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The influence of hedgerow structural condition on wildlife habitat provision in farmed landscapes

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A B S T R A C T

In this review, we discuss the role of hedgerow structure and condition in determining the value of hedgerow habitat for biodiversity conservation within an agricultural context, to inform and evaluate hedgerow management decisions and policy. Through a systematic literature review, narrative synthesis and vote counting, key structural condition indicators were identified for a range of conservation priority taxa. Abundance, survival or fecundity of ground vegetation, birds, mammals and invertebrates were affected by height, width, woody biomass, foliar quality and quantity, and gappiness of hedgerows. Although general patterns may not occur, a response to a particular structural feature can vary both within and between taxonomic groups, many responses are synergistic and interdependent. In conclusion, the definition of a "good quality" hedgerow for biodiversity conservation should be expanded to include all those key structural features which are important across taxa. Furthermore, the importance of heterogeneity in hedgerow structural condition is highlighted, where no fixed set of hedgerow characteristics were found to benefit all taxa. If uniform hedgerow management is overprescribed, as has been the tendency with some agri-environment schemes, some species (including those of conservation concern) are likely to be adversely affected by a loss of suitable habitat or resource decline.

1. Introduction

Hedgerows consist of lines of trees, shrubs, and associated herbaceous understory vegetation, forming a contiguous network across the farmed landscapes of temperate Western Europe (Hannon and Sisk, 2009), with similar features found elsewhere (e.g. in Canada, Australia and Scandinavia (Boutin et al., 2001); the mediterranean (Connor et al., 2014); and North America (Morandin et al., 2016)). Their species composition is floristically native (French and Cummins, 2001). In Europe, woody species typically include *Prunus spinosa* (blackthorn), *Crataegus* spp. (hawthorn), *Corylus avellana* (hazel), *Rosa canina* (dog rose) and *Sambucus nigra* (elder) (French and Cummins, 2001; Gosling et al., 2016). In the Republic of Ireland, hedgerows cover 1.5% of land surface area (Smal, 1995), equating to 11% of farm area (Sheridan et al., 2017). In Great Britain, the extent of hedgerows (477,000 km as of the 2007 Countryside Survey) make them one of the largest (Carey et al., 2008) and most widely distributed (Baudry et al., 2000) semi-natural habitats within farmed landscapes.

Traditionally built for stock proofing and provision of shelter (Baudry et al., 2000), hedgerows play a wider role in biodiversity conservation; providing food, shelter and breeding sites for a range of species typically dependent on woodland edge, scrub or grassland habitats (Hinsley and Bellamy, 2000; Merckx et al., 2012; Staley et al., 2016; Lecq et al., 2017), and may also facilitate movement of organisms through the landscape (Cranmer et al., 2012; Slade et al., 2013). Hedgerow structure and landscape context can also influence microclimate (Walker et al., 2006). Hedgerows thus contribute to the conservation of biodiversity locally, regionally and internationally by providing refugia in landscapes that otherwise lack in suitable habitat, food and shelter (Weibull and Ostman, 2003). Hedgerows across Europe are considered a priority habitat for conservation efforts (JNCC and Defra, 2012). UK hedgerows for instance have been associated with > 600 plant species, 1500 insects, 65 birds and 20 mammals (UK Biodiversity Steering Group, 1995). Hedgerow habitat is also noted as important for species of conservation concern, which face multiple pressures within the agricultural landscapes of Europe (Webb et al., 2010). Conservation actions involving hedgerow management were specifically recommended for 45 of the priority species afforded legislative status under section 41 of the Natural Environment and Rural Communities (NERC) act in the UK (Natural England, 2013). The presence of hedgerows is a consistent predictor of abundance for conservation concern bird species and farmland specialist bird species in

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Poland (Sanderson et al., 2009; Wuczyński, 2016), and the UK (Hinsley and Bellamy, 2000). In an Italian study the abundance of five common spring and four common winter birds are associated with the % cover of hedgerows in the landscape (Assandri et al., 2017). The biodiversity supported by hedgerows influences the provision of pest regulation (Morandin et al., 2014) and pollination services (Morandin and Kremen, 2013b; Morandin et al., 2016), essential for agricultural productivity (Natural England, 2012).

Although once widespread, hedgerow removal is becoming less common across Europe (Baudry et al., 2000) and is now restricted by law in the UK (Oreszczyn and Lane, 2000). However, the value and importance of a hedgerow is not necessarily ensured simply by its presence or that of a hedgerow network, on a farm or in the wider landscape, but is shaped by hedgerow management and resulting habitat quality (Homberger et al., 2017). Management has a strong effect on hedgerow structural condition (Hinsley and Bellamy, 2000; Maudsley, 2000; Staley et al., 2015). Hedgerow structure is complex, providing a range of niche habitats and food provisions throughout the year (Weibull and Ostman, 2003), not found elsewhere within the surrounding agricultural matrix. Management is therefore essential throughout the lifecycle of a hedgerow, having the potential for positive influence on the biodiversity of agri-ecosystems (La Coeur et al., 2002). Both the timing and techniques of hedgerow management play a role in determining the structural condition and value of hedgerows as a wildlife habitat (Croxton et al., 2002). An absence of management can be as detrimental to hedgerow structural condition as over-frequent management (Garbutt and Sparks, 2002). For example, absence of hedgerow management led to a 23% decrease in managed hedgerow length between 1984 and 2007 in Britain, contributing to a 49% increase in the length of lines of trees and relict hedgerows over the same period (Carey et al., 2008). There is also a trend to value and maintain “neat” or “tidy” farm landscapes and hedgerows in the UK, Ireland and France (Oreszczyn and Lane, 2000; Britt et al., 2011; Power et al., 2013; Kohler et al., 2014). Such changing attitudes and management practices over time have meant changes to the structural condition and value for wildlife of not only individual hedgerows but the whole agricultural landscape.

Hedgerows are recognised both as a priority wildlife habitat and as an important part of ecological networks in the UK (Wolton, 2009b; Lawton, 2010), Belgium (Deckers et al., 2005), France, Germany and Ireland (Baudry et al., 2000). Within agri-environment policy, that of the EU is considered to have the most thorough scientific assessment and widest scope (Heath et al., 2017). Hedgerow planting, management and maintenance play a significant role within agri-environment schemes across Europe (Alignier and Baudry, 2015). In the United States, farmers are encouraged through voluntary on-farm conservation projects to offset the impacts of agricultural intensification, yet little hedgerow management advice is provided (Heath et al., 2017).

The recently implemented Countryside Stewardship scheme in England provides payments for traditional hedgerow laying, coppicing and management of the cutting regime (cutting on a 2–3 year rotation ideally in late winter), with the aim of encouraging taller and wider hedgerows, with increased berry and blossom provisions (Natural England, 2016). Similar schemes operate elsewhere in Europe (Fuentes-Montemayor et al., 2011). Currently only 48% of UK hedgerows are considered to be in “good condition” (Norton et al., 2012). This assessment is based on meeting numerous thresholds, including criteria centred on structural condition: hedgerow height should be a minimum of 1 m, width a minimum of 1.5 m and cross-sectional area a minimum of 3 m^2. Structural integrity and connectivity are also increasingly important in the assessment of ‘good condition’ hedgerows (Defra, 2007).

