale approaches to reducing declines in moth numbers (Ellis *et al.,* 2012; Fox *et al*., 2013). Hedgerows are also specifically highlighted as important habitats for some UK moth species, with hedgerow tree, margins and vegetative diversity listed as key aspects of these features (Merckx *et al.*, 2009b; Merckx, 2010).

This study found a direct positive correlation between the number of Bramble clumps along a hedgerow and the abundance and diversity of moth visitors to hedgerows (Figures 8.3 and 8.4). Nocturnal visitors to hedgerow flowering plants were mostly moths, a taxa group both understudied and heavily in decline in the UK (Conrad *et al.,* 2006; Fox *et al.,* 2011b; Fox *et al*., 2013; Ricketts *et al*, 2002). The results of this study suggest that management of hedgerows should consider the following:

1. Later cutting of hedgerows to avoid reducing nectar and fruit resources.
2. Reduced hedge-bottom management and chemical applications avoided where possible to improve the vegetative diversity and reduce excessive enrichment.
3. Well-spaced rotations of hedge-laying which avoids large lengths of hedge-laying in one year (something which could impact on the floral resources within hedgerows).
4. Varied management of hedgerows i.e. minimal intervention, hedge-laying, varied cutting and coppicing to improve the heterogeneity of hedgerows across the landscape.

All the points above have been either put forward or alluded to in previous studies (Benton *et al.,* 2010; Manley, 2000; Staley *et al.,* 2010), however point three above appears to have been somewhat overlooked, or at least not yet included in Agri-Environment Scheme prescriptions. Current Higher Level AES in the UK require landowners to manage a relatively high proportion of their hedges in the first couple of years of entering the scheme (Natural England, 2013a and Natural England 2013b). This approach may well save possibly neglected hedgerows from becoming defunct; however in some cases it may be a drastic option which might be detrimental to the floral diversity and as a result faunal diversity, of the hedgerow. As with woodland habitats, intensive management can cause a short-term deficit in diversity.

One factor which could be influential in terms of nectar availability is the eutrophication or enrichment of hedgerows and associated margins throughout farmland. The vegetative diversity of these habitats may be poor and as a result flowering species richness would be low (McCollin, 2000a). Wider field margins prescribed under AES help to provide buffer zones for chemical applications and help to maintain and improve vegetative diversity and resulting nectar resources (Chiverton and Sotherton, 1991; Dover, 1989; Dover *et al.,* 1990; Game and Wildlife Conservation Trust, 2014; Hassall *et al.,* 1992; Kleijn and van der Voort, 1997; Macdonald *et al.,* 2012; Sotherton, 1984; Sotherton, 1985).

Current research already highlights the importance of avoiding blanket management prescriptions, due to their mixed results for different woody species (Croxton *et al.,* 2004). Research comparing different hedgerow management techniques showed that hedgerow management had an impact on indicator species, numbers of different hedgerow plant species, and structural diversity (Staley *et al.,* 2013). The researchers suggested that hedgerow management should be rotational and sympathetic to provide feeding and shelter resources for fauna all year round (Staley *et al.,* 2013).

The lower numbers of flowering species across the Kelmarsh site may have been due to the recent laying of hedgerows across the site. Rotation and variation of hedgerow management would prevent a farm-scale drop in floral resources at any one time and so increase structural diversity.

8.5 Summary

Both macro and micro moths were found to be visiting hedgerow flowers across the study site. Of the nocturnal visitors to these plants, Lepidoptera made up 53% of the total, suggesting that moths are key visitors to at least some hedgerow flowering species. Of the hedgerow flora studied in this research, Bramble had the majority of the invertebrate visitors (74%) and moth visitors specifically (97%). This research suggests that hedgerow management prescriptions under AES should consider the improvement of floral diversity for invertebrates both nocturnally and diurnally. Further research is needed to confirm the value of moths as pollinators to such hedgerow flora and gauge the possible ecosystem services which could be provided to other flowering plants nocturnally by moths.

Plate 1: *Udea olivalis* on Bramble flower.

Plate 2: *Hypena proboscidalis* on Bramble flower.

Plate 2: *Alcis repandata* on Bramble flower.

Chapter Nine: Conclusions and Management Implications

9.1 Initial Summary

The growing field of research into UK moths has suggested that they are in serious decline (Fox *et al.,* 2011b; Fox *et al*., 2013). The two main influences on moth abundance have been identified as climate change and land use (Fox *et al.*, 2014). Macro-moth abundance and diversity in farmland has been linked to the presence of field margins, hedgerow trees and the patch size and vegetative diversity of farmland woodlands (Ellis *et al.,*2012; Merckx *et al.,* 2009a; Merckx *et al.,* 2009b Merckx *et al.*, 2010; Fuentes-Montemayor *et al.,* 2012).

The research detailed within this thesis investigated the localised effects and uses of linear boundary features such as hedgerows and field margins as well as the landscape-scale effects of land-use at a variety of spatial scales (Fuentes-Montemayor *et al.,* 2012).

9.2 Landscape-Scale Influences on the County Abundance of Moths

CCA suggested that urban or suburban areas and woodland were having two opposing influences on the spread of the moth abundance data. More focused analysis of the data using correlations and multiple regression confirmed that this was the case and showed that urban and suburban land use around the trap sites had a negative effect on many of the moth guilds, whereas broadleaved woodland cover had a positive relationship with the overall moth abundance and species richness, as well as abundance of different moth guilds (particularly specialist habitat species). These findings reinforce those of previous researchers who have found that land use has a significant effect on moth abundance and that woodland cover in the landscape is positively associated with moth abundance and diversity at 500m or less (Fox *et al.,* 2014; Fuentes-Montemayor *et al.,* 2012). In conclusion, these results support a landscape-scale approach to moth conservation, with a focus on ecological networks and increased woodland areas, particularly in intensive farmland.

It is important that further landscape-scale studies of moth abundance and diversity are carried out if conclusions are to be made about the influences on moths across the UK. There are still relatively few studies published on the landscape-scale influences on moths, and it is suggested that the field needs further attention before moth declines across the UK reach a critical level and further species are lost (Conrad *et al.,* 2006; Fox *et al.,* 2014; Merckx *et al.,* 2009a; Merckx *et al.,* 2009b; Ricketts *et al.,* 2002).

9.3 Local and Landscape-Scale Influences on Farmland Moth Abundance and Diversity

9.3.1 Landscape-Scale Abundance and Diversity of Macro-Moths

For farmland invertebrates, the habitat cover within the landscape, as well as the presence and connectivity of linear boundary features are thought to be particularly influential (Bates *et al.,* 2014; Petit and Burel, 1998; Rundolf and Smith, 2006; Schmidt *et al.,* 2005; Wiebull *et al.,* 2000). For moths in particular, the factors considered to influence abundance are thought to be species-specific (Bates *et al.,* 2014).

