UNIVERSITY OF OXFORD

A comparison of hedgerow management upon butterfly biodiversity in Oxfordshire and Buckinghamshire

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Contents

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Chapter 1

Abstract

Hedgerows form a network of often relict woodland habitat across the UK. They are also important features in our cultural history and landscape. They are habited by many woodland and woodland edge species, including butterflies that utilise them as a food source, for shelter and reproduction. Butterflies are one of the simplest invertebrates to monitor and can provide a good indication of the health and biodiversity of a habitat.

The mechanisation of farming in the 20th century saw the destruction of at least 50% of our hedgerows. This destruction puts further pressure on our native species that have already been marginalised by the lack of natural and semi-natural land available in the UK. The correct management of hedgerows could conceivably provide a connected and permanent habitat for these species in the wider countryside. The ubiquity of hedgerows could thus also allow for the adaptation required due to the changes in our climate moving into the future.

Hedgerows, as a man-made habitat, have to be regularly maintained. Hedge-laying is thousands of years old, but despite resurgence in the traditional techniques, most hedges in the UK are management only with a flail, which presents problems for biodiversity. An innovative technique devised in Buckinghamshire aims to improve hedge-laying for biodiversity. This study looks into the diversity of flora and butterflies at 18 hedges managed with one of three types: traditional laying, wildlife laying and flailing. The results indicate that it is a combination of factors that control the biodiversity found at a hedge, and that this biodiversity, particularly of invertebrates, may be subject to rapid change in the wider countryside. Wildlife-laying alone will not save biodiversity in the UK countryside, but it is a fantastic step in the right direction to developing new techniques for hedge management.

Key words: Butterflies; Hedgerows; Hedge-laying; Environmental Stewardship; Landscape biodiversity; Landscape conservation

Preface

The focus of this study is to elucidate whether the management method applied to a hedgerow affects the invertebrate diversity, specifically butterflies, found within the hedge. Hedgerows provide landscape wide, connected habitat, through much of our agricultural land, which may otherwise be largely inhospitable to invertebrate fauna. Moving to the future, suitable habitat with high connectivity at the landscape level may help UK species to adapt more easily to a changing climate. Therefore, making our hedgerows as biodiversity-friendly as possible is very important.

The second chapter aims to place the importance of the study in the literature and conservation in the UK. The ecology and conservation status of butterflies and of hedgerows are examined. The current methods used to survey and protect these two groups are highlighted. Concerns for the future of butterflies in the UK and Europe are discussed and the role of hedgerows in the adaptation to climate change is considered. Management of hedgerows currently and in the UK historically is introduced.

The third chapter presents the data collected on the different hedge management types; the traditional- and wildlife-laying types, and flailing. The three management types are compared and contrasted with reference to the diversity of woody and herbaceous plants and the diversity of butterflies. Standard methodologies used in the UK by the British Butterfly Monitoring Scheme and by the Department for Environment, Farming and Rural Affairs (Defra) and Natural England are applied to ensure that the research would be repeatable and analogous to studies on a similar topic in the future. Hedges are studied from a variety of land-use types in order to present a more representative picture of the affect of the hedge management techniques in the wider countryside. The results of the field work are discussed in relation to the knowledge gained in chapter 2.

Chapter 2 : The UK Countryside – Hedges and Butterflies

Butterflies

Butterfly monitoring

The UK Butterfly Monitoring Scheme (BMS) was originally set up in order to provide objective information about the changes in abundance of butterflies in the UK. Early trials for the methodology began in Monks Wood in Cambridgeshire in 1973 (Pollard and Yates, 1993); the scheme has officially been monitoring butterflies since 1976 (UK Butterfly Monitoring Scheme, 2006b). The aim was to develop a sampling method that could be used UK wide, that would be quick, simple and provide good estimates of population size. Since methods of invertebrate survey such as capture-mark-recapture were considered to be too time-consuming and risked altering the butterflies' behaviour, the transect method was used. The transect method involves mapping out a route (the transect) within the required habitat, including areas perceived to be good and bad for butterflies. The transect routes are separated into a maximum of 15 sections, each of which is recorded separately. This allows the spatial distribution of butterflies within the habitat to be monitored. The surveyor walks the transect route at steady pace, recording all the butterflies they see within an approximately 5m extent. The optimum transect is considered to be approximately 3km and should take between 60-90 minutes to record. The transect method results in an index of relative abundance, rather than an actual measurement of the population size. Various rules surround the recorder to ensure that one individual is not counted twice and that a true sample of the butterflies present is taken. Recording is restricted to between 10.15 and 15.45 British Summer Time, when the shade temperature is over 17°C and the wind speed is no more than force 5 on the Beaufort scale. The recording season, lasts from the 1st April to the 29th

September, inclusive; a dip in the number recorded in June is normally expected (Pollard and Yates, 1993).

This year, a new method, based upon the British Trust for Ornithology's Breeding Bird Survey is being introduced. Over 1000, randomly selected 1km squares are due to be sampled by volunteers. The aim is to provide a truly representative picture of the status of common species in the UK (Bowles and Fox, 2009). The bias with the BMS data is that the transect routes are most commonly on nature reserve land. The new surveys will include farmland, plantation woodland, uplands and urban areas also (Butterfly Conservation, 2009a). Smart *et al*. (2000) found less correlation with food plants of butterflies than had previously been recorded; however, as suggested by the authors, their data was based upon the UK BMS data and vegetation information on agricultural land. Sedentary species in this study may, therefore have been misrepresented; knowing the vegetation and butterfly diversity in the same location is advantageous to analysis.

Butterfly status and conservation

The UK BMS has indicated that there has been a general decline in butterfly species over the last 30 years. Specialist species have tended to fair worse than generalist species, and although there was a rising population trend between 2001 and 2005 (UK Butterfly Monitoring Scheme, 2006a), the last two years have been particularly bad for butterflies (Butterfly Conservation, 2009). In 2008, the Common Blue (*Polyommatus icarus* Rottemberg) was down 50% on its 2006 sightings; the Peacock (*Inachis io* Linnaeus) and the Dingy and Large Skippers (*Ochlodes sylvanus* Esper and *Erynnis tages* Linnaeus) had their worst years on record; the Green Hairstreak (*Callophrys rubi* Linnaeus) and Small Tortoiseshell (*Aglais urticae* Linnaeus) were down by 40% each from the 2007 averages;

and, the Orange-tip (*Anthocharis cardamines* Linnaeus) was down 25% as well. Migrant species such as the Painted Lady (*Vanessa cardui* Linnaeus) and Red Admiral (*Vanessa atalandta* Linnaeus) also had reduced numbers from their 2007 figures (Butterfly Conservation, 2009). The overall cause of the decline is thought to be a reduction in suitable habitats: such as heathland, coppiced woodlands and unimproved chalk grasslands (Pollard and Yates, 1993). However, the poor summer weather is thought to have played a large part in the declines over recent years. Heavy rain reduces adult survival, fecundity and migrations (Cowling, 2009). The Whites managed small increases, displaying their resilience to the poor weather, and some other species such as the Ringlet (*Aphantopus hyperantus* Linnaeus) and Speckled Wood (*Pararge aegeria* Linnaeus) showed some improvements in 2008, from their 2007 lows. However, this didn't stop 2008 from being the second poorest year for butterflies since monitoring began by the UK BMS. Fortunately, recent research has indicated that many species have benefited from refuge in private gardens (Vickery, 2009); the declines in most species were less pronounced in private gardens than the UK BMS results would suggest. The hope is, that 2009 will be a better year for butterflies, preliminary evidence suggests that the situation has improved from 2008, with large numbers of Painted Ladies emerging in North Africa and a number of our spring species emerging sooner than expected, for example, the Green Hairstreak, Common Blue and Duke of Burgundy (*Hamearis lucina* Linnaeus). A good number of individuals were recorded in the second week of April and several recorders reached their "best ever one-day April scores" (Bowles and Fox, 2009).

Looking to the future, climate change is expected to have the biggest impact on butterfly numbers in the UK, and Europe as a whole. The last few wet years have shown what effect the weather can have on populations in the short term. In the last two decades, 15 British species have shown marked northern and western movements in the UK. The Climatic Risk

Atlas of European Butterflies, developed by Settele *et al*. in Germany (Warren and Collins, 2009), uses Bioclimatic Envelope Modelling methodology to map how the range of any given species might change under different climate change scenarios and varying levels of dispersal. For example, the Small Tortoiseshell stands to lose up to 55% of its climatic niche if it is unable to disperse. However, even with full dispersal, the loss could still reach 46% (Warren and Collins, 2009). The most extreme scenarios show that 24% of butterfly species in Europe could lose more than 95% of their climatic space, whilst the least extreme scenarios expect only 3% of species to lose 95% of their climatic niche space (Warren and Collins, 2009). The variation in projection means that maintaining large populations in diverse, connected, resilient habitats, while reducing greenhouse gas emissions and adopting more wildlife friendly land management options is the only way that we have a hope of mitigating and allowing adaption to these changes (Settele *et al.*, 2008).

Butterflies as a surrogate for biodiversity

For the purpose of conservation planning, it is necessary to understand the state of the biodiversity in the area(s) in question. Invertebrates are considered to be "indispensable components" of biodiversity (Lovell *et al.*, 2007), but, full invertebrate surveys are time consuming, poorly funded and require considerable expertise for identification across the many taxa (Lovell *et al.*, 2007). As a result of these issues, examining the plausibility of suitable surrogates for biodiversity has become quite popular within the scientific literature. A surrogate should be an easily monitored factor that holds a close association with biodiversity, so the measurement of such factor may be used to infer the level of biodiversity present in a system. A surrogate might be an environmental variable (Bossenbroek *et al.*, 2005), such as temperature, or, more usually, it might be a particular Group or Family of species; it can also refer to using a higher taxon than the species level to identify an individual.

Different types of surrogate have been investigated for identifying different scales of biodiversity, with mixed success. Using higher taxa for identification has been quite a successful surrogacy method, but only in species-poor Genera and Families (Lovell *et al.*, 2007). Generalising, success has been borne more frequently when working at the single habitat scale (Prendergast and Eversham, 1997) and using a multi-taxa approach to represent the total biodiversity (Sauberer *et al.*, 2004). Biodiversity, when measured in terms of number of species and abundance, also makes the use of a surrogate more successful than just using species richness alone (Maccherini *et al.*, 2009). At smaller scales, this type of surrogacy works more rarely, presumably because other environmental and species interaction factors come into play and/or the scale of measurement chosen may well be smaller than the home ranges of the individuals or populations in question (Lovell *et al.*, 2007).