Habitat structural condition refers to the composition, spatial distribution and characteristics of a habitat's features, which contribute to habitat suitability and provide a sufficient quantity and quality of resources for a range of taxa. In this review, we summarise the effect of hedgerow management techniques on a range of individual structural features, using this information to explore synergies and conflicts in the management of hedgerows for biodiversity and for individual taxa. Few previous attempts to collate the findings of studies on different taxa exist in this context, none of which are recent (Barr et al., 2005). This is despite the gap in our understanding of potential complementarity, and conflicts in hedgerow structural requirements between taxa being highlighted over a decade ago within an international review of hedgerow management (Baudry et al., 2000). Furthermore, previous studies assessing the effects of hedgerow structure on wildlife conservation have not considered the cyclic management of hedgerows (Baudry et al., 2000) or the seasonality of the presence and use of individual structural components.

2. Review methodology

2.1. Review structure and approach

We begin by considering the impacts of cutting and rejuvenation techniques on woody hedgerow structure and habitat quality. Secondly, we review the association of a wide range of taxa with individual component features and characteristics of the hedgerow. Attention is given to two case studies: *Erinaceus europaeus* (European hedgehog), once widespread but now of conservation concern (listed ‘of principal concern’ in Section 41 of the Natural Environment and Rural Communities Act, 2006); and Lepidoptera, the most studied invertebrate taxa, with a range of responses to hedgerow management and structural condition.

Although this review is relevant to the management of a habitat type acknowledged in the literature as ecologically important across geographically diverse agri-ecosystems, most of the evidence collated in this review comes from the UK and Western France from where the bulk of the most recently published research originates (Baudry et al., 2000) (Table 1a). Despite this, exploring the synergies and conflicts in the management of hedgerows for the conservation of a wide range of species with differing habitat requirements has international relevance for agri-environment policy and hedgerow management.

2.2. Systematic literature review

Using the Science Direct, CAB abstracts, and IHS Environmental Management databases, the search terms ‘hedge’, ‘hedgerow’, ‘fencerow’, ‘green lane’ and ‘greenway’ returned 9827 unique articles published between 1990 and 2017. This initial search was narrowed to obtain information regarding specific taxa, habitat structural components and management techniques as necessary (Table 1), selecting the included literature based on reading of titles and abstracts in the English language.

It is worth acknowledging that defining a hedgerow is, as discussed in Wright (2016), challenging, as hedgerows are subject to regional variation in form and function. Throughout this review we consider hedgerows to be distinctive, and dynamic woody landscape features, actively managed for their function, thereby excluding other similar linear vegetation (51 studies). The exclusions included relict and defunct hedgerows, lines of trees, and fencerows (a term which dominantly refers to unmanaged, relict and uncultivated herbaceous vegetation) in the Americas that do not meet this definition, having had a different natural or management history to hedgerows (Sutton, 1992). We excluded studies which only considered the presence or abundance of hedgerows in the landscape (76 studies) rather than their structural condition and management. Urban hedgerows (4 studies) are also excluded from this review, although also important habitats for wildlife (Gosling et al., 2016), they are less studied than their rural counterparts. Discussion of hedgerow banks, ditches, and debris (Lecq et al., 2017), also fall beyond the scope of this review (2 studies).

Precedence was given to studies published since the 2005 review of a similar nature (Barr et al., 2005). Primary research was prioritised

Table 1
Systematic literature review methodology - (a) a summary of the literature search and exclusion criteria used to inform the narrative, qualitative and quantitative components of this review, primary resources are further presented by geographical area. (b) a tally of vote counting inputs summarised by taxonomic group and hedgerow structural attribute.

(a)	Search criteria		(b)	Detailed breakdown of primary resources	
	Hedgerow OR fencerow OR greenway OR green lane	9827		Papers with no specific species or taxa referenced	21
	AND structure OR management	6448		Papers with specific species or taxa referenced	97
	AND species OR wildlife OR habitat	478		Papers with no specific structural feature referenced	33
				Papers with specific structural feature referenced	85
	Exclusion criteria - titles and abstracts			Papers suitable for vote counting (Table 2)	64
	Linear vegetation other than a functional managed hedgerow	51		Papers suitable for management effects summary (Appendix A)	30
	Hedgerow presence, density, or extent only	76			
	Urban hedgerows	4		**Results by taxa (across 64 papers)**	
	Hedgerow refugia/ground substrate	2		Herbaceous plants	16
	Agronomic or other ecosystem service from hedgerow	122		Mammals (bats)	32(14)
	Otherwise irrelevant (e.g. hedge funds)	57		Birds	26
				Invertebrates (Lepidoptera)	32(13)
	Remaining resources				
	Primary sources	118		**Results by structural component (across 64 papers)**	
	Reviews	6		Surface area and volume	8
	Grey literature	42		Hedgerow height	14
				Hedgerow width	14
	Primary resources by geographical region			Woody biomass/density	21
	USA	4		Structural complexity and layering	7
	Canada	2		Species diversity/richness	4
	UK	35		Species composition	7
	Republic of Ireland	21		Foliage quality	2
	France	29		Foliage quantity	4
	Germany	6		Berry and flower resources	7
	Mediterranean	19		Diversity of age structure	5
	Scandinavia	2		Connectivity and gaps	13

with lesser focus given to research within the broader conceptual framework and wider contexts to provide narrative, and grey literature dealing with hedgerow policy and management. Older review papers were also included, allowing for an understanding of the knowledge base. References from such review papers were followed up to identify further primary sources. It is noted that the structural habitat requirements of some wildlife may be under-represented in the literature for reasons other than their lack of an association with hedgerow (Maudsley, 2000; Wolton et al., 2013), such as unpopularity, rarity or difficulty to sample (Green et al., 1994).

As is common in ecological reviews, our research question uncovered a broad array of response variables (structural components) (Table 1b), taxa affected (Table 1b), research methods, and statistical reporting (inconsistent outcomes measured or metrics reported). As a result, the data are too heterogeneous to allow any meaningful synthesis or meta-analysis. Instead we aimed to generalise across species and studies where possible. Vote counting is used to identify knowledge gaps, where further primary research is needed. This is presented in Table 2, which highlights the relationships between individual hedgerow structural components and broad taxonomic groups, to explore synergies and conflicts in the management of hedgerows for different taxa. We follow a standard vote counting procedure where significant positive effects, significant negative effects, and no significant effects are assigned a 'vote' in order to integrate information and generalise the effect direction for each structural component on each taxonomic group. We acknowledge that a vote counting approach, as a compromise, fails to account for statistical significance, study size or effect size (Koricheva et al., 2013). Unlike most vote counting methods which declare the effect direction with the most votes as dominant, we attempt to explain and highlight synergies and conflicts throughout our narrative review. By doing so, we provide the first summary in over a decade of research into hedgerow structural condition for multi-taxa hedgerow management. Recommendations for hedgerow management which take into account the role of hedgerow structure and habitat quality in biodiversity conservation are provided.

3. The impact of cutting and rejuvenation techniques on woody hedgerow structure

Hedgerow management relating to the technique, timing and

Table 2
Summary of the role of hedgerow structural features in determining the habitat suitability of a hedgerow for a range of taxonomic groups across 64 papers. Using a vote counting method, +/− indicate the direction of the relationship observed, **o** indicates no observed relationship. Where multiple symbols are displayed, an effect was observed in multiple results or studies. Where no evidence for this relationship was encountered in this review, the cell is empty. The number of votes shared across each row or column is highlighted in parenthesis.