Due to the constraints of this research, coarse-scale landscape factors could not be investigated with regards the moth trapping carried out. The finer-scale variables including hedgerow connectivity factors however, were included in the analysis for this research. Moth trapping was carried out over three summers. The trapping results from all years of this study were broken down and analysed a number of ways, however no significant results were found for the overall numbers of moths with any local-scale variables. The same was true when moths were categorised according to feeding guilds or habitat preferences. One clear finding however, was that very few BAP or research priority BAP species were trapped, the majority of which are habitat specialists. In addition, the vast majority of moths trapped were of open habitat, generalist species. Very few habitat or food-plant specialists were recorded. This result alone suggests that intensive agricultural areas may be mostly frequented by generalist macro-moth species, rather than specialists. It is small wonder that macro-moth populations are significantly declining in the UK if the specialist species are being severely affected by agricultural intensification and habitat fragmentation.

No significant relationships were found for either of the diversity indices and local or landscape-scale variables for any of the trapping data. Initial comparisons of moth abundance, however revealed that six species in 2011/12 and 25 species in 2013 were significantly different in their numbers over the two sites. One of these, the Common Swift, was different in both trapping studies, with both data sets (2011/12 and 2013) revealing higher numbers at Kelmarsh than Moulton. Many of these significant differences could be due to localised emergence events at one of the study sites, which may result in high numbers at a local scale. For example, the Double Dart was only trapped in 2013 at Kelmarsh and is known to have a localised abundance at a county and national scale, due to seasonal emergence events (Blincow and Ward, 2002; Kimber, 2014). Other factors were investigated using correlation and regression analysis.

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As mentioned above, coarser landscape-scale variables could not be investigated within this research, however from looking at the county moth records and their relationships with land-cover, it is clear that habitat cover is influential on the abundance of macro-moths. Landscape-scale conservation efforts, such as those being carried out by Butterfly Conservation, are probably one the most effective way to improve populations of 'common and widespread' generalist moth species in UK landscapes, however resource-based projects and fine-scale habitat management should not be overlooked, due to the reliance of moth species on specific food-plants and nectar resources (Ellis *et al.,* 2012; Dennis *et al.,* 2003, 2006 & 2013).

9.3.2 Local-Scale Abundance and Diversity of Macro-Moths

The impact of local-scale influences such as hedgerow and margin features was investigated and the abundance of only four moth species were shown to have a positive association with local-scale variables. The two aspects of hedgerows which were influencing moth numbers in these years were the hedgerow vegetative diversity and the number of gaps in the hedgerow. In 2013 three species had a significant relationship with local hedgerow variables and although hedgerow gaps were again revealed as affecting some species, hedgerow dimensions and margin width were also factors. From the results of this study it was not possible to say whether localised hedgerow and margin features were having any effect on the diversity of moths trapped or the overall abundance of moths across the sites, however it appears that they are influencing specific macro-moth species significantly.

In 2013, one further factor influential on moth taxa appeared to be hedgerow length. This could be related to the overall connectivity of the hedgerow-woodland network. A number of previous studies have suggested the importance of woodlands for macro-moth diversity, so this result is as expected (Broome *et al.,* 2011; Fuentes-Montemayor *et al.,* 2012; Schmidt and Roland, 2006; Usher and Keiller, 1998). It can be concluded that at least in this study, hedgerow connectivity factors do not account for the overall abundance and species richness of macro-moths, but had an influence on a small number of families, sub-families and individual species

Although it could not clearly be shown by this study, it is nonetheless very likely that local hedgerow and margin features were having an impact on overall moth abundance or species richness, although these influences may be greater for specialist and poor dispersal species (Merck *et al.,* 2009a; Merckx *et al.,* 2009b; Merckx *et al.,* 2010). It is likely that the presence or absence of larval food plants or nectar resources will have a significant impact on the abundance and diversity of moths at local scales, due to the diversity of moth feeding guilds and taxonomy (Waring *et al.,* 2009; Kimber, 2014). The findings of Chapter Eight suggest that the presence of flowering hedgerow species is important for moths and other invertebrates as a nectar source.

9.4 Moth Movement along Linear Boundary Features

The moth movement studies of this project aimed to ascertain whether moths might be using hedgerows as corridors and how different moth activity differed in relation to the proximity to hedgerows. The results of the moth movement studies had two main findings:

1. More macro-moths were active at the hedgerow face than at a remove (more individuals observed at 1m from the hedge than 5m and then 10m respectively),
2. That the majority of macro-moths present around hedgerows are moving along the hedgerow rather than in other directions (i.e. across open fields).

These results suggest that moths are using hedgerows within farmland as corridors at least to some extent. These results could be due to a combination of factors including: sheltered dispersal routes, presence of hedgerow nectar resources and larval food plants. Lepidoptera are known to be affected by weather conditions such as precipitation, temperature and wind, so hedgerows are likely to provide both sheltered travel routes and resting places for species during inclement weather spells (Dover and Fry, 2001; Maudsley*,* 2000). These results may also partially explain the use of hedgerows as flight paths for bat species in the UK, as they probably provide good food sources (Bat Conservation Trust, no date; Boughey *et al.,* 2011; Entwhistle *et al.*, 2001, Oakeley and Jones, 1998, Russ and Montgomery, 2002; Verboom and Huitema, 1997).

It is possible that hedgerows may be acting as barriers to the movement of some flying insect species such as moths and that their movement along such features may not be intentional. Observational notes of moth behaviour at hedgerow gaps suggested that small gaps did not appear to affect the directional movement of moth species, but that larger gaps of around 2m or more generally caused a change in flight behaviour. These observations were not carried out in terms of a full study, so any conclusions would be purely speculative. Previous studies on butterfly movements and simulated hedgerows found varied responses in different species and it is likely the same would be true of moths due to their wide morphological and behavioural diversity (Dover and Fry, 2001).

Observations during the movement study suggested that there were a variety of different sized moths, with different flight behaviours flying along the study hedgerows, confirming a diverse collection of macro-moth species present (as found in the trapping). These observations combined with the results of the trapping and floral visitation studies show the diversity of moth species which may be using hedgerow as corridors or for resources and it is possible that differently sized moths are more or less reliant on linear boundary features such as hedgerows. A mark-release-recapture study with selected moth species could help determine this, such as that carried out by Merckx *et al.* (2010) in relation to hedgerow trees, however species would need to be carefully selected.

Some initial observations made of moth flight behaviour around gaps suggested that larger gaps (those over 2m) interrupt flight direction. This assumption is based only a very small number of observations during the study and should be investigated further in order to determine the full effect of defunct, gappy hedgerows on the dispersal of macro-moths around farmland. Landowners or managers should ensure the presence of lengths of dense hedgerow for sheltered movements of moth species around the landscape, however the importance of ‘gappy’ hedgerows for some species should not be overlooked and a heterogeneous approach should be encouraged. Without further research into the behavioural ecology of macro-moths, it is hard to make clear assumptions, aside to say that conservation of macro-moths is more diverse than for many other UK taxa.

Hedgerow gaps at Moulton were almost always enriched and filled by ruderal farmland weed species such as Bramble and Nettle, species which are known food plants for many moth species (Crafer, 2005; Waring *et al.,* 2009; Kimber, 2014). Especially when there is little or no margin present adjacent to the hedgerow the importance of small patches of weedy growth cannot be overlooked as egg laying or feeding resources. Wider margins would provide areas of weedy species, as well as protecting hedgerow floral diversity.