At the scale of the habitat, vascular plants have been shown to be a good surrogate for biodiversity generally (Sauberer *et al.*, 2004, Su *et al.*, 2004, Kati *et al.*, 2004); for butterflies (Su *et al.*, 2004) and, for invertebrates as a whole (Panzer and Schwartz, 1998, Saetersdal *et al.*, 2004). Accordingly to the literature, the most important thing when choosing a suitable surrogate is the scale at which you are working, both of the habitats and of the taxa you wish to survey. Hedgerows may be a suitable habitat scale; as they are distinct from the habitat surrounding them and as such may provide a refuge for species with those specific requirements. Hence, hedgerow vegetation may be a suitable surrogate of hedgerow biodiversity. The diversity of vegetation directly affects the number of species guilds that can feed in a habitat; utilising the leaves, stems, barks, buds, flowers, fruits, seeds (Maudsley, 2000) and dead material (Jonsson *et al.*, 2005). In turn, this drives the diversity of predatory, parasitic and symbiotic species (Maudsley, 2000) that survive. A wide range of vegetation allows there to be a supply of food sources throughout the year, the phenology creating different opportunities for different species. In particular, the growth of new leaves and abundance of flowers allows for the success of species whose life-cycle coincides with these events (Maudsley, 2000), such as butterflies. Consequently, all aspects of a hedge, including the trees, structural species and basal vegetation contribute towards the diversity of invertebrates that can be found within, as the range of ecological niches available increases (Maudsley, 2000).

Butterflies and vascular plants also show considerable correlation in diversity, probably due to their co-evolution (Maccherini *et al.*, 2009). However, plants take longer to react to changing conditions than insects do (Maccherini *et al.*, 2009), therefore, in the case of hedgerows, which are disrupted by being laid, trimmed or affected by agricultural activities; insects themselves are likely to be a better indicator of the biodiversity of the faunal element of the hedgerow in question. Butterflies have been used effectively to assess the success of grassland restoration, because of their close relationship with plants and as an indicator for other invertebrates (Maccherini *et al.*, 2009). In particular, butterflies may be representative of other nectar-feeding invertebrates, for example bees. Due to the current decline in bee species in the UK and the world, their conservation is of growing importance (Pywell *et al.*, 2006). The importance of invertebrates as a whole in ecosystems should not be under-estimated; they are key components of pollination, soil formation, soil fertility, plant productivity, organic decomposition and regulation of other populations by predation and parasitism (Lovell *et al.*, 2007).

Habitat requirements

The precise habitat requirements of butterflies vary greatly from species to species. Famously, the Adonis Blue butterfly (*Polyommatus bellargus* Rottemburg) has a complex life cycle associated with its larval foodplant, Horseshoe Vetch (*Hippocrepis comosa* Linnaeus) and its symbiotic relationship with, the red ant, *Myrmica sabuleti* Meinert or the small black ant, *Lasius alienus* Foerster (Butterfly Conservation & Defra, 2005). Other species, such as the Ringlet, feed on many plants, including a variety of grasses and sedges (Pollard and Yates, 1993). Croxton *et al* (2005) found strong correlation between vegetation diversity and butterfly diversity when studying green lanes in Cambridgeshire. They found that the double hedgerows that made up the green lanes provided increased shelter from herbicide application and a greater diversity of microclimates suitable for butterfly oviposition. From their findings they postulate that infrequent management of the green lanes, at an optimum level of disturbance to enhance the number of flowering species in the interior but not so much as to destroy the butterfly populations, is best. Landscape features such as green lanes, banks and verges can also provide shelter against predation and unfavourable weather conditions (Dover, 1996). The provision of shelter is especially important for those species with more closed populations, such as the Meadow Brown (*Maniola jurtina* Linnaeus) or Gatekeeper (*Pyronia tithonus* Linnaeus). Conversely, butterflies such as the Large White (*Pieris brassicae* Linnaeus), Small Tortoiseshell and Brimstone (*Gonepteryx rhamni* Linnaeus) are likely to be less affect by the provision of sheltered habitat (Dover, 1996). Excessive disruptions, either by frequency or intensity, such as hedge-laying or agro-chemical drift can greatly affect ecosystems, by making the supply of resources unpredictable (Feber *et al.*, 1996). In the case of butterflies, it is the supply of the adult and juvenile food plants that are most important. These are mostly perennial herbs, but many grasses are also required by some species e.g. Meadow Brown and Gatekeeper for oviposition. The adults and juvenile stages are most affected by the resource supply and direct mortality factors such as insecticide spray (Feber and Smith, 1995).

Hedgerows

Hedgerow structure and ecology

A hedgerow is a man-made structure; a more or less continuous line of trees and/or shrubs that is more than 20 metres long and less than 5 metres wide at the base (Defra, 2007). Hedge-laying, of various styles and techniques has been practiced since before 55BC (National Hedgelaying Society, 2009b). In the UK, the traditional hedge-laying known today has been around since the 18th century (National Hedgelaying Society, 2009b). Hedgerows are normally placed on boundary lines to indicate land ownership, but also have other uses such as, to contain livestock or for aesthetics. The hedgerow may also include any earth banks, ditches or walls, where they provide an integral component of the structure. The extent of a hedgerow can be defined by major changes in its structure (a node). At the node, the hedgerow is considered to be finished. Joins with woodlands, fences, rivers, ponds and roads, also represent nodes. In addition, if there is a change in character or major management type for more than 20 metres, then the hedgerow is also considered to have changed sufficiently to be recorded as a second hedge. The structure of a hedge, in terms of banks, walls and fences as well as the living structures varies enormously across the UK and between individual hedges (Maudsley, 2000).

A review by Maudsley (2000) describes the state of invertebrate ecology and conservation in hedgerows. Initially, work into hedgerow ecology in the UK focussed on them as a source for insect pests. Hedges are notoriously difficult to evaluate in terms of invertebrate ecology, as accessing the central parts of the hedge is almost impossible using conventional methods. As a result, most of the studies that have been done on hedgerows focus on butterflies (Maudsley, 2000). Agricultural land covers approximately 74% of the surface of the UK thus, the 468,000 km network of hedgerows (Defra, 2005, Barr *et al.*, 1991) often appear on agricultural land. It is generally considered that hedgerows are important for much of our native wildlife as the majority of our countryside has been altered for farming, housing and industry. The flora and fauna contained within most hedges are likely to be characteristic of other habitats, such as woodlands (Feber and Smith, 1995). Comparatively speaking, much less is known about the ecology of hedgerows, compared to other protected habitats, such as heathland (Maudsley, 2000).

In order to help direct conservation efforts, particular characteristics, known to affect the diversity, abundance and behaviour of invertebrates, can be used to clarify general patterns in hedgerows. A high diversity of plant species has been shown a number of times to directly influence the diversity of invertebrates (Sauberer *et al.*, 2004, Su *et al.*, 2004, Kati *et al.*, 2004, Saetersdal *et al.*, 2004, Panzer and Schwartz, 1998). However, it is not simply the diversity of plants that is important, but the individual species that exist there as well; some species support considerably more invertebrates than others for example, Hawthorn (*Crataegus monogyna* Linnaeus) may be associated with over 200 invertebrate species but Holly (*Ilex aquifolium* Linnaeus) with only 10 (Maudsley, 2000). In addition, the presence of hedgerow trees, which vary the structure of the hedgerow further have also been shown to be an important factor for invertebrates, particularly moths (Merckx *et al.*, 2009). The adjacent shelter provided by the hedge is very important for invertebrates; higher abundance and species richness is usually found closer to the hedge itself (Dover, 1996) and also more sustained populations are found at nodes (Dover, 1996). Finally, hedges create a connected and relatively continuous habitat through the landscape and hence, may provide a suitable corridor for a number of species (Maudsley, 2000). Accordingly, the potential for hedgerows, as sheltering, diverse, connected and continuous habitat for our native butterfly species across the landscape is huge.

In the UK, ancient and/or species rich hedgerows have protection under the UK Biodiversity Action Plan (BAP) and there are at least 47 species of conservation concern thought to utilise hedgerows (Maudsley, 2000, The UK Biodiversity Steering Group, 1995). The majority of these are vertebrates, moths and butterfly species. However, this is more likely an indication of the gaps in our knowledge than a representation of all the endangered species that use hedgerows (Maudsley, 2000), especially other invertebrates. Dover and Sparks (2000) reported that 64% of all native or regular migrant British butterfly species had been recorded from hedgerows. They estimate that 26 species may be able to breed in hedgerows. This compares well with unimproved farmland habitats, in terms of species richness alone, thus, alongside unimproved, semi-natural and protected areas, hedgerows are very important for butterfly conservation. It has also been shown that the main shelter of the hedgerow may extend to 4 times its own height for Lepidoptera species (Dover and Sparks, 2000). Thus, when in conjunction with other land management techniques, for example, large field margins as recommended by the Entry Level Stewardship Scheme (Natural England, 2008), the area supported by a hedgerow may be 4 times the area measured by its length alone.

Traditional management

If left without interference (termed neglected), hedges will form a row of trees; a hedgerow is always a man-made, man-maintained structure. As previously discussed, when the hedgerow is highly diverse in terms of vegetation species richness and structure, the number of faunal species that it can support is expected to be higher. Therefore, ideally hedgerows will be managed to increase species and structural diversity. Hedge-laying, coppicing and trimming (or flailing) have all been used to maintain hedgerows (National Hedgelaying Society, 2009a). Diminished shelter, caused by gaps in the hedgerow may reduce the abundance of species (Maudsley, 2000) so continued maintenance is vital.

Hedge-laying comes in many forms. Although all techniques involve partially cutting the trunk of the tree or shrub close to the base and then folding and weaving the lengths (pleachers or stools) along the boundary line. These are then secured with stakes and in some cases with binding along the top of the hedge for additional stability (National Hedgelaying Society, 2009b), see figure 1. A living fence is created that should be impenetrable by livestock and able to re-grow. New shoots should come up from the main stem slits creating a dense hedge. The central pleachers may eventually die off (National Hedgelaying Society, 2009b), but this shouldn't affect the life of the hedge and in fact just adds another dimension to the complexity of the hedge.

Figure 1 The hedge at T7. The pleachers can just be seen towards the bottom of the hedge, weaving in between the vertical stakes. This hedge has been bound at the top for further stability.

Coppicing management can also be used; removal of the stems from the base, and so complete removal of the hedge, encourages new growth from the stumps. Coppicing is particularly useful for regenerating neglected hedges, although a stock proof barrier is necessary to prevent damaging from browsing during the earlier stages of re-growth (Brooks and Agate, 1998). Coppicing has previously been adopted as part of the harvesting of timber, for building works, furniture and fuel, but this practice has reduced in recent years (Hedgelink, 2008c).

Figure 2 The hedge at F3. The flailed hedge can be seen to the right-hand-side. The hedge is uniform in shape and the bulk of the foliage starts higher off the ground than the traditional hedge in figure 1

Trimming, often using an attachment to a tractor called a flail, hence the term flailing, was developed during the mechanisation of the farming industry during the twentieth century, see figure 2. All hedges, including laid ones need to be trimmed in order to encourage bushy growth (Brooks and Agate, 1998). However, careful timing of trimming is required in order to reduce the impact on wildlife (Bealey *et al.*, 2009). Modern techniques that involve only flail trimming also lead to other problems, such as loss of stock-proofing by the openness of the base of the hedge and a reduction in the recruitment of hedgerow trees (Brooks and Agate, 1998).

Wildlife management

Traditional hedge-laying is a time consuming and costly technique which, particularly in the short term, does not appear to be favourable to wildlife (Scott, 2005). In response, another technique, using mechanical tools has been developed and titled wildlife-laying, see figure 3.