Woody vegetation structural feature:	Herbaceous plants (16)	Mammals (18)	Bats (14)	Birds (26)	Invertebrates (19)	Lepidoptera (13)
Surface area and volume (8)	+ +	+ +	+	+	+	+
Hedgerow height (14)	o − −	+ + +	+ +	+ + + + −	**o**	
Hedgerow width (14)	+	+ + + +	+ + +	+ + + +	+ +	
Woody biomass/density (21)	+ + − − −	+ + +	+ + − −	+ + + −	+ + + +	+
Structural complexity & layering (7)		**o**	−	+ +	+ +	+
Species diversity/richness (4)		+		+ +	+	
Species composition (7)	+			+ + +	+	+ +
Foliage quality (2)					+ +	
Foliage quantity (4)					+ +	+ +
Berry and flower resources (7)				+ +	+ +	+ + +
Diversity of age structure (5)	+			+	+	+ +
Connectivity and gaps (13)	+ + +	+ + + −	+ + +	+ +		+

intensity of both cutting and rejuvenation techniques, influences numerous structural characteristics of the hedgerow (Croxton et al., 2004; Amy et al., 2015; Staley et al., 2015). Over time, common farming practice has shifted towards more intensive management techniques favouring higher yield. Increased mechanisation and increased fertiliser inputs are two such examples, which have led to widely divergent habitat structure and resulting habitat quality within hedgerows.

The hedgerow cutting regime is an integral part of hedgerow management (Barr and Gillespie, 2000) and has been shown to impact hedgerow structural condition differently depending on the timing, frequency and height increment of cutting activity (Croxton and Sparks, 2002; Staley et al., 2012). Trimming is usually performed with a mechanical flail (Boutin et al., 2001), removing all the previous season's growth. Post-harvest annual cutting has been the most common cutting regime practiced in the UK (Sparks and Croxton, 2007), this generality remains true a decade later, despite recommendations for longer cutting time increments through agri-environment schemes across Europe (Merckx et al., 2009b; Britt et al., 2011). Frequent cutting results in lower woody biomass (Maudsley, 2000) and a lower sub-branching density (number of sub branches in a sample area) resulting in a less complex branching structure (Facey et al., 2014). Further, annual cutting reduces vertical structural density (Croxton et al., 2004).

Crataegus monogyna (common hawthorn) and *Fraxinus excelsior* (ash) were found to be more resilient to an intensive annual trimming regime with a flail compared to *C. avellana* and *P. spinosa* (Wolton, 1994), suggesting that the woody species composition of the hedgerow could be affected by hedgerow cutting frequency. However, evidence of the effect of cutting regime and cutting frequency on woody species diversity is not conclusive. In a review by Barr et al. (2005) mixed evidence is presented, with the majority of studies reviewed indicating that the effects of cutting frequency and other environmental factors cannot often be distinguished. Frequently cut hedgerows are also stressed chemically, as foliage and branch damage can increase the breakdown and mobilisation of nitrogen to the leaves (Facey et al., 2014). Uncut *C. monogyna* hedgerows are significantly more prolific in terms of berry production (Croxton et al., 2002), uncut control hedgerows, were found to have 83% and 75% more berries and flowers respectively than annually cut hedgerows (Staley et al., 2012). This is linked to the removal of most of the previous season's growth during cutting, 2nd year growth is necessary for berry production. Few young stems remain, which would otherwise bear buds the following spring (Sparks and Croxton, 2007). The berries produced by other herbaceous species found in frequently cut plots, including *P. spinosa*, *R. canina* and *Rubus fruticosus* (bramble), also have significantly lower yields (Sparks and Martin, 1999).

Hedgerow rejuvenation is an important management step in a hedgerow's lifecycle and is required periodically to maintain a dense woody structure by encouraging regrowth from the hedge base (Croxton et al., 2004). Traditional rejuvenation by hedge laying, a practice whereby leggy stems (long stems with few leaves at the base) are partially cut at the base and laid down and interwoven along the hedge length, results in a high density of woody biomass in the hedge base, particularly at one side. An immediate removal of approximately 1/3 of total biomass occurs (Croxton et al., 2004; Staley et al., 2015). Hedge laying was prevalent historically across Europe, with countries and regions developing individual styles and techniques (Muller, 2013). In central England, for example, the prevalence of grazing cattle reared for beef led to the development of “midlands style” hedge-laying to create robust stock proof barriers. Cut branches are placed to one side of the hedgerow and held in place by stakes and binders. Coppicing was also widely practiced, whereby stems are cut to the ground to encourage basal growth (Deckers et al., 2004). Such techniques were once widespread across the UK, but are no longer considered cost effective. Evidence shows a current wider adoption and interest in alternative and potentially cheaper and quicker rejuvenation techniques such as conservation hedging, wildlife hedging and the use of circular saw (Amy et al., 2015). Conservation hedging is similar to midlands style laying but was developed as a quicker, cheaper alternative which involves laying branches to both sides of the hedgerow instead of one (Staley et al., 2015). Wildlife hedging is a more mechanised version of the traditional laying technique; a chainsaw is used to make rough basal cuts, which may sever when pushed over by machinery (Dodds, 2005), here, brash is left in situ. Circular saw rejuvenation involves reshaping the hedgerow by cutting the top and sides with a tractor mounted circular saw, the result is a box shaped hedge (Staley et al., 2015). The choice of technique applied can impact on subsequent regrowth of the hedgerow.

Coppicing creates comparatively open, light habitats when woody biomass is removed (Staley et al., 2013). This encourages *C. monogyna* to produce new shoots, rapidly rejuvenating hedgerow growth. In a recent experiment, the abundance of recent *C. monogyna* shoots was found to be twice as great in coppiced hedgerow compared to hedgerow managed under other rejuvenation treatments (Staley et al., 2015). However, this also creates an immediate short-term loss of hedgerow habitat with almost complete removal of biomass. Woody species richness appeared to benefit from historic coppicing or laying techniques, perhaps due to the removal of woody biomass, reducing competition for resources and allowing the persistence of slower growing species in the hedgerow (Staley et al., 2013). Traditional hedge-laying, conservation hedging and wildlife hedging also achieve similar increased density of woody biomass in the base of the hedgerow with fewer gaps (Staley et al., 2015).

Amy et al. (2015) studied the effect of different rejuvenation techniques on hedgerow structural characteristics including gappiness, where wildlife hedging produced the structure with the fewest gaps. More architecturally complex woody habitats (i.e. those with higher levels of branching complexity) have been shown to support higher levels of herbivorous insect diversity (AraÚJo et al., 2006), as is also the case with wildlife hedging and conservation hedging techniques, compared to control hedgerows (Amy et al., 2015).

4. Hedgerow habitat structure and associated species

4.1. Ground vegetation

An interaction between hedge network length, landscape context and complexity, and time determine herbaceous species diversity in a hedgerow (Batary et al., 2011; Ernoult and Alard, 2011). In theory, all hedgerow-associated and locally occurring plant species have a greater potential to occur within a hedgerow with time (Roy and de Blois, 2008). Longer hedgerows also provide a greater habitat area. However, habitat quality will differ considerably according to structural characteristics along a hedge length (Burel and Baudrey, 1990). Structurally diverse hedgerows are expected to support greater plant species richness. Management variability and resulting structural attribute variability have a greater influence on plant species distribution than hedgerow habitat spatial configuration and landscape context (Deckers et al., 2004). A hedgerow which provides a similar environment to a plant's natural autoecological requirements is key to determining floral composition (McCollin et al., 2000). Management that affects light levels, temperature and disturbance within a hedgerow are key due to the hedgerow's similarity to a woodland edge (McCollin et al., 2000; Jackson, 2001).