There was a higher diversity of woody plant species in the hedgerows of Moulton compared with Kelmarsh where hedgerows mostly consisted of hawthorn and blackthorn plants. The importance of this for different species was highlighted to some extent by the results of the local-scale analysis, where some moth species had a significant association with woody diversity and others with herbaceous diversity. Although larval surveys were not carried out by this study, this is an area which needs further research, as it is likely that the presence or absence of plant species in hedgerows has an impact on the abundance and diversity of moth larvae (Merckx *et al.*, 2012; Waring *et al.,* 2009).

9.5 Moth Visitation to Hedgerow Flowering Species

With Lepidoptera making up the majority (53%) of the nocturnal visitors to hedgerow flowering plants over the course of the visitation study, it is clear that moths are regular visitors to some hedgerow and margin flora. The importance of hedgerow floral resources for butterflies (Dennis *et al.,* 2013; Dover and Sparks, 2000; Ouin and Burel, 2002) is also true for moths, as indicated for the 29 species recorded on flowers during this research. Although there are many moth species which do not feed on nectar in their adult stage, there are many species which do (Kimber, 2014; Waring *et al.,* 2009). This study confirms that, at least for the 29 species recorded over the course of this study, hedgerows provide a potential feeding source for adults in farmland landscapes, which may otherwise be lacking in nectar sources due to enrichment and poor management.

The main flowering species visited by moths was Bramble, which is abundant throughout the UK countryside (Rose and O'Reilly, 2006). Often considered a weed of waste areas, this plant does obviously provide some benefits to wildlife when found within hedgerows (Amor, 1974; Rose and O'Reilly, 2006). As linear models of moth numbers in relation to Bramble flower indicate, the more abundant the Bramble flowering heads in the hedgerow, the higher the abundance and diversity of moths to be found on a hedgerow nocturnally (Figure 8.3 and 8.4). Of course moths may well be visiting floral resources in other habitats across the landscape and this should not be ignored by future researchers. Further research should be carried out to determine the extent of nocturnal floral visitation by moths in the UK. Urban and suburban habitats in particular may be a worthwhile area of study, as they are known to be important areas for many moth species and could provide essential refuges for these species (Bates *et al.,* 2014; Waring *et al.*, 2009).

Management of hedgerows in intensive farmland landscapes should avoid over or under-management which could impact on floral resources and, as a result, fruit sets (Staley *et al.,* 2013; Croxton and Martin, 1999; Croxton and Sparks, 2002). The latest AES prescriptions are more sympathetic to such issues and encourage a less intensive approach to cutting regimes, which should in turn positively impact on the vegetative diversity (Natural England, 2013b). With previous studies supporting the benefits of heterogeneous landscapes and habitat areas, it is unarguably essential to vary farmland habitat management if local biodiversity is to be preserved and even increased (Benton *et al.,* 2003; Maudsley, 2000).

The value of wild populations of pollinating insects is a growing consideration for agriculture, with declines in honey bee populations turning the focus on other taxonomic groups (Goulson *et al.,* 2008). Bumblebees, butterflies and hoverflies are some of those invertebrates considered important for pollination in the UK, however moths are often overlooked (Garbuzov and Ratnieks, 2014). The findings of this research demonstrate that moths are visiting flowers in agricultural landscapes and could be providing ecosystem services in the form of pollination.

9.6 Possible Errors or Bias

With regards the Northamptonshire historic moth records, there is a clear possibility for inaccurate records, as is the case when amateur enthusiasts are used to collect data of this kind. Although all records are sent to the county recorder and care was taken to remove any anomalies, there may still have been some miss-identifications. This could also have been the case for the applied field research, which again relied heavily on amateur enthusiasts. All species which were doubtful were sent to the county recorder in the form of photographs, however there are many species which are very difficult to identify without dissection and as such errors could be made. Using moth trapping also means that a small number of moths could escape prior to identification, resulting in some species being missed. Although care was taken to release moths at a third site in between the two trapping locations, there was still a possibility of re-captures for some of the more mobile moths. Future research could include marking of individuals to prevent these moths from being recorded twice. During the movement studies, it was sometimes difficult to determine what flying insects were moths, when they were moving at high speed and although only insects over 1cm were included to reduce this, some observations may have been from other insect orders. Over the course of the visitation study a lot of feeding behaviour was observed, however this could not be verified for all individuals. Further research is needed to determine the feeding behaviours of moth species on hedgerow flowers and to discover to what extent these species are pollinating rather than just visiting.

9.7 Recommendations for Further Research

Although this research successfully addressed a key weak spot in the current literature regarding macro moths in intensive farmland landscapes, there were a number of areas which became apparent as requiring further research, either through the research itself or through study of the literature. Key recommendations for further studies are as follows;

- National scale landscape-scale analysis of historic moth data.
- Research into the relationships between local and landscape-scale larval food plant abundance and moth abundance.
- Larval hedgerow and margin surveys to determine the use of these habitats as habitats for moths in their larval stage.

- Wider scale intensive trapping studies to confirm the influences of land use on moth abundance and diversity.
- Specialist and BAP focused research for macro moths using local and landscape-scale analysis.
- Further floral visitation studies in a range of habitats across intensive farmland landscapes.
- Moth pollination surveys to determine the nectar feeding of these species and their possible effectiveness as pollinators compared with diurnal visitors.

9.8 Summary

This study aimed to determine the possible benefits of hedgerows and adjacent margins for moth species in UK farmland, as well as the landscape-scale influences on moth abundance and diversity in intensive agricultural areas. The project aimed to investigate the following three aspects in relation to moth abundance and diversity: local-scale hedgerow and margin management, land cover statistics and hedgerow-woodland networks. The research included moth trapping and subsequent local and landscape-scale analysis, landscape-scale analysis of historic trapping records, nocturnal hedgerow transect surveys and moth movement observations. These aims were achieved and results of these studies are summarised below.

The management of linear boundary features such as hedgerows and associated field margins are without doubt important for the conservation of invertebrates including moths in farmland. Although this study could not conclusively determine any significant local-scale relationships between moth abundance and local hedgerow or margin features, other than species-specific responses, landscape-scale influences were found to be affecting the abundance of moths at the county scale. The findings of the historic trapping data confirmed those of previous studies, that woodland cover and to some extent other semi-natural habitats in the landscape (between 250 and

3000m) are positive for moth abundance, and that urban and suburban land use has a negative relationship with moth numbers. A heterogeneous landscape would support a wider range of moth species, providing there are robust and sustainable ecological networks such as those represented by hedgerow-woodland connectivity. More research is needed in this field to improve understanding of moth ecology and the impacts of both local and landscape-scale conservation approaches. Providing relevant land use data can be gathered, landscape-scale analysis of moth trap records from across the UK could quite easily be carried out to increase the understanding of these relationships.

9.9 Key Findings and Management Suggestions

- Macro-moth abundance has a significant relationship with landscape-scale variables and land use at a range of spatial scales.
- Woodland areas are important for macro-moths and should be protected and increased in the farmland landscape.
- The connectivity of hedgerows is important for some moths, so a connected and robust hedgerow ecological network is important to promote their biodiversity in agricultural areas.
- Local-scale management of hedgerows may be important for some moth groups or species; heterogeneity is important for moth diversity.
- Vegetative diversity of hedgerows should be encouraged.
- -Hedgerow management should be varied and less intensive to produce structural and vegetative diversity for invertebrate resources.
- A heterogeneous approach to both local and landscape-scale management should be a priority if the biodiversity of moths is to be conserved.