Figure 3 The hedge at W4. The laid wildlife hedge is generally wider than it is tall. The cross-sectional shape is closer to an 'A', rather than the top-heavy cross-sectional shape of the failed hedge.

The new technique involves cutting part the way through each main stem as close to the ground as possible using a petrol driven pruning saw. Using a telescopic handler mounted on a tractor, the stems are then gently pushed over following the hedge line; stakes and binders are not used. The hedge that is created is generally wide, particularly at the base, and somewhat messy-looking when compared to its traditionally laid or trimmed counterparts (Scott, 2005, Dodds, 2005). When the technique was first developed the hedge was used as a stock-proof barrier, the farmer reported that it provided good shelter for lambs during the lambing season, creating an improve survival rate (Scott, 2005). There are some possibly significant advantages to this technique when carried out properly:

- As much of the outer branch material is left as possible. Thus, the hedgerow will flower and fruit as normal during the first season after laying. Thus, any wildlife already in the hedge, Black hairstreak (*Satyrium pruni* Linnaeus) butterfly eggs for example (Maudsley, 2000), plausibly have a higher chance of survival during that first year, compared to the other techniques, because they and their food source are not destroyed.
- The resulting hedge is wider than the hedges the other techniques tend to produce and contains more dead material within its complex structure. Further complexity is thought to pertain to higher biodiversity, particularly affecting the invertebrate fauna (Maudsley, 2000, Jonsson *et al.*, 2005).
- It is cheaper and quicker than laying a traditional hedge of the same length (Dodds, 2005, Scott, 2005).

The new technique has not received universal praise so far. This is, in part, due to its appearance. The wildlife hedge looks untidy and the feeling among many people is that this indicates poor management. Man’s control over nature is not a topic to be discussed in detail here. However, there is increasing acceptance that good environmental management is not always equivalent to aesthetic appearance (Bealey *et al.*, 2009). There is also concern that the wildlife technique is not viable in the long-term. The placement of the cut in the main stems, together with the 'heal' behind the cut remaining, rather than being removed as in traditional hedge-laying, means that a number of the stems snap, and re-growth from the bottom of the hedge is less vigorous than hoped by some. Re-growth from the bottom of the hedge is essential if the hedge is to be re-laid in the future (Ledder, 2009).

One study (Halcro-Johnston, un-published) looked into the diversity of birds in wildlife-laid hedges compared to traditional, flailed and un-managed hedges. Recently laid hedges were not very good for birds, although in the first year after laying the wildlife hedges did perform better than their counterparts. Flailed hedges on the recommended 3 year cutting rotation were as biodiverse as the wildlife hedges.

Further research, involving this laying technique is currently being carried out. A recent Defra research contract was let to the Centre for Ecology and Hydrology (CEH) and is being led by Richard Pywell. It focuses on the management techniques that are required to maintain and restore the hedgerow resource under the agri-environment schemes in the UK. The research intentions are to examine, identify and develop low-cost and practical options for hedgerow management that would be applicable under the Environmental Stewardship Scheme in the UK (Ledder, 2009).

Adjacent management

In addition to laying techniques, hedges are also affected by the management adjacent to them. In agricultural circumstances, they may be directly or indirectly affected by agro-chemical applications. Fertilisers can cause serious reductions in biodiversity as the increase in nutrients allows annual weeds such as *Urtica dioica* (Stinging Nettles) and *Cirsium arvense* (Creeping Thistle) to take over from perennial, stress-tolerant species. Hedgerows and the land immediately adjacent to them may also be affected by careless ploughing. The introduction of un-cropped field margins and conservation headlands (reduced farming management in the outer 6m of the field) can help to reduce the impacts of farming on hedgerows. Mowing has also been shown to negatively affect butterfly biodiversity by reducing the average vegetation height and removing fluoresces (Feber and Smith, 1995). When hedges are next to roads, the width of the grass margin could significantly affect the diversity of butterflies able to habit that area. Munguira and Thomas (1992) found that road side verge width was significantly associated with butterfly diversity and that habitat quality and quantity was more significant than vehicle-related mortalities to the community size.

Hedgerow loss

As described by Robinson and Sutherland (2002), during the period of time after the Second World War, agriculture in the UK changed. Import subsidies of the 19th century had reduced the area of arable farms in the UK and during the Second World War; food shortages, particularly of cereals, created the aspiration to become self-sufficient once again. The drive for an improved quality of life led to the Agriculture Act of 1947. Subsidies, price fixes, new cropping regimes and increased mechanisation meant that arable crop production in the UK increased dramatically despite a reduction in the number of farms and farm labourers. Between 1945 and 2002 there was a 77% reduction in the number of farm labourers and a 65% decline in the number of farms. They also estimated that 50% of hedgerows have been lost since the end of the War in order to increase the size of fields and to reduce the impact of shading from the hedges. Many of the endeavours of the Agriculture Act 1947 were included in the European Common Agriculture Policy, 1962 (CAP). This led to a significant level of over-production (to the tune of 20-30% annually in the 1980s) which, due to the high cost and wastage, led to the reform of the CAP in the early 1990s. Despite the knowledge of our overproduction of commodities, Barr *et al* (1991) calculated that even between 1984 and 1990, there was still a loss of approximately 121,000 km of hedgerows in the UK. Part of this loss was due to neglect (Croxton *et al.*, 2004), but many were also destroyed to make field bigger still.

The historical, cultural and wider-environmental importance of hedges

Hedgerows are protected by the UK government through two major mechanisms: the first is through the Hedgerows Regulations, 1997 which were made under Section 97 of the Environment Act 1995 (Hedgelink, 2008b). Essentially, landowners must seek permission from the Local Planning Authority (LPA) before removing or causing the destruction of a hedgerow. If the hedgerow is considered 'important' by the Regulations, the LPA may refuse the removal. A hedgerow may be considered important if it is over 30 years old and has value from either an archaeological, historical, landscape or wildlife perspective. This may include being part of a known archaeological site, in a historical county or by containing specific species. The landowner may appeal a refusal to the Secretary of State (Hedgelink, 2008b). Hedgerows may also come under legal protection if they encompass a tree with a Tree Preservation Order (TPO) (Hedgelink, 2008b). Although the hedgerow itself cannot have a TPO, management activities surrounding the protected tree may be affected. Secondly, the UK Government responded to the signing of the Convention on Biological Diversity in 1992 (CBD) by initiating the UK BAP (Hedgelink, 2008a). An inventory of UK species was taken for the UK BAP and those species and habitats of conservation importance were identified and published in 1994. In 2007 the UK's BAP list was updated to include 1149 species and 65 habitats that require conservation action. This is a considerable increase from the number in the first list. Hedgerows were listed in the first round, but during the update the criteria for hedgerows was altered, moving from only identifying ancient/species-rich hedgerows, to including all those containing at least 80% of one native woody species of tree or shrub (Hedgelink, 2008a). This change was in recognition of the importance of hedgerows as habitat for many species and as connectivity in the UK landscape. There are now targets set for maintaining healthy or 'favourable' hedgerows. These include (Defra, 2007):

- Maintaining the isolated and veteran hedgerow trees
- Not over-managed i.e. not trimmed annually
- Maintenance of woody species and herbaceous species diversity
- Have 35% (243,000km) of hedgerows by 2010 and 50% (348,000 km) by 2015 in a 'favourable condition'.

Hedgerows are also highly regarded cultural features of the quintessentially British landscape. Some hedgerows are thought to be as much as 800 years old (Hedgelink, 2008c); representing the remnants of the landscape that once covered the British Isles. Annual competitions in hedge-laying still take place (National Hedgelaying Society, 2009a), and after the push to mechanisation and intensification of the mid-twentieth century, saving traditional skills is becoming more and more popular to British communities. The importance of hedgerows as regulators, in terms of soil erosion, water catchments and pollution, is being realised more and more in recent years (Hedgelink, 2008c). Finally, in light of global warming and rising gas and oil prices, the possibilities to return to using hedgerow wood as a fuel source has also been suggested (Hedgelink, 2008c). All of these factors show that management of British hedgerows reaches far beyond that required for flora and fauna.

What makes a good hedgerow?

According to the Defra Hedgerow Survey Handbook, hedges are the "green veins" of the future of UK biodiversity. However, there is not enough information on the exact composition and structure of most of the hedges in the UK, let alone detail on their condition for wildlife. The UK BAP has several guidelines to assess "favourable condition" in British hedgerows. 'Favourable condition' attributes include (Defra, 2007):

- Adjacent undisturbed ground of at least 2 metres
- Herbaceous vegetation width of at least 1 metre
- Less than 20% cover of nettles, cleavers and docks
- Maximum of 10% non-native herbaceous species and 10% non-native woody species.
- At least 1 x 1.5 metres in size (or cross sectional area of 3 m^2)
- Less than 10% gaps and no gaps more than 5 metres wide
- The base of the canopy needs to be less than 0.5 metres above the ground

In accordance with general ecological opinion, plant diversity is seen as an important controlling factor of insect diversity. The diversity of plant life found in a hedgerow is directly affected by the adjacent land-use practices as well as the direct management of the hedge itself and crucially its size and length (Field *et al.*, 2006). Feber *et al* (2007) found that butterfly species richness and abundance was greater on organically farmed land compared to conventionally farm land, despite not seeing any statistical difference in species richness of grass or forbs species between the two farming types. They did however; find a frequency difference between some individual plant species, with the organic land preferentially having more biennial and perennial species than the conventional farms. These species have been shown to be good nectar sources for butterflies (Feber *et al.*, 2007, Feber *et al.*, 1994) and bumblebees (Pywell *et al.*, 2006) and their frequency is known to be affected by herbicide application and drift (Aude *et al.*, 2004, Feber and Smith, 1995).

The size of field margins has also been shown to affect plant diversity (Field *et al.*, 2006, Feber *et al.*, 1996). Hedgerows provide shelter that can reach up to 10 times further, laterally, than their height, and specifically, up to 4 times for Lepidoptera (Dover and Sparks, 2000). Field *et al* (2006) found that along small stretches of 2 m field margins, the presence of hedges significantly increased the floral diversity. They also found that 6 m wide field margins contained significantly higher floral diversity than 2 m wide margins (Field *et al.*, 2006). Although, it should be noted that after a margin length of up to 4 times the height of the hedge, the presence of specific host plants for butterflies and their larvae such as crucifers and fine-leaved fescues may be considered more important for butterfly diversity specifically (Pywell *et al.*, 2004). As reported by Maudsley (2000) maintenance of the structural diversity without over-managing the hedgerow can also greatly increase biodiversity. In particular, annually flailing a hedgerow and/or trimming at the wrong time of year can reduce the number of larvae. Hedges flailed in September may be void or low in eggs for the following year due to their removal (Maudsley, 2000). Highly mobile species in particular have been shown to be negatively affected by regular flailing; the likely reason for this is the reduction in flowering and diminished shelter provided by the hedgerow afterwards (Maudsley, 2000). Hedges left to grow into a line of trees, or allowed to develop large gaps tend towards lower vegetation biodiversity (Maudsley, 2000) as well, hence the need for continued hedgerow management.