The effect of hedgerow management and structure on ground flora species is little studied compared to the effect of management on the woody vegetation directly. Any interest shown in hedgerow ground flora was, until relatively recently, concerned primarily with weed control and their suppression and removal (Alignier and Baudry, 2015). Also, conclusions drawn on the effect of management were based on observational rather than experimental evidence (Wolton, 1994). Presently, it is recommended that hedgerow management should aim to retain the conditions responsible for floristic diversity (Garbutt and

Sparks, 2002), whilst acknowledging that hedgerow plant communities are indicative of higher soil fertility, higher soil temperature and reduced soil acidity compared to woodland (McCollin et al., 2000). However, the effects of long term management history can remain evident in the composition of floral communities after 2 to12 years (Alignier and Baudry, 2015), and communities may remain impoverished in the long term, their functional character altered partly in response to light levels, microclimate and disturbance linked to the hedgerow management regime (Critchley et al., 2013).

Staley et al. (2013) found a general trend towards taxonomic homogenisation of hedgerow ground flora in Dorset (UK), driven by a decline in traditional hedgerow management techniques applied by hand, and increased eutrophication over time (from excess soil enrichment). Similarly in Northern Germany, hedgerow plant community richness has declined, hedgerows are now dominated by nitrophilous species in response to eutrophication and acidification (Litza and Diekmann, 2017). Generalist herbaceous hedge species benefited from the open, light habitats created by historic management techniques such as coppicing, and from the gradual opening up of the hedge base and increasing gappiness in the absence of management (Staley et al., 2013). Evidently, creating a habitat with higher light levels does not benefit all herbaceous species, trade-offs are demonstrated in the loss of shade tolerant “ancient woodland indicator species” from hedgerows with historical coppice management (mean number of species lost between 1930 and 2001 presence/absence surveys per hedgerow site = 1.25 + −0.63) (Staley et al., 2013). Forest herb species, typical of partial shade, including *Glechoma hederacea* (ground ivy) and *Torilis arvensis* (hedge parsley), may be sensitive to both hedgerow width, and high vegetation density - where light levels become partially restricted; similarly shade intolerant species are negatively correlated with increased hedgerow dimensions (Mountford et al., 1994), as larger, and denser hedgerows provide more shade. When hedgerows are allowed to mature, native shrubs naturally become established. A well-developed shrub layer can physically shelter the herbaceous understory, both from direct sun and from livestock grazing and trampling (Hannon and Sisk, 2009). Such an effect is likely to favour shade loving perennials typical of woodland. Dense hedgerows may also limit drift of agri-chemicals into hedgerow basal flora (Tsiourus and Marshall, 1998), which may be responsible for the long term decline of hedgerow basal flora including *Mercurialis perennis* (dogs mercury), *Hyacinthoides non-scripta* (bluebell) and *Anemone nemorosa* (wood anemone) observed by Garbutt and Sparks (2002). Indeed, similar community level (functional) differences in hedgerow ground flora in response to soil nutrient status and pH have been used to classify hedgerows for restoration objectives (Critchley et al., 2013).

4.2. Mammals

The vegetation structure of the hedgerow is critical to the presence and abundance of small mammal species. Hedgerow dimensions are important for most small mammals which use the hedgerow. Hedgerow width and length increase the total habitat area, indirectly increasing microhabitat complexity and refuge from predators (Gelling et al., 2007) for species including *Myodes glareolus* (bank vole) and *Apodemus flavicollis* (yellow necked mouse). Integrity and connectivity of the hedgerow structure is also important when traversing through a hedgerow (Bright, 1998). Small mammals avoid hedgerows with large gaps (> 3 m), A decrease in *M. glareolus* density (Gelling et al., 2007) is associated with increased hedgerow gappiness. *Apodemus flavicollis* density has also been associated with the presence of a ditch as part of the hedgerow structure (Gelling et al., 2007), aiding mobility between burrows and foraging areas. *Muscardinus avellanarius* (dormouse), an arboreal species, uses hedgerows all year round, favouring large, dense, species rich hedgerows (Bright and MacPherson, 2002). Hedgerows with a dense, well-developed shrub layer can support a greater abundance of *M. avellanarius* (Dondina et al., 2016). Hedgerow width can also affect whether small mammals are present (Wolton, 2009a); it is assumed by the author that this finding is linked to the shelter provided by a wider hedgerow. For *M. avellanarius*, hedgerow height is also important for the selection of nest sites (Wolton, 2009a).

Bats, including *Pipistrellus pipistrellus* (common pipistrelle), *Myotis daubentonii* (Daubenton's bat), *Myotis nattereri* (Natterer's bat), *Rhinolophus ferrumequinum* (greater horseshoe bat), *Rhinolophus hipposideros* (lesser horseshoe bat), and *Plecotus auritus* (brown long-eared bat), are known to fly along hedgerows (Downs and Racey, 2006). Linear features do not only function as commuting routes, but also provide benefits to bats independent of this primary function (Boughey et al., 2011), although the effect of local habitat structural condition is not much studied (Lacoeuilhe et al., 2016). Vespertilionid species, including *P. pipistrellus* (Downs and Racey, 2006), use linear habitats such as hedgerows for feeding, shelter and navigation at a range of scales (Walsh and Harris, 1996). Bats, not unlike many other small mammals found within the hedgerow, are macro-invertebrate feeders, so structural components of the hedgerow, which increase the abundance of macro-invertebrates, may also benefit bats by increasing food availability.

Those with particularly short range echo location calls, such as *P. auritus*, rely on linear landscape elements for orientation within a landscape (Barr et al., 2005). This suggests that the connectivity and integrity of hedgerows is important for bats, and that complete removal of a hedgerow, through coppice management, may be disruptive. The activity of pipistrelle bats and bats with short to medium range echolocation are negatively affected by foliage height variability along the profile of wooded landscapes (Froidevaux et al., 2016). Where foliage height diversity is high, the ability of certain bats to access forage and shelter is restricted by a scattered vegetation distribution, limiting their manoeuvrability across the landscape. It can be inferred that some bat species or groups may respond negatively to hedgerows with similarly heterogeneous height profiles, within a landscape context.

Rhinolophus ferrumequinum prefer to travel along larger hedgerows, with a height and width above 2 m (Duverge and Jones, 2003). A study comparing bat activity between organic and conventional farms found that bats were thought to prefer organic farms due to the presence of taller hedgerows, providing more shelter (Wickramasinghe et al., 2003). Bats were also found to avoid short, over-trimmed hedgerows in a Northern Ireland study (Russ and Montgomery, 2002), suggesting hedgerow height to be important for multiple species of bat as a proxy for larger hedgerow habitat and greater food availability. The abundance of bat species is negatively (five species of which two significant) or positively associated (four species of which one significant) with woody biomass (including hedgerow and woodland in the landscape) at a 50 m scale. This effect is less variable and more significant (eight species of which four significant with a positive association) at larger spatial scales (e.g. 1000 m), suggesting that for most bat species local structural condition is less important than habitat structure and connectivity in the wider landscape, particularly for mobile species and aerial foragers (Lacoeuilhe et al., 2016). However, less mobile and gleaner species were most influenced by woody biomass at smaller spatial scales (100 to 300 m).

Meles meles (badger) are known to site their sets and latrines in hedgerows (preferring dense basal and shrub vegetation) and use the hedgerows for over-ground movement around agricultural landscapes (O'Brien et al., 2016). Hedgerows whose structural condition encourages this preference provide a means of reducing contact between *M. meles* and cattle, therefore reducing the spread of bovine tuberculosis (Mathews et al., 2006; Winkler and Mathews, 2015).