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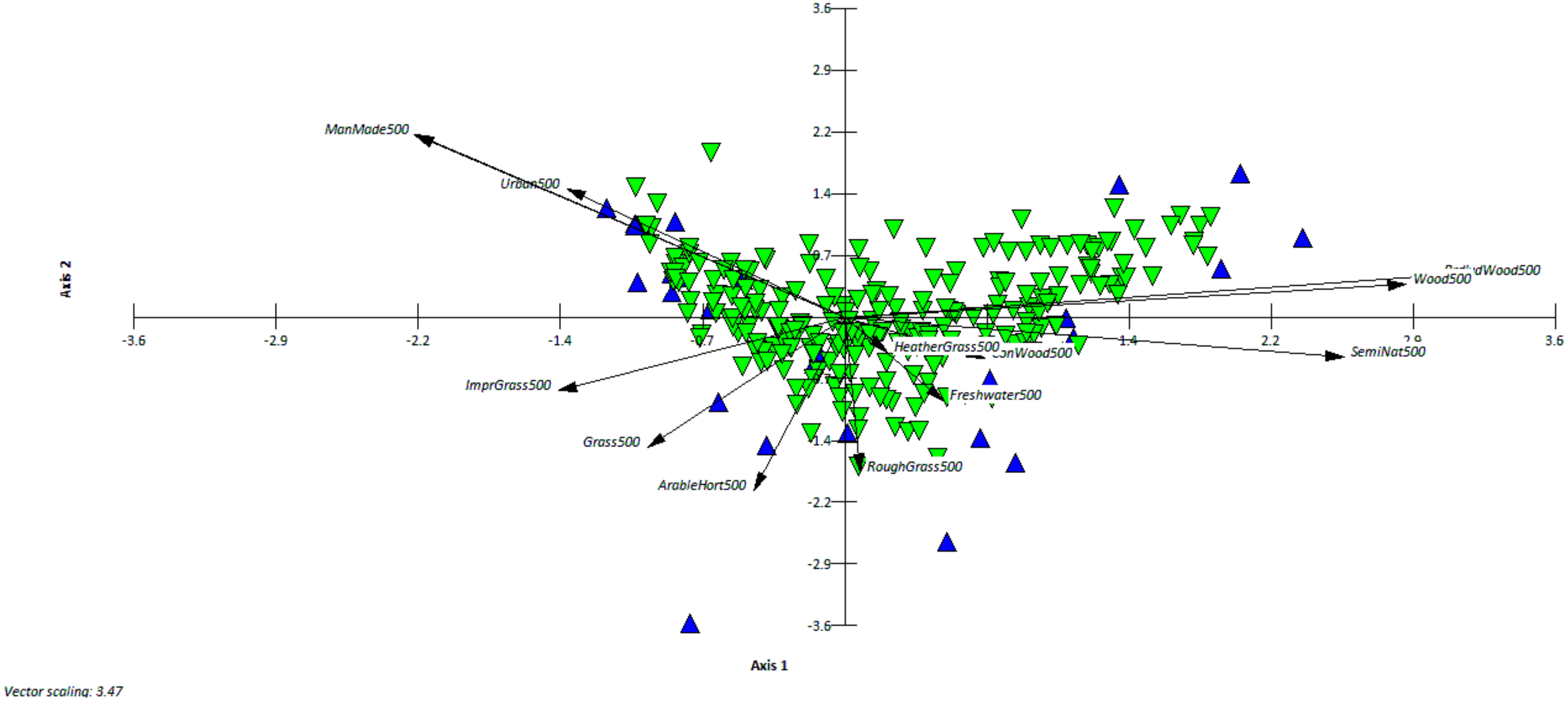
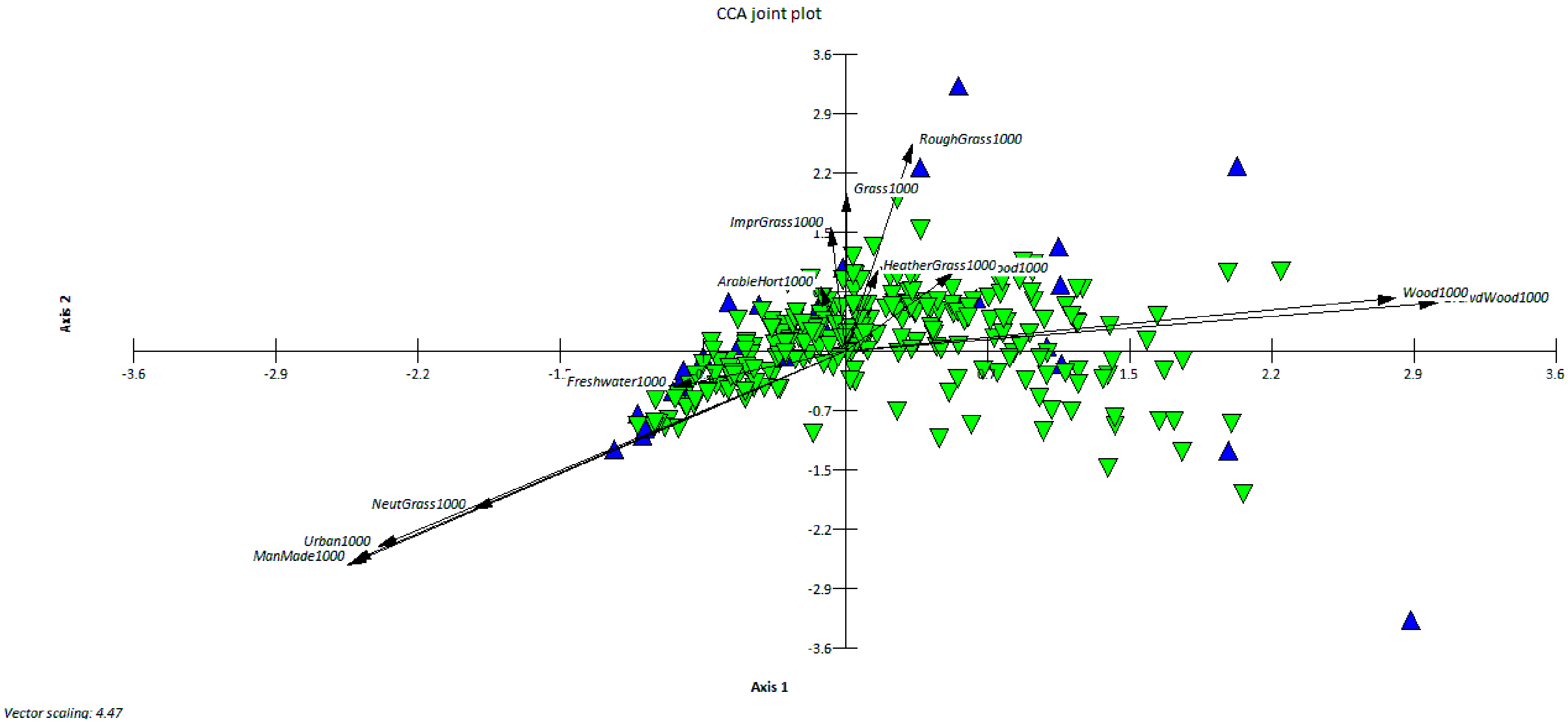
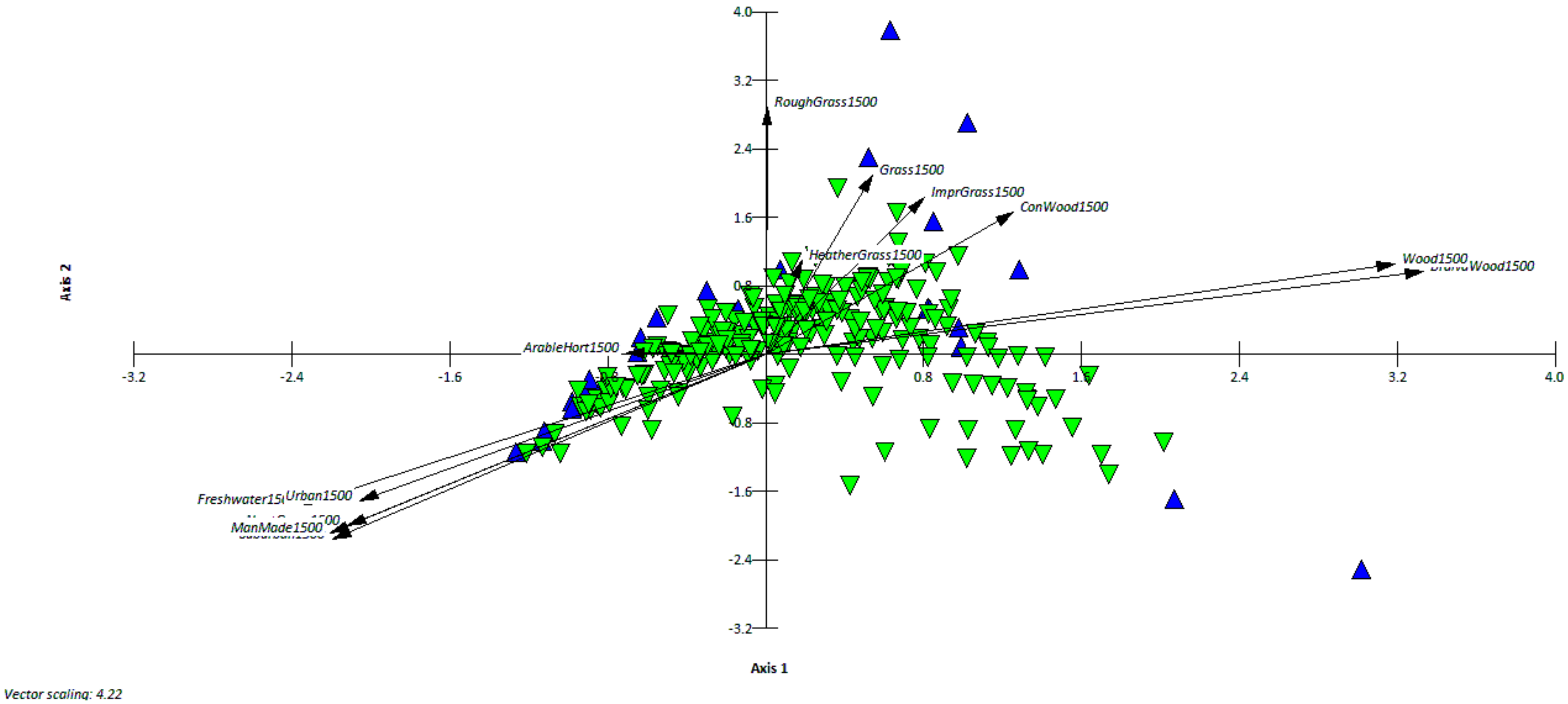
Appendix 1: CCA bi-plot for Northamptonshire county moth trap data and Land Cover Map landscape variables at 500m buffer zone (Chapter Four).