Landowner responsibility

Previously, the EU CAP rewarded farmers for their productivity. A number of reforms, the most recent in late 2008, have slowly departed from rewarding production, to rewarding land management for the health and welfare of the public, animals, plants and the environment. The Single Payment (SP) scheme is the most recent method of rewarding farmers for managing their land in an environmentally appropriate manner. The SP scheme is a payment given, for specific farming practices, on prearranged eligible land. However, at the same time, all of the land owned by the farmer in question must be kept to basic, legal, "cross-compliance" standards. These standards follow basic animal, plant and environmental welfare management. In addition, the UK currently awards landowners further using the Environmental Stewardship Scheme (ESS), launched in 2005, a development from the Countryside Stewardship Scheme (CSS) and the Environmentally Sensitive Areas (ESAs) schemes.

Currently, the ESS, like the SP scheme, is voluntary. It is the aim of the scheme to ensure that the environment is able to adapt to climate change and using good land management, agriculture may also help to mitigate climate change by reducing greenhouse gas emissions and storing carbon (Natural England, 2008). The ESS is separated into three levels; entry level, higher level and organic. At each level, points have to be earned for land to qualify for the subsidy. Landowners are paid £30 per hectare for the land that they enter into the entry level scheme and up to £600 per hectare for the organic level. The higher level scheme works slightly differently, and the payment made depends on the work the landowner agrees to. At each level, hedge management can contribute to the points required to obtain the payment. For example, hedges should not be trimmed more than once every two calendar years, and should be maintained on a coppicing or laying cycle, that is not applied to all the hedges in a landowners holdings at the same point in time. Currently, laying refers to the traditional laying methods, not the wildlife technique. Also, hedgerow trees should be allowed to develop and the hedge in its entirety should be made up of no less than 80% native woody species (Natural England, 2008). Under the ESS, the landowner must also comply with the cross-compliance criteria under the SP scheme, regardless of whether they are sign up to the SP scheme, thus, they also must not spray herbicides or pesticides within 2 metres of the central line of the hedge, to encourage perennial herbaceous growth. There are many other criteria, for different levels of hedge care and/or environmentally friendly practice under the ESS, this highlights only a few.

Chapter 3 – **Do Hedge Management Techniques Affect Butterfly Diversity?**

The alarming reduction in UK biodiversity as a whole, and UK biodiversity as described by various bodies including the UK BMS (Butterfly Conservation, 2009) is the fuel to the investigations of how UK biodiversity can be saved from further damage (Hedgelink, 2008b), and how the mistakes of the twentieth century in particular, may be reversed. The limited area of natural or semi-natural habitat in the UK increases the importance of any green space that is available, whether that is a private garden (Vickery, 2009) or a hedgerow (Maudsley, 2000) in a landscape of largely agriculture (Barr *et al.*, 1991). Although previous work has tended to focus on protected areas, future work is set to include the wider countryside as well (Butterfly Conservation, 2009a). The future of biodiversity is focussed around the changes that may occur in relation to climate change (Settele *et al.*, 2008) and the mechanisms by which the landscape can be managed to facilitate the changes that need to occur, without further damage to the environment, either for the sake of biodiversity or for humans.

Hedgerows are rooted in the British psyche (Hedgelink, 2008c, Butterfly Conservation, 2009a) as an integral part of the countryside, and may realise further potential as the lasting areas of habitat for many animals and plants in the human-altered landscape. Despite the huge losses of hedges in the twentieth century following the Second World War (Robinson and Sutherland, 2002), their protection under UK (Hedgelink, 2008b) and European Law (Robinson and Sutherland, 2002) continues to increase and become more specific. In the attempt to design a hedge-laying technique that would be kinder to the environment, counter the waste disposal issues and be cheaper and quicker to lay than traditional methods, the wildlife hedge-laying technique was developed (Dodds, 2005, Scott, 2005). Wildlife-laying is cheaper and quicker to lay than traditional hedges and in addition, it intuitively would seem to be better for biodiversity (Dodds, 2005, Scott, 2005). The assessment of a hedge for biodiversity is however, very difficult. Many techniques have been developed (Pollard and Yates, 1993, Defra, 2007) and tested for such tasks and the use of surrogates for biodiversity is relatively common. In addition, hedges vary greatly across the UK and thus, patterns of biodiversity and the management techniques that led to them can be difficult to deduce and therefore, repeat.

In response to the requirement to involve the network of hedgerows so important to the future of British biodiversity in the wider landscape, this study will explore the biodiversity of butterflies on hedgerows managed using different mechanisms, the traditional, modern flailing and wildlife, on agricultural and protected land. The main aims of this study are to find out which hedge management type is most biodiverse in terms of butterflies and in terms of vegetation. The final aim will be to elucidate any associations between the management technique(s) and/or associated hedge characteristics and the biodiversity found within the hedgerows. Butterflies will be utilised for their properties as surrogates for invertebrate biodiversity (Maccherini *et al.*, 2009), in the absence of the resources and time to complete a full invertebrate survey.

Methods

Study area

The hedgerows in this study were identified based upon the date they were last managed. Only sites that were managed during the winter of 2008 – 2009 were used. Unfortunately, this did reduce the number of hedges available to survey, but it is justified as the shorter time scale since management reduces the frequency of error cause by other factors, such as agro-chemical use or variable adjacent land-uses. The sites stretched from the Berks, Bucks, and Oxon Wildlife Trust (BBOWT) reserves in Oxfordshire through to as far north as the National Trusts' Landscape Gardens at Stowe in Buckinghamshire. The sites are identified on the map in figure 4. The original aim was to survey 10 hedges in each management type, however, issues with access and changes to the management forced the replicates down to 6 hedges per management type. The land-use associated with the hedgerows varies, from nature reserve land and higher level entry farming to road sides and intensively managed agriculture. The total length of hedgerows surveyed equates to 3.5 km, with 883.31 m traditionally laid, 1292.68 m wildlife laid and 1323.79 m managed with a flail.

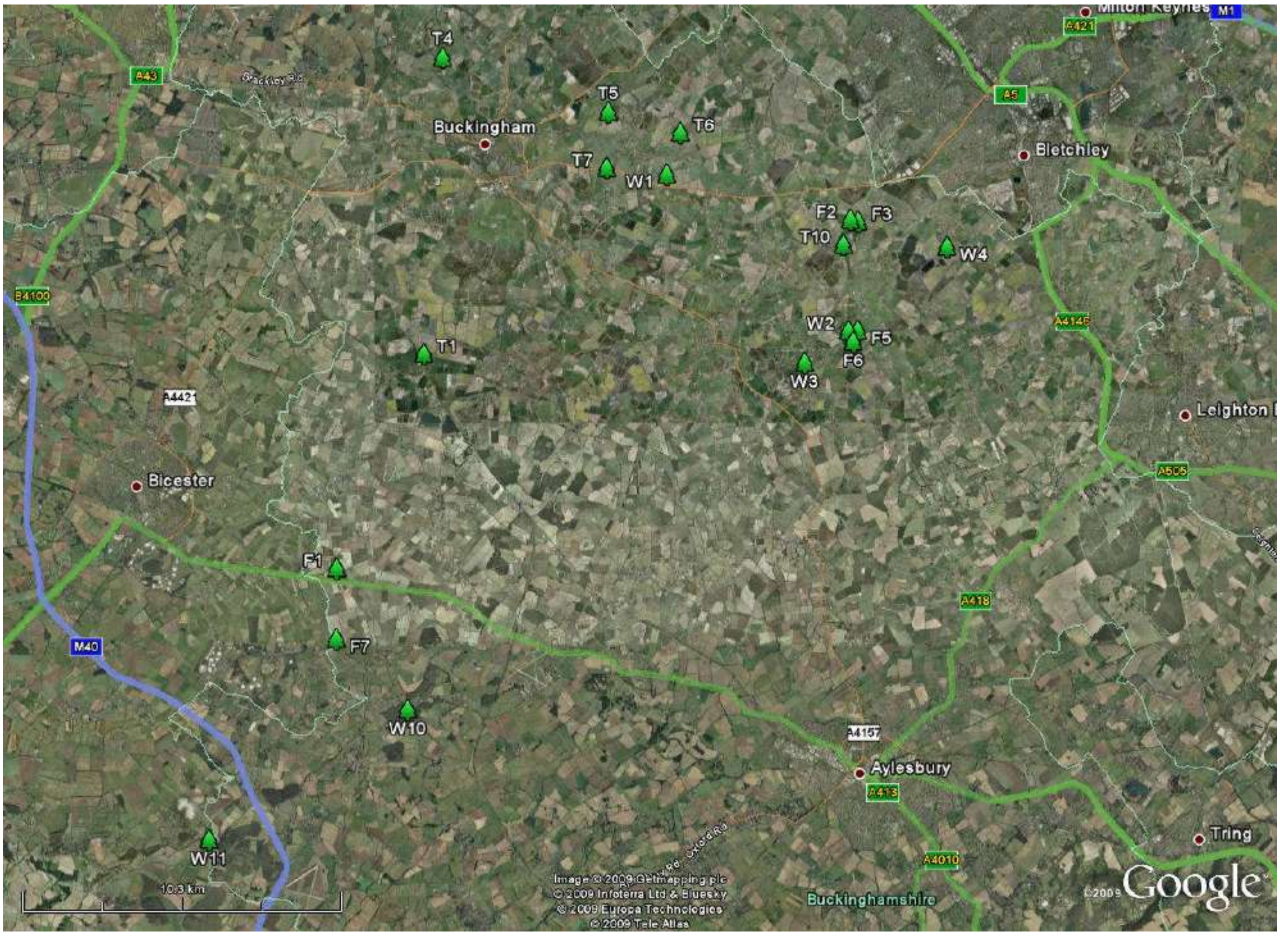


Figure 4 Map of the hedgerow sites in relation to the wider landscape. The sites can be distinguished by the suffix W, T or F, referring to wildlife laid, traditionally laid and flailed hedges.

Hedgerow survey

The method used to survey all the hedgerow vegetation was based upon the Hedgerow Survey Handbook publication by Defra (2007), adjusted to suit the purposes of this study, as recommended in the handbook. The methodology was designed in order to ascertain the distribution, character and special attributes of hedgerows in terms of their biodiversity and structure. The key to defining a hedgerow is continuity of the vegetation and characteristics, separated from other hedgerows by large gaps (20 m or more) or changes to another type of feature, such as a wood or fence. This study measured the continuity (e.g. presence of gaps), height, width, aspect, isolated hedgerow trees, adjacent land-use type, enrichment indicators (percentage cover of nettles, cleaves and docks) and special characters (e.g. presence of a ditch, stream or fence). Within the 50 m section surveyed for ground flora, the woody vegetation that makes up the structure of the hedge was recorded according to percentage cover.

Floral survey

A 50 m section of the hedge was taken, 30 m from one end (or node) of the hedge and surveyed using 50 cm x 50 cm quadrats placed at regular 5 m intervals. The quadrats alternated from being placed right at the base of the hedge to being placed 50cm out from the base of the hedge. This survey design differs slightly from the methodology in the Defra (2007) handbook. This was done in order to make the equipment more portable. The ground flora species in each quadrat were identified and assessed for percentage cover. Identification of woody species and ground flora was confirmed using the series of books by Sterry (2008b, 2008a). Also, although all ground flora species found within the quadrats were identified, those species previously identified as being important for British butterfly species according to Eeles (2008) were also highlighted for use in the analysis.