Vulpes vulpes (red fox) are mentioned in the Barr et al. review (2005) to site their sets in hedgerow banks, however no studies were encountered in our review which considered the effect of hedgerow structural condition on use of the hedgerow by this species. Likewise, no studies specifically link hedgerow habitat structure to *Lepus europaeus* (brown hare) or *Leporidae* spp. (rabbits).

4.2.1. Conservation concern case study 1: European hedgehog, *Erinaceus europaeus*

Erinaceus europaeus is a generalist macro-invertebrate feeding species associated with grassland and edge habitats including hedgerows in the agri-environment (Hof and Bright, 2010). Their distribution across many Western European countries is declining (Hof et al., 2012). In studies in Britain and the Netherlands, this decline has been attributed in part to increased predation by *M. meles* and road traffic accidents (van de Poel et al., 2015). Their choice of edge habitats may be related to predator avoidance, particularly by *M. meles* (Hof et al., 2012). They are more likely to nest in areas of the hedgerow with 'prickly vegetation' (53.5% of nest sites) (Reeve, 1981). In Irish hedgerows nest sites are commonly located in *R. fruticosus* dominant hedgerows (Haigh et al., 2012). Connectivity and integrity of hedgerows across the landscape is important for the dispersal of this mobile species (Moorhouse et al., 2014). Deterioration in hedgerow habitat quality and loss of functional hedgerows has been indicated as responsible for their recent decline, reducing their shelter from *M. meles* predation particularly during hibernation. In contrast, *M. meles* rarely utilise intact linear habitats to actively forage or hunt (Young et al., 2006). *E. europaeus* mortality for instance was observed most frequently in "open, sparse, bare based hedgerows" (Hof and Bright, 2010). Encouraging dense basal vegetation is surmised to benefit *E. europaeus* by providing shelter and increasing insectivorous prey availability (French and Cummins, 2001; Barr et al., 2005; Hof et al., 2012; Gosling et al., 2016).

4.3. Birds

Due to the often-varied habitat composition of farmland in rural Europe, birds associated with hedgerows consist of both farmland and woodland species. Seven species are considered hedgerow specialists, including *Prunella modularis* (dunnock), *Sylvia communis* (whitethroat), *Sylvia curruca* (lesser whitethroat), *Linaria cannabina* (linnet), *Carduelis carduelis* (goldfinch), *Chloris chloris* (greenfinch) and *Emberiza citrinella* (yellow hammer) (Fuller et al., 2001). Literature on optimising hedgerow structure for birds often alludes to conflicts between bird species which use hedgerows for foraging, nesting or for cover from predation when foraging in neighbouring open areas (Whittingham and Evans, 2004). Although each bird species has its own preferences, many passerine species, which are generally associated with woodland, prefer to nest in large hedgerows. Tall hedgerows support species such as *P. modularis*, *Erithacus rubecula* (robin), *Turdus philomelos* (song thrush), *Phylloscopus trochilus* (willow warbler) and *S. curruca* (Green et al., 1994) and woodland species such as *Fringilla coelebs* (common chaffinch) (Lack, 1992). Wide hedgerows are associated with *C. chloris*, *C. carduelis*, *Troglodytes troglodytes* (wren), *E. rubecula* and *Turdus merula* (common blackbird) (Green et al., 1994). Variation in bird abundance and diversity between farming systems is also attributed to the structural character of hedgerow habitat (Chamberlain et al., 1999), which tends to be taller and wider on organic farms. In contrast, *L. cannabina* and *E. citrinella* favour, or at least tolerate shorter hedgerows (Green et al., 1994). This preference of many bird species to nest in tall and wide hedgerows is supported by Whittingham et al. (2009), who found associations with seven and three species of bird respectively. The predation rate of song bird nests by corvids is higher where nest sites are open and more accessible (Dunn et al., 2016), nest site selection favours dense vegetation, which results in higher chick survival. This cover is better provided by hedgerows within a cutting cycle, rather than recently coppiced or remnant hedgerows.

Hedgerows with greater berry abundance will provide better food resources for birds (Hinsley and Bellamy, 2000), with *Turdidae* spp. (thrush) preferring *C. monogyna* berries (Sparks and Martin, 1999). Vegetation structure in the hedgerow basal layer is particularly important for nest site selection and nesting success (Hinsley and Bellamy, 2000). Ground nesting species require dense vegetation at the hedgerow base for cover from predation. Shrub nesting species, *Pyrrhula pyrrhula* (bullfinch) and *T. philomelos* also breed in dense, species rich hedgerows, and are found to be significantly associated with landscapes that have hedgerows managed under Environment Stewardship options (A UK agri-environment scheme) that encourage these characteristics (Baker et al., 2012).

Species composition and age structure of the hedgerow is also important for bird breeding success. Dead and decaying woody vegetation can provide nesting sites for arboreal nesting species (Hinsley and Bellamy, 2000; Natural England, 2009). Structural complexity, provided by a diversity of woody and herbaceous species, may also play a role in reduced predation by providing both cover and advantageous perching/lookout positions (Hinsley and Bellamy, 2000), although Whittingham and Evans (2004) caution that dense, structurally complex vegetation may also conceal predators; this speculation is supported by the studies mentioned in Section 4.2. Furthermore, the dominance of individual woody or herbaceous plant species is associated with a significant difference in the percentage incidence of some bird species. For example, *S. communis* were encountered more often within *Ulmus sp*. (elm) dominant hedgerows (11.6% incidence) compared to *C. monogyna* dominant hedgerows (4.5% incidence), *T. merula* were more abundant within Apiaceae spp. (parsley family) ground flora dominant hedgerow (39.9% incidence) compared to *M. perennis* dominant hedgerows (16.7% incidence) (Green et al., 1994). The incidence of farmland bird species is positively associated with woody species-rich hedgerows (30 m long plots) (Green et al., 1994) and with green lanes with a greater percentage of *C. monogyna* ($p = 0.03$) and *R. fruticosus* ($p = 0.02$) (Walker et al., 2005).

4.4. Invertebrates

The majority of species which occur within the hedgerow environment are invertebrates, including members of the taxonomic groups Araneae (spiders), Coleoptera (beetles), Diptera (true flies), Hemiptera (true bugs), Lepidoptera (butterflies and moths) and Hymenoptera (bees, wasps, ants) (Pollard and Holland, 2006). Invertebrates are more diverse within hedgerows than elsewhere in the agri-environment (Maudsley, 2000). Hedgerows are expected to provide key resources for species within most arthropod taxa and functional groups (predators, parasitoids, herbivores and scavengers) found within a hedgerow, including shelter, appropriate environmental conditions and food resources (Pollard and Holland, 2006).