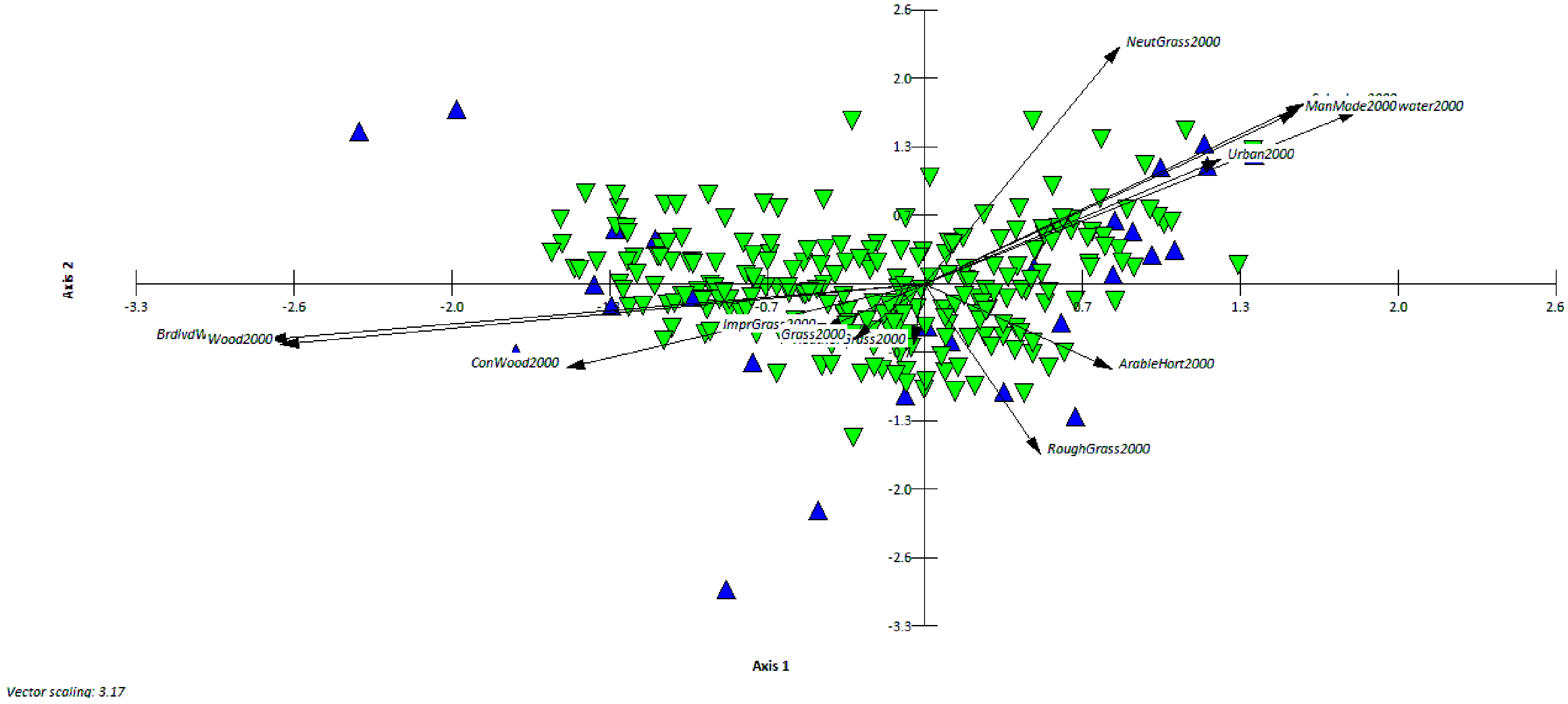
Appendix 2: CCA bi-plot for Northamptonshire county moth trap data and Land Cover Map landscape variables at 1000m buffer zone (Chapter Four).