Butterfly survey

The abundance of species and number of individuals were counted along the entire length of each of the hedgerows in accordance with the general principals of the UK BMS as set out by Pollard and Yates (1993). This is a standardised method of measuring butterfly diversity. It follows strict guidelines about the weather conditions that the counts may be taken during as well as the field technique; survey only between the hours of 10:45 and 15:45 British Summer Time with a temperature of more than 13˚C if it is sunny and 17˚C if it is overcast (Pollard and Yates, 1993). The method is referred to as a “transect” or “transect walk”. Both sides of the hedgerow were surveyed during each transect walk, in order to include all species of butterfly, both highly mobile and more sedentary species. In particular with a large hedge, the ecosystem niche on either side of the feature may be very different, and therefore support different communities of butterflies. Each transect was monitored 3 times and the biodiversity values obtained added together. Each repeat transect was a minimum of 10 days apart in order to not bias the results based upon which species have or have not emerged between the beginning and the end of the field work period. The species will be identified as per the Field Studies Council recommendations (Lewington and Bebbington, 2005).

Statistics

One-way Analysis of Variance (ANOVA) was used to compare the means of most results. ANOVA is a powerful parametric test; an extension of the T-test (Gotelli and Ellison, 2004) that should be used when two or more factors are involved, as in this case; investigating the three hedge management techniques. The Kruskal-Wallis test was used in the minority of cases where the data could not be normalised. Regression analysis was used to investigate the relationship between the continuous variables. All statistics were calculated using the software Minitab® Statistical Software version 15 (2007).

Ground flora and woody species biodiversity was measured using the Shannon Index as this index is the most appropriate when dealing with proportional measurements. Butterfly biodiversity was measured using the Simpson's Diversity Index and Evenness index and the Shannon index. The Simpson Index is considered to be more powerful than the Shannon index (Magurran, 2004) but is designed to use actual values rather than proportional values.

Shannon Index:

$$H = -\sum_{i=1}^{s} pi \ln pi$$

Simpson's Index:

$$D = \sum \frac{ni(ni-1)}{N(N-1)}$$

Where, S = number of species; *pi* = relative abundance of species. *ni* = the number of individuals in the *i*th species and N equates to the total number of individuals.

Results

The total number of butterflies recorded across all the hedgerows was 1468. The flailed hedges and the traditionally laid hedges showed very little variance in the number of butterflies recorded, 433 and 430 respectively. At the wildlife hedges 605 individuals were recorded. The total species richness varied little between all three hedge types, the values were 17, 18 and 19 for the flailed, traditional and wildlife hedges respectively. Painted Lady butterflies were not found at any of the flailed hedges and only 1 Grizzled Skipper was seen at wildlife hedge number W10. The most common species were the Meadow Brown, Ringlet, Small White, Large White and Gatekeeper, together they made up more than 75% of the individuals seen. With regard to the ground flora vegetation, all the hedges varied considerably. The flailed hedges did have more than 60% grasses cover though, compared to 37% at the wildlife hedges and 15% at the traditional hedges. The traditionally laid hedges also had the highest amount of bare ground associated with them, at 28% this was more than double the amount found at the other two hedges types. Hedgerow trees differed greatly between the hedge types; only 6 trees were associated with the flailed hedges, compared to 29 and 35 for the wildlife and traditionally laid types. There appeared to be little discernable difference between the woody species that made up the three hedge types. Blackthorn and Hawthorn were by far the most common species, making up a total of 75% of all the woody species in the hedgerows. Two-thirds of all the hedges had over 20% nutrient enrichment indicator species; this included all of the traditionally laid hedges, 2 of the flailed hedges and 4 of the wildlife hedges.

The heights of the different hedges varied little, but the average width of the wildlife hedge was over 3 m, compared to less than 2.15 m for the other two types. The newly laid traditional hedges had an average cross-sectional area of 1.46 m^2, the flailed hedges equated to 4.34 m^2 and the wildlife hedges had a large average cross-sectional area of 6.57 m^2. There appeared to be little variation between the hedges with regard to perennial width, or vegetation height, or percentage of gaps.

Butterfly abundance and species richness

The richness of butterfly species between each management type was found to vary little (CI = 95%; F = 0.44; P = 0.654; R^2 = 5.50%). The error bars indicate that the variation within each management group was comparatively large (Figure 5). The abundance data in figure 5 suggests that there is a steady increase in the abundance of butterflies present at the different hedge types, with flailed hedges having the fewest individuals and wildlife hedges having the most. However, statistical analysis indicated that there was no significant difference in this group either (CI = 95%; F = 1.28; P = 0.307; R^2 = 14.56%).

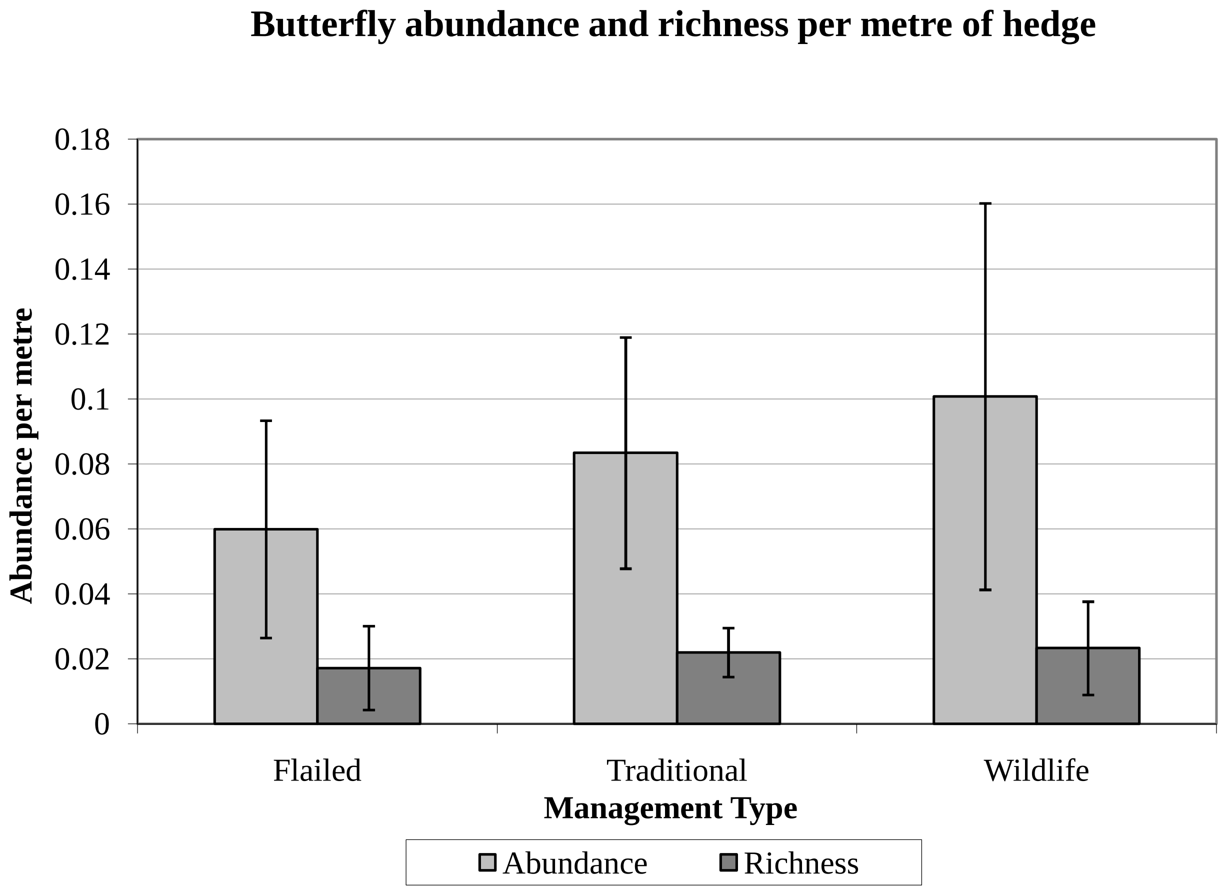
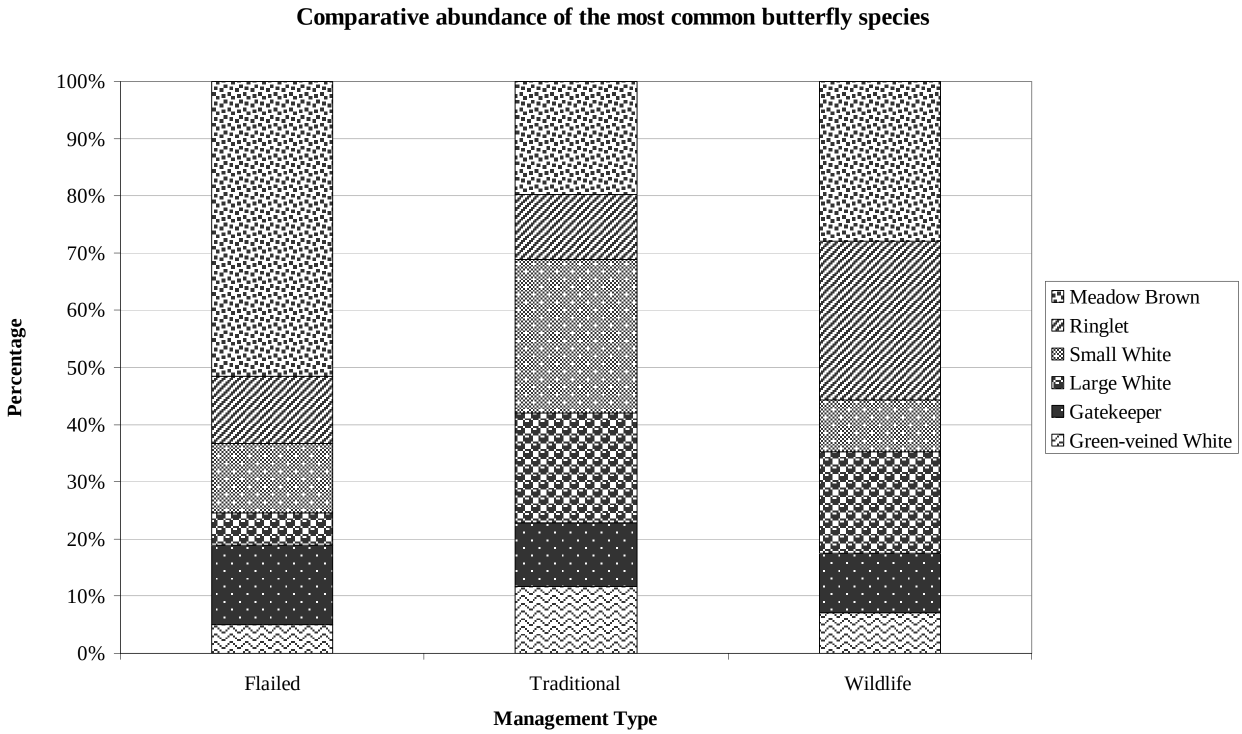