Structural complexity (i.e. the number or magnitude of structural components present and their variability (Carvalho et al., 2017)) is important for arthropods at a range of spatial scales across a range of habitats. At the scale of an individual plant, structural architecture affects the density of a range of invertebrate predator and parasitoid guilds, particularly hunting Araneae, with less complex structured plants supporting fewer invertebrates (Langellotto and Denno, 2004). The abundance of invertebrate predators (including Araneae, Acarina (mites) and Coleoptera has been related to habitat level structural complexity (Langellotto and Denno, 2004). This includes increased detritus, leaf density and branch structure. Complex structured hedgerows with many vegetation layers have high associated invertebrate diversity (Maudsley, 2000; Maudsley et al., 2002). Hedgerow vegetation density within the base and shrub layer of a hedge may also provide a potential windbreak in habitat selection by Araneae (Maudsley et al., 2002). A larger habitat area tends to be more complex, fulfilling more niche requirements and providing more resources (Weibull and Ostman, 2003). Differences have been observed in the composition of Carabidae (ground beetles) and Staphylinidae (rove beetles) assemblages within managed hedgerows, relict hedgerows and remnant hedgerows, the latter being more dominated by species of low dispersal abilities (Griffiths et al., 2007). These hedgerow types were structurally different from each other in terms of dimensions, gappiness/integrity and woody and herbaceous species richness and density. Griffiths et al. (2007), and Maudsley (2000) also present evidence in support of plant species diversity for invertebrates. A wider hedge base is beneficial for Staphylinidae by reducing habitat disturbance and edge effect (Maudsley et al., 2002). An established shrub layer can provide important forage for Apoidea (bees) and other pollinator species (Hannon and Sisk, 2009), especially where the abundance and diversity of floral resources has been enhanced by management (Morandin and Kremen, 2013a). Similarly, another American study on habitat restoration in agricultural landscapes found enhanced pollinator persistence where more time had elapsed since hedgerow restoration, using hedgerow age as a proxy for the abundance of floral resources and high quality nesting substrate (M'Gonigle et al., 2015). Where basal vegetation is enclosed and dense, hedgerows also possess a greater range of invertebrate taxa (Griffiths et al., 2007). Large, complex hedgerows therefore benefit invertebrates through increased availability and diversity of food resources, woody material and ground litter for foraging, cover and shelter from predation (Maudsley, 2000) and provide a favourable microclimate and abiotic shelter (Langellotto and Denno, 2004).

The direct effect of hedgerow cutting on invertebrates is often mortality or displacement (Maudsley, 2000). Eggs present on autumnal foliage or overwintering invertebrates can be removed by inappropriately timed cutting. Hedgerows with increased new foliage growth after regular cutting may favour some herbivorous insects (Maudsley, 2000). The immediate new foliar growth on recently cut hedgerows contains increased nitrogen, which is often limiting to invertebrates. The carbon-to-nitrogen ratio has been shown in other habitats to be an important determinant of moth and fruit fly survivorship, affecting moth larvae size, and growth rate in adults (Colasurdo et al., 2009). A recent study by Amy et al. (2015) found increased foliage quality (in terms of foliar nitrogen content) to be less influential overall to the abundance of invertebrates than overall foliage quantity. Hedgerow rejuvenation treatments affect the abundance of invertebrate trophic groups. When compared with circular saw treatments, hedgerows managed using hedge-laying approaches had greater abundance of detritivores, herbivores and predators (Amy et al., 2015).

Many invertebrate groups benefit from mature growth hedgerows. They provide a range of flowers and cavity nesting spaces for a variety of pollinators, resulting in greater abundance of Apoidea in mature hedgerows (Kremen and M'Gonigle, 2015). They also offer a variety of ageing and dead plant material beneficial to detritivores and hole boring invertebrates (Marshall et al., 2001). Hedgerow species composition is also important, the existence of individual woody species or combination of species within a hedgerow could favour particular invertebrate assemblages over others (Butler et al., 2012). For instance, pollinators were found to favour hedgerows with native species over introduced species in a California based study (Morandin and Kremen, 2013a). Invertebrates were also more diverse in mixed species compared to *C. monogyna* dominant hedgerows (Institute of Grassland and Environment Research, 2000).

4.4.1. *Conservation concern case study 2: butterflies and moths order Lepidoptera*

Lepidoptera are the most studied order in relation to hedgerow habitat and management. There are 165 Lepidoptera species listed as high conservation priority under section 41 of the UK Natural Environment and Rural Communities act, a higher number than any other invertebrate order (Webb et al., 2010). The recent decline of Lepidoptera has been attributed to the loss of resource quantity and quality through agricultural intensification (Conrad et al., 2006; Fox, 2013) and for some species, more specifically, to the increased prevalence of annual cutting regimes in the management of hedgerows (Merckx and Berwaerts, 2010). This has led to high levels of mortality and localised extinctions. For instance, *Thecla betulae* (brown hairstreak), a species now of conservation concern, was once characteristic (albeit at low densities) of farmed landscapes containing networks of hedgerows, woodland and coppice, particularly where it's host plant, *P. spinosa*, was abundant (Merckx and Berwaerts, 2010). Recent evidence has shown annual cutting regimes led to lower *T. betulae* egg abundance, compared with hedgerows cut in less frequent rotations (Staley et al., 2017-in this issue). The dominance of autumn cutting outside of environmental stewardship schemes can kill, injure or disturb species still active beyond September (Maudsley, 2000). However, Fuentes-Montemayor et al. (2011) found no significant difference in moth abundance between hedgerows managed under agri-environmental scheme, and hedgerows managed outside of these recommendations.

A 75% reduction in floral resources on annually cut compared to uncut hedgerows has been observed (Staley et al., 2012), with potential impacts on adult Lepidoptera that use the floral resources provided by a hedgerow for nectar (Sparks and Parish, 1995). Shading of floral resources by dense hedgerow foliage has been negatively associated with butterfly visitation. Contrastingly, high density cover (Dover and Sparks, 2000) and hedgerow trees (Merckx et al., 2010) can also provide favourable wind sheltered conditions for butterflies. The presence of hedgerow trees can increase abundance (by 80%) and diversity (by 38%) of large moths (Merckx et al., 2009b). This is particularly true for less mobile species (Merckx et al., 2009a).

For Lepidoptera who use the hedgerow for oviposition, the timing and intensity of hedgerow cutting can impact both the selection of hedgerow for egg laying and the survivorship of eggs and juvenile larvae and caterpillars. Free living larvae and pupae were significantly more abundant on hedgerows cut in the winter (16% more larvae and pupae than on autumn cut hedgerows), and on hedgerows cut every three years (4% more larvae and pupae that on annual cut hedgerows) (Staley et al., 2016). Similarly, concealed moth larvae are more abundant on hedgerows cut infrequently (Facey et al., 2014). Lepidoptera present a wide range of life histories, so the optimal hedgerow habitat structural condition will differ both between individual species and throughout the lifecycle of an individual. After cutting, the incidence of protruding young stems into shade-free conditions is beneficial to *T. betulae* fecundity and survivorship (Barr et al., 2005). Young growth also provides a better quality of feed resource for immature larvae (Merckx and Berwaerts, 2010). Eggs of *T. betulae* – laid close to buds and thorns in late summer/early autumn and remaining over winter, are abundant on young growth stems. They are therefore vulnerable in hedgerows where young growth is removed during cutting (Merckx and Berwaerts, 2010); delaying cutting until winter may not benefit this species (Staley et al., 2016). Lepidoptera may also avoid laying eggs in areas where larval growth will be inhibited by a cold microclimate (Merckx and Berwaerts, 2010).

5. Optimising hedgerow habitat structural condition for biodiversity: Synergies and conflicts between taxa

Hedgerow structural condition determines the value of hedgerow habitat for biodiversity conservation within an agricultural setting for a range of taxa, with differences in habitat preference and tolerance between taxa (Barr et al., 2005). Understanding how different taxa utilise their habitat, in order to better conserve them, requires considering the role of individual habitat structural components, their spatial arrangement and condition in response to hedgerow management. In the case of hedgerow habitat, it is difficult to isolate the key factors of habitat quality for individual species or groups, but identifying general patterns is possible (Maudsley et al., 2002). Policy often requires this type of prioritisation. Although, recent work has both compared a range of habitat requirements for two hedgerow species (*M. meles* and *M. avellanarius*) (Dondina et al., 2016) and discussed the importance of a singular component feature across taxa (e.g. hedge refugia in Lecq et al., 2017), this is the first review in over a decade (Barr et al., 2005) that attempts to bring together current understanding of individual species and taxa requirements and preferences for a wide range of hedgerow structural components for biodiversity conservation.