Appendix 3: CCA bi-plot for Northamptonshire county moth trap data and Land Cover Map landscape variables at 1500m buffer zone (Chapter Four).



Appendix 4: CCA bi-plot for Northamptonshire county moth trap data and Land Cover Map landscape variables at 2000m buffer zone (Chapter Four).



Appendix 5: 2011/12 trapping: species list with national and local status, as well as total abundance at the two study sites.

Common Name	Scientific Name	Status	Local Abundance	Moulton	Kelmarsh
Angle shades	*Phlogophora meticulosa*	Common and widespread	Common	1	2
Centre-barred sallow	*Atethmia centrago*	Common and widespread	Common	2	0
Barred straw	*Eulithis pyraliata*	Common and widespread	Common	11	4
Blood vein	*Timandra comae*	Research only BAP	Common	1	2
Bright-line brown eye	*Lacanobia oleracea*	Common and widespread	Common	8	3
Brimstone	*Opisthograptis luteolata*	Common and widespread	Very common	8	12
Brindled beauty	*Lycia hirtaria*	Research only BAP	Fairly common	1	0
Brown line bright eye	*Mythimna conigera*	Common and widespread	Common	89	39
Brown rustic	*Rusina ferruginea*	Common and widespread	Common	1	2
Buff arches	*Habrosyne pyritoides*	Common and widespread	Common	0	3
Buff Ermine	*Spilosoma luteum*	Research only BAP	Common	7	9
Buff tip	*Phalera bucephala*	Common and widespread	Common	1	0
Burnished Brass	*Diachrysia chrysitis*	Common and widespread	Common	1	3
Chestnut	*Conistra vaccinii*	Common and widespread	Common	0	1
Chinese character moth	*Cilix glaucata*	Common and widespread	Common	0	1
Clay	*Mythimna ferrago*	Common and widespread	Common	0	2
Cloaked minor	*Mesoligia furuncula*	Common and widespread	Common	3	1
Clouded bordered brindle	*Apamea crenata*	Common and widespread	Common	0	1
Clouded brindle	*Apamea epomidion*	Common and widespread	Fairly common	1	1
Clouded drab	*Orthosia incerta*	Common and widespread	Very common	1	0
Clouded silver	*Lomographa temerata*	Common and widespread	Common	3	7
Common carpet	*Epirrhoe alternata*	Common and widespread	Common	67	34
Common footman	*Eilema lurideola*	Common and widespread	Very common	4	1

Common Name	**Scientific Name**	**Status**	**Local Abundance**	**Moulton**	**Kelmarsh**
Common quaker	*Orthosia cerasi*	Common and widespread	Very common	4	0
Common rustic	*Mesapamea secalis*	Common and widespread	Very common	82	97
Common swift	*Hepialus lupulinus*	Common and widespread	Very common	337	694
Common wainscot	*Mythimna pallens*	Common and widespread	Very common	157	118
Common wave	*Cabera exanthemata*	Common and widespread	Common	1	0
Copper Underwing	*Amphipyra pyramidea*	Common and widespread	Common	3	2
Coxcomb prominent	*Ptilodon capucina*	Common and widespread	Common	2	2
Dark arches	*Apamea monoglypha*	Common and widespread	Very common	90	57
Dark brocade	*Blepharita adusta*	Common and widespread	Locally common	1	0
Dark dagger	*Acronicta tridens*	Common and widespread		1	0
Dingy footman	*Eilema griseola*	Common and widespread		23	26
Double Square-spot	*Xestia triangulum*	Common and widespread		0	2
Drinker	*Euthrix potatoria*	Common and widespread		2	0
Dun-bar	*Cosmia trapezina*	Common and widespread		2	11
Dusky Sallow	*Eremobia ochroleuca*	Common and widespread		6	19
Early thorn	*Cosmia trapezina*	Common and widespread		2	9
Flame	*Axylia putris*	Common and widespread		4	3
Flame shoulder	*Ochropleura plecta*	Common and widespread		5	17
Flounced Rustic	*Luperina testacea*	Common and widespread		124	89
Gothic	*Naenia typica*	Common and widespread		47	26
Green carpet	*Colostygia pectinataria*	Common and widespread		0	3
Heart and Club	*Agrotis clavis*	Common and widespread		2	0
Heart and dart	*Agrotis exclamationis*	Common and widespread		201	155
Hebrew character	*Orthosia gothica*	Common and widespread		26	3
Herald	*Scoliopteryx libatrix*	Common and widespread		0	2
Ingrailed clay	*Diarsia mendica*	Common and widespread		32	49
July highflyer	*Hydriomena furcata*	Common and widespread		0	1
Large nutmeg	*Apamea anceps*	Research only BAP		10	12

Common Name	Scientific Name	Status	Local Abundance	Moulton	Kelmarsh
Large wainscoat	*Rhizedra lutosa*	Research only BAP		1	0
Large yellow underwing	*Noctua pronuba*	Common and widespread		39	16
Least yellow underwing	*Noctua interjecta*	Common and widespread		9	2
Lesser broad-bordered yellow underwing	*Noctua janthe*	Common and widespread		14	23
Lesser yellow underwing	*Noctua comes*	Common and widespread		7	13
Light arches	*Apamea lithoxylaea*	Common and widespread		1	1
Lychnis	*Mesapamea didyma*	Common and widespread		2	0
Magpie	*Abraxas grossulariata*	Common and widespread		1	18
Marbled minor	*Oligia strigilis*	Common and widespread		14	3
Middle-barred minor	*Oligia fasciuncula*	Common and widespread		36	17
Mottled Beauty	*Alcis repandata*	Common and widespread		8	7
Mottled rustic	*Caradrina morpheus*	Research only BAP		1	0
Mouse moth	*Amphipyra tragopoginis*	Research only BAP		2	0
Muslin moth	*Diaphora mendica*	Common and widespread		10	7
Nutmeg	*Discestra trifolii*	Common and widespread		34	26
Orange swift	*Hepialus sylvina*	Common and widespread		17	6
Pale mottled willow	*Paradrina clavipalpis*	Common and widespread		4	0
Pale prominent	*Pterostoma palpina*	Common and widespread		3	0
Pebble prominent	*Notodonta ziczac*	Common and widespread		1	0
Peppered moth (insularia)	*Biston betularia*	Common and widespread		1	2
Pinion streaked snout	*Schrankia costaestrigalis*	Common and widespread		2	2
Poplar hawkmoth	*Laothoe populi*	Common and widespread		0	1
Plain Gold Y	*Autographa jota*	Common and widespread		4	8
Powdered quaker	*Orthosia gracilis*	Research only BAP		1	1
Privet hawkmoth	*Sphinx ligustri*	Common and widespread		2	3
Pug (Eupithicus sp.)	*Eupithecia species*	Common and widespread		33	22
Red twin-spot carpet	*Xanthorhoe spadicearia*	Common and widespread		1	0
Riband Wave	*Idaea aversata*	Common and widespread		16	13