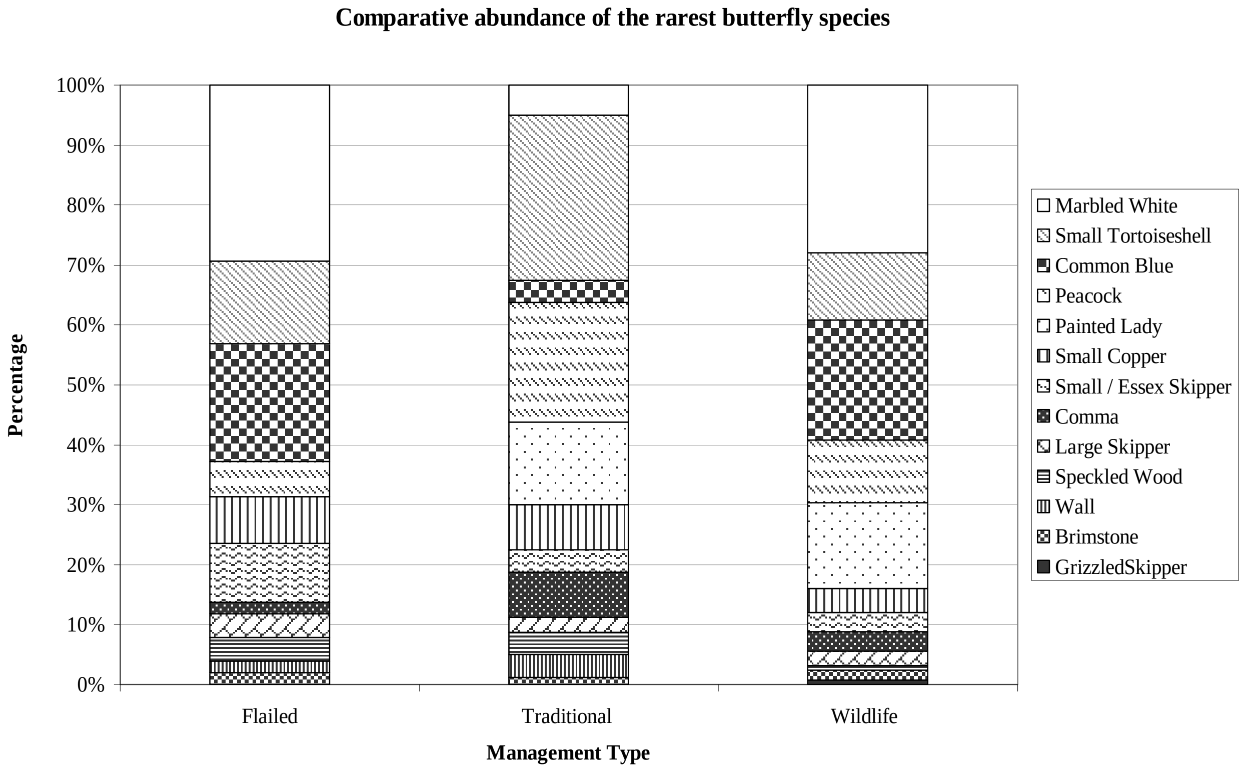
Figure 5 **The average abundance and richness of butterflies per metre, per hedge management type. Hedgerows differed greatly in size, with an average length of 195 m but a range of 47-601 m. The error bars represent the standard deviation of the values obtained.**

Butterfly biodiversity

The graph in figure 6 suggests that wildlife and traditional hedges are more biodiverse than the flailed type of hedge. The flailed hedge seemingly has a significantly larger proportion of Meadow Brown butterflies compared to the other species found within the hedge as well as between the management types. Both the wildlife and the traditional hedge types seem to have an even spread of species and abundance, biodiversity. This is reflected in the Shannon's Diversity Indices applied to the different hedge types, where the flailed hedge equals H = 1.87, the traditional hedge is H = 2.29 and the wildlife hedge is H = 2.24, using absolute recorded richness and abundance values.



<u>Figure 6</u> The graph shows the relative proportion of each common species found at each of the hedge management types. A common species in this case can be described as the most frequently found species across all hedges in this experiment only and does not refer to the UK wide state of the species.



<u>Figure 7</u> The graph shows the relative proportion of each rare species found at each of the hedge management types. A rare species in the case can be described as the least frequently occurring species across all the hedges in this experiment only and does not refer to the UK wide state of the species.

However, no statistical significance between the management types either within the common group of species (Kruskal-Wallis: CI = 95%; H = 2.05; DF = 2; P = 0.359) or the rare species, see figure 7 (One-way ANOVA: CI = 95%; F = 3.55; P = 0.055; R^2 = 32.11%) or, indeed, overall (CI = 95%; F = 2.50; P = 0.116 ; R^2=25.01%). The Simpson diversity indices did not reflect any significant changes between management types either.

Vegetation biodiversity

Figure 8 would seem to indicate a strong similarity between the traditionally laid hedges and the wildlife laid hedges with regard to ground flora. Both these management types appear to have greater biodiversity than the flailed type, but this is not reflected in the statistical analysis for ground flora (CI = 95%; F = 2.64; P = 0.1.4; R^2 = 26.07%) or for woody vegetation biodiversity (CI = 95%; H = 1.56; DF = 2; P = 0.459 adjusted for ties). The diversity of isolated hedgerow trees found in the flailed hedge does however differ significantly from the other two management types (CI = 95%; H = 8.20; DF = 2; P = 0.017 adjusted for ties).

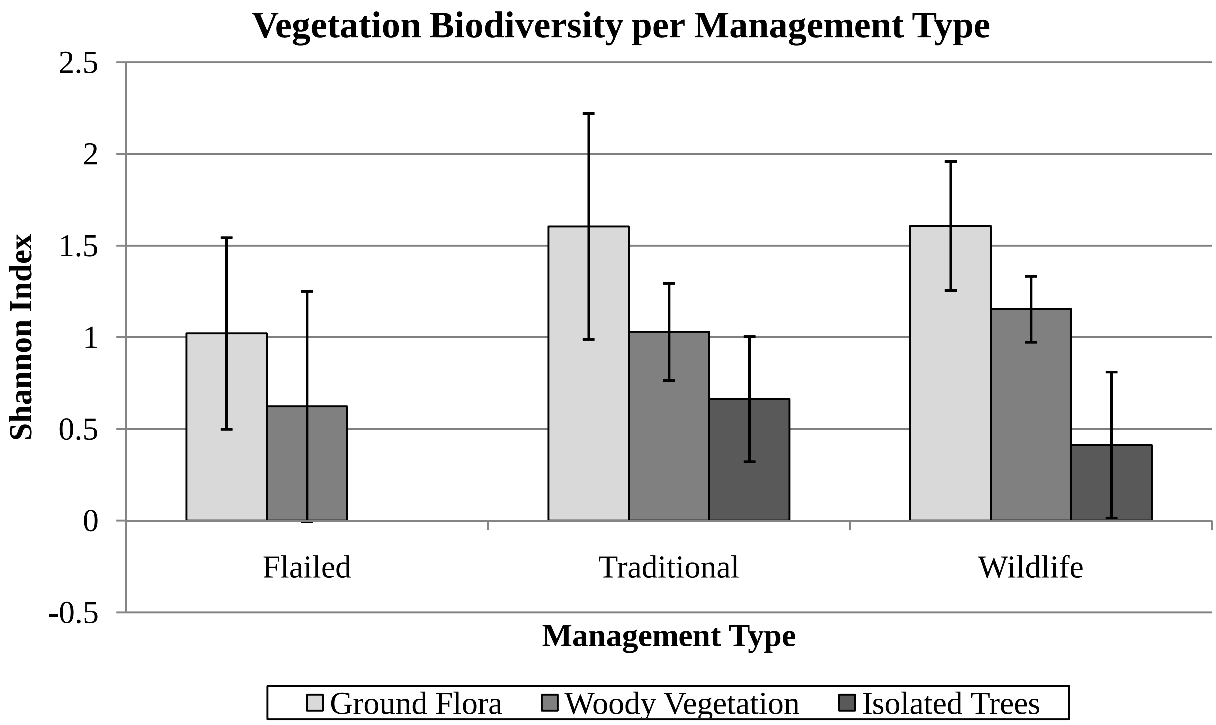
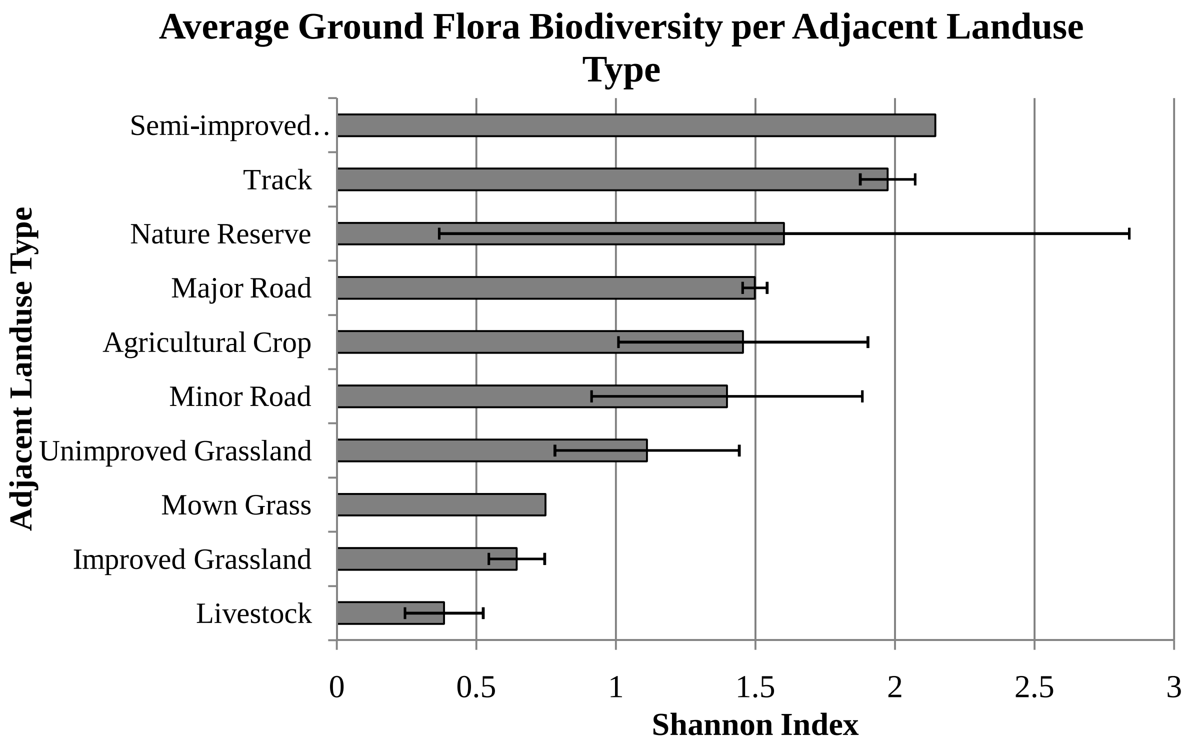


Figure 8 The graph shows the Shannon Index of biodiversity for the ground flora associated with the hedge, the woody species that make up the hedge structure and the isolated hedgerow trees that have been allowed to develop within the hedge.