Several structural characteristics; height, width, woody biomass, structural complexity and layering, foliar quantity, quality, and gappiness, are all identified in the literature as key condition indicators of the presence, abundance, survival or fecundity of a range of farmland taxa. A summary is provided (Table 2), highlighting the potential impact of different structural characteristics on herbaceous plants, mammals, birds and invertebrates.

When considering the role of hedgerow structural condition in supporting biodiversity, in general, having and maintaining larger hedgerows through rotational cutting (performed less frequently than annually), will benefit wildlife by providing a greater habitat area linked to the presence of small mammals, bats and birds. Larger hedgerows tend to provide a greater variety and quantity of resources (Weibull and Ostman, 2003) and greater cover. Woody and leafy density is important for shelter, connectivity and as a resource for a range of taxa, so management which creates denser hedgerows and preserves new growth will be beneficial. Connectivity of the hedgerow is important at a range of scales, particularly for mobile groups at the landscape scale, with gappiness, within hedge connectivity and branching architecture important for less mobile invertebrates. The availability of seasonal resources including foliage, berries and flowers is also important to wildlife that uses the hedgerow. Although less well studied, greater food and resource abundance had a beneficial effect on all studied groups, and was particularly important for invertebrates throughout their lifecycles.

Despite being able to make some generalisations, species and groups of taxa have heterogeneous requirements for hedgerows with differing structural conditions and responses to management. Hedgerow height is less beneficial to herbaceous plants, sometimes causing a shading effect (Mountford et al., 1994), similarly tall hedgerows are not the preferred habitat for some farmland birds (Hinsley and Bellamy, 2000). Tall hedgerows can be further detrimental to some bird species when concealed predators are considered (Whittingham and Evans, 2004). Given the decline in farmland bird species across Europe (Hinsley and Bellamy, 2000; Fuller et al., 2001), care needs to be taken to account for heterogeneous habitat requirements. It is also important to consider the scale and time period involved in taking management decisions and consider their impact. Coppicing for example causes temporary but complete loss of the hedgerow habitat in the short-term, but has positive long-term effects on hedgerow biodiversity, including ground flora (Staley et al., 2013; Staley et al., 2015). The response among Lepidoptera to the timing of hedgerow cutting varies by species based on life history. For instance, *T. betulae* are active later and therefore, unlike other species, their eggs may be removed by winter cutting (Staley et al., 2016).

Barr et al. (2005) noted a shortage of data from long term replicated field experiments studying the effects of different management on hedgerow wildlife. This review has highlighted that for certain groups of taxa and for specific features of hedgerow habitat structure, this limitation remains (Table 2). It is also evident from our systematic review that particular structural features are described, measured and quantified differently across studies, with different statistical inferences reported, or not reported at all (Section 2.2). As these methodological inconsistencies can limit our ability to analyse and draw conclusions, we would recommend further work to identify an optimum and consistent approach to the study of hedgerow structure.

5.1. Conclusions

It is noted that many of the relationships between hedgerow structure and associated biodiversity are:

- Interdependent – for instance predators benefit from structural characteristics which increase their prey resources;
- Synergistic – some key conclusions and generalisations can be drawn regarding the management of hedgerows for biodiversity to benefit the majority of species;
- Multi-directional – individual species, functional and taxonomic groups are affected differently;
- Due to variation in methodology or data reporting, existing studies lack comparability. There is also a lack of quantitative, primary studies, for some taxa.

This review has provided an update on previous attempts to summarise the effect of hedgerow management on wildlife (Barr et al., 2005). While many of the effects of hedgerow management discussed in previous work are given further support by the inclusion of more recent studies; others have been expanded to explicitly include the role of individual structural components of the hedgerow both in response to management and in determining habitat condition.

Current recommendations for hedgerow management through the medium of agri-environment schemes should enhance hedgerow habitat quality for a wide range of taxa, by creating larger and denser hedgerows with a greater abundance of resources, as emphasised in this review. Not all structural characteristics highlighted in this review are currently included in assessments of hedgerow condition, nor are they usually measured as part of hedgerow surveys. Their inclusion could improve management recommendations, enhancing the success and monitoring of management outcomes for biodiversity conservation at a range of scales. For example in the UK, the new mid-tier Countryside Stewardship scheme states successfully managed hedgerows will be taller and wider, with < 10% gaps, dense cover and greater berry and floral production to benefit wildlife (Natural England, 2016). Yet, no mention is given to some structural attributes which would maintain hedgerows in ‘favourable condition’ as noted in previous government recommendations (Defra, 2007), such as maintaining a basal canopy above 1.5 m or a preference for native woody and herbaceous species, both still supported by recent evidence presented within this review. Nor are any recommendations provided for assessing hedgerow structural condition based on the other features highlighted in this review; foliage quality, age structure and branching architecture remain ignored. Hedgerow management could benefit from expansion of the definition of a ‘good quality’ hedgerow for biodiversity conservation in the agri-environment to include all of these key structural features. Doing so will greatly enhance the potential of hedgerows to support biodiversity. Furthermore, the importance of heterogeneity in hedgerow structural condition is highlighted through this review, where no fixed set of hedgerow characteristics were found to benefit all taxa. If uniform hedgerow management to benefit wider biodiversity is overprescribed, some species (including those of conservation concern) are likely to be adversely affected by a loss of suitable habitat or resource decline. We recommend that the individual requirements for these species continue to be considered with reference to targeted hedgerow management, management at a range of spatial scales and consideration of management heterogeneity over both time and space.

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References

Alignier, A., Baudry, J., 2015. Changes in management practices over time explain most variation in vegetation of field margins in Brittany, France. Agric. Ecosyst. Environ. 211, 164–172.
Amy, S.R., Heard, M.S., Hartley, S.E., George, C.T., Pywell, R.F., Staley, J.T., 2015. Hedgerow rejuvenation management affects invertebrate communities through changes to habitat structure. Basic Appl. Ecol. 16 (5), 443–451.
AraÚJo, A.P.A., De Paula, J.D.A., Carneiro, M.A.A., Schoereder, J.H., 2006. Effects of host plant architecture on colonization by galling insects. Austral Ecol. 31 (3), 343–348.
Assandri, G., Bogliani, G., Pedrini, P., Brambilla, M., 2017. Assessing common birds' ecological requirements to address nature conservation in permanent crops: lessons