Common Name	**Scientific Name**	**Status**	**Local Abundance**	**Moulton**	**Kelmarsh**
Rosy Rustic	*Hydraecia micacea*	Research only BAP		0	10
Ruby tiger	*Phragmatobia fuliginosa*	Common and widespread		2	16
Rustic	*Hoplodrina blanda*	Research only BAP		3	14
Rustic shoulder-knot	*Apamea sordens*	Common and widespread		83	42
Scalloped hazel	*Odontopera bidentata*	Common and widespread		64	10
Scalloped oak	*Crocallis elinguaria*	Common and widespread		1	0
Setaceous hebrew character	*Xestia c-nigrum*	Common and widespread		1	4
Shaded broad bar	*Scotopteryx chenopodiata*	Common and widespread		0	1
Shoulder-striped wainscot	*Mythimna comma*	Common and widespread		2	0
Shuttle-shaped dart	*Agrotis puta*	Common and widespread		38	2
Silver ground carpet	*Xanthorhoe montanata*	Common and widespread		26	9
Silver Y	*Autographa gamma*	Common and widespread		22	2
Single-dotted wave	*Idaea dimidiata*	Common and widespread		0	4
Six striped rustic	*Xestia sexstrigata*	Common and widespread		0	5
Small clouded brindle	*Apamea unanimis*	Common and widespread		0	1
Small dotted buff	*Photedes minima*	Common and widespread		0	1
Small quaker	*Orthosia cruda*	Common and widespread		0	1
Small rivulet	*Perizoma alchemillata*	Common and widespread		0	1
Small square spot	*Diarsia rubi*	Common and widespread		2	0
Snout	*Hypena proboscidalis*	Common and widespread		7	1
Spinach	*Eulithis mellinata*	Research only BAP		1	0
Square-spot rustic	*Xestia xanthographa*	Common and widespread		83	99
Streamer	*Anticlea derivata*	Common and widespread		1	0
Suspected	*Parastichtis suspecta*	Common and widespread		0	1
Tawny marbled minor	*Oligia latruncula*	Common and widespread		4	2
Turnip moth	*Agrotis segetum*	Common and widespread		54	2
Twin spot carpet	*Perizoma didymata*	Common and widespread		1	0
Uncertain	*Hoplodrina alsines*	Common and widespread		57	75

Common Name	**Scientific Name**	**Status**	**Local Abundance**	**Moulton**	**Kelmarsh**
Waved umber	*Menophra abruptaria*	Common and widespread		2	0
White Ermine	*Spilosoma lubricipeda*	Research only BAP		11	16
Willow Beauty	*Peribatodes rhomboidaria*	Common and widespread		2	1

Appendix 6: 2013 trapping Moth species list with national and local status and total site abundance.

Species	**Scientific name**	**National Status**	**Local Abundance**	**Moulton**	**Kelmarsh**
Angle shades	*Phlogophora meticulosa*	Common and widespread	Common	1	0
Barred straw	*Eulithis pyraliata*	Common and widespread	Common	68	15
Beautiful hook-tip	*Laspeyria flexula*	Local	Very local	0	1
Blackneck	*Lygephila pastinum*	Local	Local	0	4
Blood vein	*Timandra comae*	Research only BAP	Common	4	51
Bright-line brown eye	*Lacanobia oleracea*	Common and widespread	Common	16	39
Brimstone	*Opisthograptis luteolata*	Common and widespread	Very common	8	2
Brown rustic	*Mythimna conigera*	Common and widespread	Common	0	9
Brown-line bright eye	*Rusina ferruginea*	Common and widespread	Common	123	79
Buff arches	*Habrosyne pyritoides*	Common and widespread	Common	0	8
Buff Ermine	*Spilosoma luteum*	Common and widespread	Common	12	11
Buff tip	*Phalera bucephala*	Common and widespread	Common	3	4
Burnished brass	*Diachrysia chrysitis*	Common and widespread	Common	9	28
Clay	*Mythimna ferrago*	Common and widespread	Common	10	30
Clouded bordered brindle	*Apamea crenata*	Common and widespread	Common	0	2
Clouded silver	*Lomographa temerata*	Common and widespread	Common	6	11
Common carpet	*Epirrhoe alternata*	Common and widespread	Common	6	0
Common footman	*Eilema lurideola*	Common and widespread	Very common	4	4
Common marbled carpet	*Chloroclysta truncata*	Common and widespread	Common	4	2
Common rustic	*Mesapamea secalis*	Common and widespread	Very common	9	7
Common swift	*Hepialus lupulinus*	Common and widespread	Very common	11	74
Common wainscot	*Mythimna pallens*	Common and widespread	Very common	16	0
Common white wave	*Cabera pusaria*	Common and widespread	Common	1	4
Coxcomb prominent	*Ptilodon capucina*	Common and widespread	Common	3	2
Cream wave	*Scopula floslactata*	Local	Rather local	12	3
Dark arches	*Apamea monoglypha*	Common and widespread	Very common	75	63
Double dart	*Graphiphora augur*	Common and widespread	Rather local	0	96

Species	**Scientific name**	**National Status**	**Local Abundance**	**Moulton**	**Kelmarsh**
Double square spot	*Xestia triangulum*	Common and widespread	Common	47	71
Drinker	*Euthrix potatoria*	Common and widespread	Common	10	25
Dwarf cream wave	*Idaea fuscovenosa*	Local	Rather local	1	0
Elephant hawk moth	*Deilephila elpenor*	Common and widespread	Common	1	0
Eyed hawk moth	*Smerinthus ocellata*	Common and widespread	Common	0	1
Flame	*Axylia putris*	Common and widespread	Common	20	5
Flame shoulder	*Ochropleura plecta*	Common and widespread	Very common	4	9
Ghost moth	*Hepialus humuli*	Common and widespread	Common	5	0
Gothic	*Naenia typica*	Common and widespread	Rather local	0	5
Green carpet	*Colostygia pectinataria*	Common and widespread	Common	12	1
Green pug	*Pasiphila rectangulata*	Common and widespread	Common	3	2
Green silver lines	*Pseudoips prasinana*	Common and widespread	Fairly Common	0	1
Grey dagger	*Acronicta psi*	Common and widespread	Common	5	1
Heart and dart	*Agrotis exclamationis*	Common and widespread	Very common	71	137
Ingrailed clay	*Diarsia mendica*	Common and widespread	Common	6	8
Knotgrass	*Acronicta rumicis*	Common and widespread	Common	0	1
Large nutmeg	*Apamea anceps*	Common and widespread	Common	1	0
Large yellow underwing	*Noctua pronuba*	Common and widespread	Very common	6	8
Small angle shades	*Euplexia lucipara*	Common and widespread	Common	0	1
Light arches	*Apamea lithoxylaea*	Common and widespread	Common	1	4
Light emerald	*Campaea margaritata*	Common and widespread	Fairly Common	5	2
Lime-speck pug	*Eupithecia centaureata*	Common and widespread	Common	0	1
Lychnis	*Mesapamea didyma*	Common and widespread	Common	14	10
Marbled minor	*Oligia strigilis*	Common and widespread	Common	31	13
Middle-barred minor	*Oligia fasciuncula*	Common and widespread	Common	93	49
Mottled Beauty	*Alcis repandata*	Common and widespread	Common	38	69
Mottled pug	*Eupithecia exiguata*	Common and widespread	Common	0	2
Mottled rustic	*Caradrina morpheus*	Common and widespread	Very common	118	140
Nutmeg	*Discestra trifolii*	Common and widespread	Fairly Common	1	2
Pale mottled willow	*Paradrina clavipalpis*	Common and widespread	Common	2	2