Land-use type was classified by the land-use status when the vegetation survey was completed and does not account for any changes in the land-use that may have occurred over the duration of the subsequent butterfly transects. For example, at hedges F2, W3 and W11, the immediately adjacent land was harvested / mown over the course of the fieldwork. Land-use did have a significant effect on ground flora biodiversity (CI = 95%; F = 2.61; P = 0.032; R^2 = 51.59%). Pairwise comparison of the means using Fisher's A Priori test indicated the direction in which the differences lie, see figure 9. The semi-improved grassland is significantly more diverse than any of the other land-use groups. However, this was one of the areas that were managed between the first and last butterfly survey, so the state of the vegetation altered. Unimproved Grassland, Agricultural Crop land, Minor Roads and tracks, nature Reserves, Major Roads, Mown Grass, Semi-improved Grassland were considered by the pairwise comparison to not be statistically significantly different, but the hedges next to livestock land were considered to be significantly low overall.



<u>Figure 9</u> The Shannon Index for Ground Flora is shown here in relation to the use of the land adjacent to the hedge. There are significant differences between the different land-use types, but the only regularly different group is the one for livestock, which is significantly lower in ground flora biodiversity than all of the other groups.

Whilst the ground flora was significantly associated with the adjacent land-use, butterfly diversity was not (CI = 95%; F = 2.03; P = 1.49; R^2 = 38.43%). To follow this, regression analysis of ground flora biodiversity and butterfly biodiversity showed that there was no significant association (CI = 95%; F = 3.21; P = 0.092; R^2 = 16.7%).

Additionally, the variance between the means of butterfly and ground flora biodiversity between the different hedge management types were analysed against proportion of pest butterfly species, aspect, field margin size, weather conditions and temperature. Regression analysis was performed to identify any correlations between biodiversity and hedge cross-sectional area, width, height, woody vegetation diversity, tree diversity and nutrient enrichment indication. Also, ground flora species specific to butterfly life cycles were regressed against butterfly richness, abundance and biodiversity; no significant associations were found. No significant correlations were found for the butterfly diversity overall either. In particular, there was no relationship between hedge size (by cross-sectional area or length) and either butterfly or ground flora diversity. No correlations could be found regarding the ground flora biodiversity, with the exception of field margin size. Whilst there is no significance to be found in the diversity of butterflies between the field margin sizes, there is significance for the ground flora biodiversity (One-way ANOVA: CI = 95%; F = 8.07; P = 0.004; R^2 = 51.85%), see figure 10.

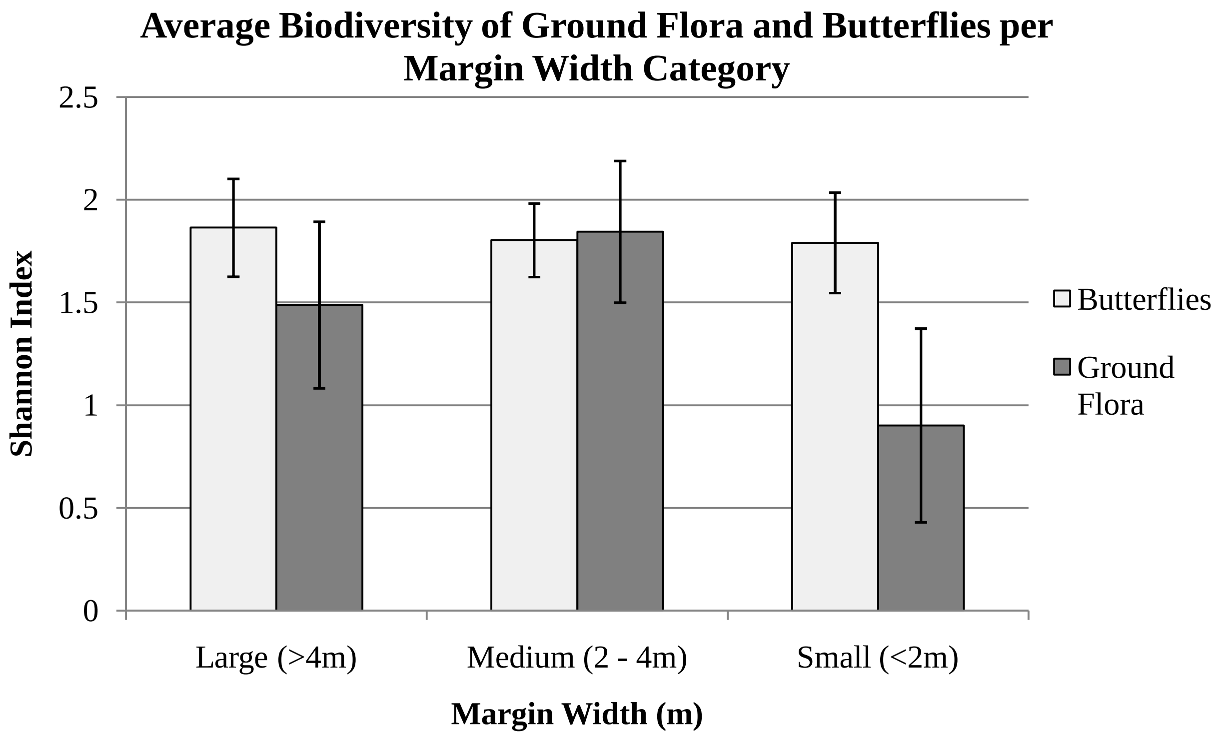


Figure 10 **The bar chart shows that the ground flora biodiversity is lower where field margins are less than 2 m. This is confirmed by the statistical analysis (One-way ANOVA: CI = 95%; F = 8.07; P = 0.004; R^2 = 51.85%). There is no statistical difference between the butterfly biodiversity and the field margins (One-way ANOVA: CI = 95%; F = 0.18; P = 0.833; R^2 = 2.41%).**

Discussion

Defra (Defra, 2007) has a number of criteria to assess whether a hedge is good or not discussed in the sub-section "What makes a good hedgerow?". The criteria include: Adjacent undisturbed ground of at least 2 metres; herbaceous vegetation width of at least 1 metre; less than 20% cover of nettles, cleavers and docks; maximum of 10% non-native herbaceous species and 10% non-native woody species; at least 1 x 1.5 metres in size (or cross sectional area of 3 m^2); less than 10% gaps and no gaps more than 5 metres wide; and, the base of the canopy needs to be less than 0.5 metres above the ground.

All of the hedgerows surveyed had less than 10% non-native herbaceous and woody species and as they had only recently been managed, had very few gaps and certainly all the laid hedges were less than 0.5m above the ground. However, the other criteria varied, even within each hedge management group. The wildlife hedges tended to be much larger in cross-sectional area than the other two types. Two-thirds of the hedges surveyed had a percentage cover of nutrient enrichment indicator species over the recommended 20% limit. This isn't especially surprising, given the number of the hedges that were on agricultural land or by roadsides and thus, likely to have been exposed to fertilisers at some point in their recent history. The width of undisturbed ground varied considerably between all the hedges, as did the width of herbaceous vegetation. This seemed to be due to the context in which the hedge was positioned i.e. the adjacent land-use and land-management. As such, one hedge management type does not lend itself to forming 'good' hedges, according to the Defra criteria, more than another because the criteria are affected by more than just the specific hedge management type.

Butterfly biodiversity

The first objective of this study was to find out whether the management technique affected the biodiversity of butterflies that could be found in a hedgerow. The data indicated that there was no significant difference between the management types for butterfly biodiversity. The same is true when comparing abundance and species richness alone. Two primary factors may explain these results. Firstly, the data set was quite small, due to the short amount of time available to the project, coupled with the additional pressure of unsuitable weather conditions whilst the butterfly transects were being carried out. Furthermore, the access to one hedgerow was withdrawn during the survey and two other wildlife hedges were flailed half way through the study, consequently, the amalgamation of the management techniques made those hedges void. Secondly, butterfly biodiversity may be more affected by other hedge attributes such as: availability of pollen sources, larval food-plants, hedge size and the application of fertilisers, herbicides and pesticides (Merckx *et al.*, 2009, Butterfly Conservation, 2009, Maudsley, 2000, Dover and Sparks, 2000, Field *et al.*, 2006, Feber *et al.*, 2007, Feber *et al.*, 1994, Pywell *et al.*, 2006, Aude *et al.*, 2004, Feber and Smith, 1995). It is plausible as well; that it is interaction of factors that contribute to the butterfly diversity at a particular hedge, and thus any one factor may not be statistically significant. The small quantity of data here, did not allow for any meaningful statistical tests of multiple factor interactions, as many combinations of factors would only result in zero or singular instances. It is unlikely that the quality of the data is at fault as the method used has been tried and tested for the last 30 years (Pollard and Yates, 1993).

The results here differ from those found by Halcro-Johnston (un-published) which, may be due to the speed at which butterflies are able to react to disturbances (Maccherini *et al.*, 2009) compared to the bird's in Halcro-Johnston's study. All of the hedges chosen were last managed during the winter of 2008-2009, but even in this short amount of time, invertebrates may react to disturbance whether this was caused by the hedge management itself or another mechanism. Intuitively, the diversity and abundance of butterflies at any given hedge would then be a factor of a combination of the different properties of the hedge, its placement and connectivity to the rest of the suitable habitat in the landscape, coupled with each species abilities to re-colonise the area. In addition, many of the hedges were adjacent to intensively managed crops and roads. Pollution from agro-chemical drift (Feber *et al.,* 2007) or road surface run-off and associated management could potentially impact on the diversity and abundance of butterflies found in the hedge (Munguira and Thomas, 1992).

A verge between hedge W11 and the road was mown during the butterfly data gathering; mowing, particularly during the summer months has a drastic affect on butterfly abundance and richness, many species, such as the Meadow Brown, will move immediately to uncut areas (Feber and Smith, 1995). Although Feber and Smith (1995) did find that populations recovered, they did not reach their previous level, this affect is likely to be similar to that of over-stocking; butterfly species richness and abundance reduces with increased stocking (Dumont *et al.*, 2009). Thus, it may be expected that if the adjacent land is managed by mowing or is occupied by livestock, that the butterfly populations will suffer.

Vegetation biodiversity

The second objective was to discover whether the vegetation biodiversity differed between hedges of different management types. Significance was not found in ground flora or woody species diversity when the different management mechanisms were compared. This means that the type of hedge management alone cannot be use to predict a level of biodiversity of ground flora resources for butterflies; reliable and predictable associations are required in order to assess how 'good' or 'favourable' a hedge might be for biodiversity.

The ground flora found within the hedges could be a factor of the disturbances occurring near the hedge. The application of chemical fertilisers in particular can have a significant impact on the diversity of herbaceous plants, causing increased growth in tall perennials and a reduction in stress-tolerant plants (Aude *et al.*, 2004). Hedges next to roads are also managed frequently, often in summer, to maintain visibility.

With reference to hedgerow trees, the flailed hedges had only 6 instances of isolated hedgerows trees, a statistically significant difference from both the laid hedges. The paucity of isolated hedgerow trees is likely to be a result of the management type (Brooks and Agate, 1998). In particular, hedges that are flailed on an annual basis are unlikely to develop trees, as they would simply be trimmed back into the hedge shape. The assumption may also be made that a hedges are trimmed on an annual basis for a reason other than either nature or heritage conservation. As such, leaving large trees in a hedge, that may shade-out crops and make trimming the hedge more difficult and time consuming, would not be a priority.

Linking ground flora to butterflies

The various ANOVA tests and regression analyses performed resulted in very few significant results. The most surprising finding was that the diversity of ground flora did not positively correlate with the butterfly diversity either when the data set was used as a whole, or when only the ground flora specific to butterfly life cycles was used. A positive correlation between ground flora and butterfly biodiversity has been found in the past, particularly when the focus is on species that are specifically relied upon by butterflies (Croxton *et al.*, 2005, Feber *et al.*, 2007, Maudsley, 2000, Feber and Smith, 1995). The lack of this correlation here compared to the previous significant results, suggests that more factors affect the biodiversity of butterflies in these hedgerows than just the availability of their food plants. Road verges and hay meadows were both cut during the collection of the butterfly data. Mowing has been shown to greatly reduce the abundance and species richness of butterflies (Munguira and Thomas, 1992). Insects are known to react more quickly to disturbance than plants (Maccherini *et al.*, 2009); this could have affected the results of this study, only to be accentuated by the small data set. In the case of disturbed habitats, butterflies are considered to be good indicators of other invertebrate fauna (Maccherini *et al.*, 2009), which indicates that there might be more considerable variation in invertebrate biodiversity across the landscape than would otherwise be expected using the ground flora biodiversity alone. Hence, faunal diversity, if used in isolation, may not be a suitable surrogate for biodiversity when investigating invertebrates in the wider countryside.

Field margin size

One factor did correlate well with the diversity of ground flora: field margin size. The appearance of this correlation is unsurprising. The larger the field margins the more the base of the hedge is protected from agricultural disturbance, such as ploughing and spraying (Feber and Smith, 1995). The resulting land is therefore more likely to contain a wider variety of perennial plants (Feber and Smith, 1995, Field *et al.*, 2006). Large field margins that are able to support larger communities of stress-tolerant perennials may then support larger communities of butterflies and other nectar-feeders. The presence of perennial plants as opposed to unpredictable annual weed species is of particular importance to nectar-feeding insects with closed population strategies. Poor dispersal and an inability to predict the presence of annual herbaceous vegetation increases mortality risk for the population as a whole (Dover, 1996). Feber *et al.* (1996) found that only by increasing field margins from 0.5m to 2m and reducing the fertiliser application and spray drift caused an increase in the abundance and richness of butterfly species on agricultural land. Interestingly, they found no significant increase in the pest species the 'Cabbage' white group and further lines of enquiry suggests that the increases in abundance were cause by other species breeding locally. In this study, there was also no significant change in the proportion of the pest species found at the different hedge types. Furthermore, the larger the field margin, the larger the area of semi-natural land within the sheltered area of the hedge; allowing the positive impacts of that shelter to be more realised (Dover, 1996). Munguira and Thomas (1992) found that, although the presence of a hedgerow did not improve the abundance and richness of butterflies found in their study, all of the best locations were bordered by hedgerows.

Adjacent land-use

Finally, adjacent land-use type did significantly affect the biodiversity of ground flora. The directionality of the effect of adjacent land-use for the different groups was complex. Although there appears to be a gradient of increasing biodiversity, the different levels group together differently, and certain land-use types are not where they might be expected. For example, unimproved grassland might be expected to allow more diversity in a hedge, however, in this study roads appear to be more conducive to high butterfly biodiversity. With hindsight, it would be best to create adjacent land-use categories specifically for this study rather than relying on the recommendations of the Defra Hedgerow Handbook (2007), which are more suitable for a different purpose. Furthermore, the category 'Agricultural Crop' covers all crops from all farming methods. Thus, a crop in a field with no field margin, sprayed with chemical fertilisers, herbicides and insecticides is put into the same group as the same crop on organically farmed land, with 6 metre field margins. These two eventualities are unlikely to have the same affects on local invertebrate life. There are also categories that are very similar, for example, the 'Livestock' category ('Other – Animals' in the Defra handbook) and 'Improved Grassland'. The hedges at F3, F6 and T6 fall into these categories. Hedges F3 and F6 appear to be very similar; the grass is heavily grazed and other biennials or perennials do not get much opportunity to develop before they are consumed. F3 falls into the 'Improved Grassland' category as it is not currently in use for livestock. F6 is currently used for livestock as part of a rotation with other fields. T6 on the other hand, despite being part of the 'Livestock' category appears very different. The adjacent land is currently being used to graze sheep, but the land is not fertilised and the number of animals is kept low (G. Hodges pers. comms.), thus reducing the herbivory pressure on the vegetation. As a result of this, the area appears more diverse overall, the grasses and sedges are of various heights and there are small shrubs and thistle species in a mosaic over the land. The butterfly biodiversity at the hedge reflects this perception of diversity, being greatest at T6 and lowest at F3, but the ground flora diversity of the hedge itself is lowest at T6, despite the overall richness being more than 50% more at T6 than at F6 and three times that of F3. Not only does this highlight the need to look at all biodiversity indicators, rather than just using biodiversity indices, but shows how important the adjacent land-use coupled with the intensity of disturbance may be.

Rare species

It should also be noted that the variation of biodiversity of rare butterfly species between the hedge types was only 0.005 off being considered statistically significant. The test indicated a difference between the biodiversity of rare butterfly species at the wildlife hedge when compared to the flailed hedges. The traditional hedges in this instance did not display any difference between either the flailed or the wildlife hedge. Thus, the wildlife technique may have some beneficial qualities to butterfly diversity that are not entirely apparent in this particular study. The diversity of hedge-laying and management techniques across the UK further demand a more substantial investigation this was possible in this one in order to categorically state whether wildlife hedges have absolutely no impact or not on invertebrates.

Further investigation and next steps

The overarching objective of this research was to elucidate whether the management method applied to a hedgerow affects the invertebrate diversity, specifically butterflies, found within the hedge. The results obtained by this study indicate that the interactions are a lot more complex than simply one management method. With reference to the graphs in figures 6 and 7, the biodiversity, in its strictest terms as a measure of species richness and evenness of abundance, appears to be greatest in the laid hedges. It is surprising that no statistical significance could be found here. In addition, the wildlife hedges may be more suitable for the rarer species of butterflies, although technically insignificant, the small data set and with only one season having been studied may be the reason for the negative result. Anecdotally, the wildlife hedges do appear to be more complex, bigger and more suitable for wildlife than the flailed hedges, thus it would be useful to obtain a larger data set to check this conclusion.

What it reassuring from this study is that there are some techniques being developed that are trying to combine conserving biodiversity with maintaining the value of hedgerows in terms of their use as barriers on land and keeping the cost of hedge management down (Ledder, 2009, Dodds, 2005). As well as being an important factor for maintaining biodiversity in the wider countryside, traditional hedge-laying is considered culturally very important by some groups. However, due to cost, most hedgerows are flailed, and many landowners, for whatever reason, choose not to follow rotational cutting regimes (Tuckwell, 2009 pers. comm.). The work to identify and test cutting regimes and hedge-laying mechanisms for the benefit of the ELS and HLS that will cover the practical and cost advantages and disadvantages of different techniques (Ledder, 2009) is commendable. Unfortunately, current compliance with the ESS is fragmented over the agricultural landscape (Dutton *et al.*, 2005). The ESS award money to landowners for wide field margins, highlighted here as having a positive impact on ground flora diversity, and maintaining livestock densities at a level to reduce the impact on the soil and flora environment, as well as rotational cutting regimes and traditional hedge management (Defra, 2008). This study supports these criteria of the ESS programme, but it will fail to have a really significant impact on UK biodiversity as a whole unless more landowners join in, in a more targeted manner (Dutton *et al.*, 2005). Therefore, what may provide a larger impact to biodiversity is greater promotion of the ways in which land can be managed for the benefit of the environment and, how landowners may be rewarded for following these strategies.

Given the status of UK butterflies in recent years and the unfortunate bout of unsuitable weather conditions for surveying butterflies that occurred during this study, it is necessary to perform more replications across a larger number of hedges to confirm or reject the findings here. Given the short amount of time available to this study, and of the similar study by Halcro-Johnston (un-published), it would also be beneficial to understand whether the wildlife hedge provides any benefits to biodiversity over longer periods of time, or whether it's only benefit is in the short-term. In conjunction with this, the effect on the biodiversity of the group of species in question very much depends on the ecology of the particular group. Butterflies react very rapidly to disturbance, what may be interesting to find out, is how rapidly they are able to move back to wildlife hedges, compared to the other management types, and thus how severe a disturbance event is. On a larger scale, reducing the severity of disturbances may be beneficial to wider populations. It would also be useful, in terms of landscape management, to find out whether wildlife-laying increases the success of other stewardship techniques, such as leaving wide field margins, when compared to the other hedge management techniques. In terms of adaption to future climate change, the scale at which this type of study is done is also important. It may be, as this study has found, that at the single hedge scale, wildlife-laying has limited significant positive effects on biodiversity. However, at a larger scale, would a succession of wildlife hedges, at different stages of management prove to be more biodiverse than a similar flailed landscape?

Conclusion

In conclusion, it cannot be the hedge management type alone that predicts the floral or butterfly biodiversity of a hedge. The ‘good’ hedgerows are likely to have a combination of favourable characteristics e.g. wide field margins, limited stocking and in-frequent active management of the adjacent land, as well as a large size and complexity. The wildlife hedge does create a larger hedge more immediately than the other two types and it is possible still, that wildlife-laying may be better than flailing for rarer species of butterflies. This work has also shown that wildlife-laying doesn’t increase the proportion of pest butterfly species either. Other work has confirmed that particularly in the short term, the wildlife hedge is more abundant in birds (Halcro-Johnston, un-published) and can improve some agricultural practices (Scott, 2005). The evidence shown here indicates that the adjacent land-use and size of field margin had a significant effect on the ground flora biodiversity adjacent to a hedgerow presumably because fertiliser, herbicide and pesticide usage have negative effects on invertebrate biodiversity and, field margins help to buffer hedgerows from this (Feber and Smith, 1995, Aude *et al.*, 2004). Thus, the success of wildlife-laying is mixed and also, the long term effect on biodiversity has not been quantified. However, if success for biodiversity in the wider countryside is reliant on the action of all landowners, conservationists need to supply practical and cost effective techniques, such as the wildlife-laying technique, that help biodiversity without producing unacceptable risks and reductions to the livelihoods of landowners. The wildlife-laying technique may require a little refining and further investigation, but it is an excellent example of an attempt to find a practical technique to improve modern hedge management.

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