Species	**Scientific name**	**National Status**	**Local Abundance**	**Moulton**	**Kelmarsh**
Pale prominent	*Pterostoma palpina*	Common and widespread	Common	2	2
Plain gold y	*Autographa jota*	Common and widespread	Common	2	9
Poplar hawkmoth	*Laothoe populi*	Common and widespread	Common	0	2
Privet hawkmoth	*Sphinx ligustri*	Common and widespread	Local	1	5
Pug	*Eupithecia species*	Common and widespread	Common	11	7
Riband wave	*Idaea aversata*	Common and widespread	Very common	1	3
Rustic shoulder knot	*Apamea sordens*	Common and widespread	Common	41	17
Sandy carpet	*Perizoma flavofasciata*	Common and widespread	Fairly Common	1	0
Scarce footman	*Eilema complana*	Local	Common	0	1
Scorched wing	*Plagodis dolabraria*	Common and widespread	Common	0	1
Setaceous hebrew character	*Xestia c-nigrum*	Common and widespread	Very common	22	9
Shoulder-striped wainscot	*Mythimna comma*	Common and widespread	Common	5	2
Silver ground carpet	*Xanthorhoe montanata*	Common and widespread	Common	25	22
Silver y	*Autographa gamma*	Common and widespread	Very common	1	1
Single dotted wave	*Idaea dimidiata*	Common and widespread	Common	9	4
Small dotted buff	*Photedes minima*	Common and widespread	Common	0	3
Smoky wainscot	*Mythimna impura*	Common and widespread	Common	47	168
Snout	*Hypena proboscidalis*	Common and widespread	Common	80	21
Spectacle	*Abrostola tripartita*	Common and widespread	Common	1	0
Square spot rustic	*Xestia xanthographa*	Common and widespread	Very common	0	3
Straw dot	*Rivula sericealis*	Common and widespread	Common	1	1
Swallowtail	*Ourapteryx sambucaria*	Common and widespread	Common	1	0
Turnip moth	*Agrotis segetum*	Common and widespread	Common	0	1
White banded carpet	*Spargania luctuata*	Local	Very local	1	0
White Ermine	*Spilosoma lubricipeda*	Common and widespread	Common	8	27
Yellow shell	*Camptogramma bilineata*	Common and widespread	Common	4	0

Appendix 7: Plant species found at the two study sites and the number of locations where species was present throughout the study.

		Number of locations present	
Common Name	**Scientific Name**	**Moulton**	**Kelmarsh**
Ash	*Fraxinus excelsior*	11	8
Black Bryony	*Dioscorea communis*	1	1
Black Nightshade	*Solanum nigrum*	3	0
Blackthorn	*Prunus spinosa*	9	13
Bladder Campion	*Silene vulgaris*	2	0
Borage	*Borago offcinalis*	0	1
Bracken	*Pteridium aquilinum*	2	0
Bramble	*Rubus fruticosus agg.*	8	14
Broad-leaved Dock	*Rumex obtusifolius*	10	12
Bulbous Buttercup	*Ranunculus bulbosus*	0	6
Burdock	*Arctium lappa*	4	1
Chickweed	*Stellaria media*	1	2
Cleavers	*Gallium aparine*	6	4
Common Field Speedwell	*Veronica persica*	4	0
Common Nettle	*Urtica dioica*	15	12
Common Ragwort	*Jacobaea vulgaris*	0	2
Cow Parsley	*Anthriscus sylvestris*	13	11
Crab Apple	*Malus sylvestris*	4	0
Crack Willow	*Salix fragilis*	2	0
Creeping Thistle	*Cirsium arvense*	2	10
Dandilion	*Taraxacum officinale*	2	4
Dog Rose	*Rosa canina*	9	9
Dogwood	*Cornus sanguinea*	2	0
Doves-foot Cranesbill	*Geranium molle*	2	6
Elder	*Sambucus nigra*	13	5
English Elm	*Ulmus procera*	7	2
English Oak	*Quercus robur*	5	7
Field Forget-me-not	*Myosotis arvensis*	0	2
Field Maple	*Acer campestre*	4	5
Garlic Mustard	*Alliaria petiolata*	3	5
Great Willowherb	*Epilobium hirsutum*	0	1
Greater Plantain	*Plantago major*	0	1
Ground Elder	*Aegopodium podagraria*	2	0
Ground Ivy	*Glechoma hederacea*	1	4
Hawthorn	*Crategus monogyna*	16	13
Hazel	*Corylus avellana*	0	1
Hedge Bindweed	*Calystegia sepium*	3	1
Hedgerow Cranesbill	*Geranium pyrenaicum*	1	0

		Number of locations present	
Common Name	**Scientific Name**	**Moulton**	**Kelmarsh**
Hoary Plantain	*Plantago media*	0	1
Hogweed	*Heracleaum sphondylium*	10	13
Horse Chestnut	*Aesculus hippocastanum*	1	1
Ivy	*Hedera helix*	7	1
Laburnum	*Laburnum anagyroides*	1	0
Lime	*Tilia platyphyllos*	3	2
Meadow Cranesbill	*Geranium pratense*	0	1
Oilseed Rape	*Brassica napus*	1	2
Pear	*Pyrus communis*	1	0
Red Campion	*Selene dioica*	1	0
Red Dead Nettle	*Lamium purpureum*	1	0
Rosebay Willowherb	*Chemerion angustifolium*	3	6
Scarlet Pimpernel	*Anagallis arvensis*	0	1
Scentless Mayweed	*Tripleurospermum inodurum*	1	3
Sessile Oak	*Quercus petraea*	1	0
Shepard's Purse	*Capsella bursa-pastoris*	1	3
Silver Birch	*Betula pendula*	1	0
Spear Thistle	*Cirsium vulgare*	6	12
Sycamore	*Acer pseudoplatynoides*	2	0
Turkey Oak	*Quercus cerris*	1	0
White Campion	*Silene latifolia*	3	0
White Clover	*Trifolium repens*	0	2
White Dead Nettle	*Lamium album*	7	3
Wild Cherry	*Prunus padas*	2	1