from Italian vineyards. J. Environ. Manag. 191, 145–154.
Baker, D.J., Freeman, S.N., Grice, P.V., Siriwardena, G.M., 2012. Landscape-scale responses of birds to agri-environment management: a test of the English environmental stewardship scheme. J. Appl. Ecol. 49 (4), 871–882.
Barr, C.J., Gillespie, M.K., 2000. Estimating hedgerow length and pattern characteristics in Great Britain using Countryside Survey data. J. Environ. Manag. 60 (1), 23–32.
Barr, C.J., Britt, C.P., Sparks, T.H., Churchward, J.M., 2005. Hedgerow Management and Wildlife - A review of Research on the Effects of Hedgerow Management and Adjacent Land on Biodiversity (BD2108). Defra, UK.
Batary, P., Baldi, A., Kleijn, D., Tscharntke, T., 2011. Landscape-moderated biodiversity effects of agri-environmental management: a meta-analysis. Proc. R. Soc. B Biol. Sci. 278, 1894–1902.
Baudry, J., Bunce, R.G.H., Burel, F., 2000. Hedgerows: an international perspective on their origin, function and management. J. Environ. Manag. 60 (1), 7–22.
Boughey, K.L., Lake, I.R., Haysom, K.A., Dolman, P.M., 2011. Improving the biodiversity benefits of hedgerows: how physical characteristics and the proximity of foraging habitat affect the use of linear features by bats. Biol. Conserv. 144 (6), 1790–1798.
Boutin, C., Jobin, B., Bélanger, L., Baril, A., Freemark, K.E., 2001. Hedgerows of the world: their ecological functions in different landscapes. In: Proceedings of the 10th Annual Conference of the International Association for Landscape Ecology. Birmingham University.
Bright, P.W., 1998. Behaviour of specialist species in habitat corridors: arboreal dormice avoid corridor gaps. Anim. Behav. 56 (6), 1485–1490.
Bright, P.W., MacPherson, D., 2002. Hedgerow Management, Dormice, and Biodiversity (ENRR454). Natural England, UK.
Britt, C., Tuffnell, N., Kirkham, F., Roberts, A., Sparks, T., 2011. Hedgerow Management: A Survey of Land Managers' and Contractors' Practices and Attitudes. Defra, London, UK [Online]. Available at: http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=16517, Accessed date: 15 January 2014.
Burel, F., Baudrey, J., 1990. Structural dynamic of a hedgerow network landscape in Brittany France. Landsc. Ecol. 4 (4), 197–210.
Butler, J., Green, T., Alexander, K., 2012. Collections of ancient trees: hotspotting biodiversity, heritage and landscape value. In: Trees Beyond the Wood. Wildtrack Publishing, Sheffield Hallam University. Sheffield, pp. 71–78.
Carey, P.D., Wallis, S., Chamberlain, P.M., Cooper, A., Emmett, B.A., Maskell, L.C., McCann, T., Murphy, J., Norton, L.R., Reynolds, B., Scott, W.A., Simpson, I.C., Smart, S.M., Ullyett, J.M., 2008. Boundary and linear features. In: Carey, P.D., Wallis, S., Chamberlain, P.M., Cooper, A., Emmett, B.A., Maskell, L.C., McCann, T., Murphy, J., Norton, L.R., Reynolds, B., Scott, W.A., Simpson, I.C., Smart, S.M., Ullyett, J.M. (Eds.), Countryside Survey: UK Results From 2007. Centre for Ecology and Hydrology, UK.
Carvalho, L.R.S., Loiola, M., Barros, F., 2017. Manipulating habitat complexity to understand its influence on benthic macrofauna. J. Exp. Mar. Biol. Ecol. 489, 48–57.
Chamberlain, D.E., Wilson, J.D., Fuller, R.J., 1999. A comparison of bird populations on organic and conventional farm systems in southern Britain. Biol. Conserv. 88 (3), 307–320.
Colasurdo, N., Gelinas, Y., Despland, E., 2009. Larval nutrition affects life history traits in a capital breeding moth. J. Exp. Biol. 212, 1794–1800.
Connor, D.J., Gómez-del-Campo, M., Rousseaux, M.C., Searles, P.S., 2014. Structure, management and productivity of hedgerow olive orchards: a review. Sci. Hortic. 169, 71–93.
Conrad, K.F., Warren, M.S., Fox, R., Parsons, M.S., Woiwod, I.P., 2006. Rapid declines of common, widespread British moths provide evidence of an insect biodiversity crisis. Biol. Conserv. 132 (3), 279–291.
Cranmer, L., McCollin, D., Ollerton, J., 2012. Landscape structure influences pollinator movements and directly affects plant reproductive success. Oikos 121 (4), 562–568.
Critchley, C.N.R., Wilson, L.A., Mole, A.C., Norton, L.R., Smart, S.M., 2013. A functional classification of herbaceous hedgerow vegetation for setting restoration objectives. Biodivers. Conserv. 22 (3), 701–717.
Croxton, P.J., Sparks, T.H., 2002. A farm-scale evaluation of the influence of hedgerow cutting frequency on hawthorn (*Crataegus monogyna*) berry yields. Agric. Ecosyst. Environ. 93 (1–3), 437–439.
Croxton, P.J., Carvell, C., Mountford, J.O., Sparks, T.H., 2002. A comparison of green lanes and field margins as bumblebee habitat in an arable landscape. Biol. Conserv. 107 (3), 365–374.
Croxton, P.J., Franssen, W., Myhill, D.G., Sparks, T.H., 2004. The restoration of neglected hedges: a comparison of management treatments. Biol. Conserv. 117 (1), 19–23.
Deckers, B., Hermy, M., Muys, B., 2004. Factors affecting plant species composition of hedgerows: relative importance and hierarchy. Acta Oecol. 26 (1), 23–37.
Deckers, B., Kerselaers, E., Gulinck, H., Muys, B., Hermy, M., 2005. Long-term spatio-temporal dynamics of a hedgerow network landscape in Flanders, Belgium. Environ. Conserv. 32 (1), 20–29.
Defra, 2007. Hedgerow Survey Handbook. Defra, London.
Dodds, M.J.W., 2005. Mechanical Hedge-laying for Wildlife. Aylesbury Vale, Buckinghamshire, England.
Dondina, O., Kataoka, L., Orioli, V., Bani, L., 2016. How to manage hedgerows as effective ecological corridors for mammals: a two-species approach. Agric. Ecosyst. Environ. 231, 283–290.
Dover, J., Sparks, T., 2000. A review of the ecology of butterflies in British hedgerows. J. Environ. Manag. 60 (1), 51–63.
Downs, N.C., Racey, P.A., 2006. The use by bats of habitat features in mixed farmland in Scotland. Acta Chiropterologica 8 (1), 169–185.
Dunn, J.C., Gruar, D., Stoate, C., Szczur, J., Peach, W.J., 2016. Can hedgerow management mitigate the impacts of predation on songbird nest survival? J. Environ. Manag. 184 (3), 353–544.
Duverge, P.L., Jones, G., 2003. Use of farmland habitats by greater horseshoe bats. In: Tattersall, F., Manley, W. (Eds.), Conservation and Conflict. Mammals and Farming in Britain. The Linnean Society, London, pp. 64–81.
Ernoult, A., Alard, D., 2011. Structural dynamic of a hedgerow network landscape in Brittany France. Landsc. Ecol. 26 (5), 683–696.
Facey, S.L., Botham, M.S., Heard, M.S., Pywell, R.F., Staley, J.T., 2014. Moth communities and agri-environment schemes: examining the effects of hedgerow cutting regime on diversity, abundance, and parasitism. Insect Conserv. Divers. 7, 543–552.
Fox, R., 2013. The decline of moths in Great Britain: a review of possible causes. Insect Conserv. Divers. 6 (1), 5–19.
French, D.D., Cummins, R.P., 2001. Classification, composition, richness and diversity of British hedgerows. Appl. Veg. Sci. 4 (2), 213–228.
Froidevaux, J.S.P., Zellweger, F., Bollmann, K., Jones, G., Obrist, M.K., 2016. From field surveys to LiDAR: shining a light on how bats respond to forest structure. Remote Sens. Environ. 175, 242–250.
Fuentes-Montemayor, E., Goulson, D., Park, K.J., 2011. The effectiveness of agri-environment schemes for the conservation of farmland moths: assessing the importance of a landscape-scale management approach. J. Appl. Ecol. 48 (3), 532–542.
Fuller, R.J., Chamberlain, D.E., Burton, N.H.K., Gough, S.J., 2001. Distributions of birds in lowland agricultural landscapes of England and Wales: how distinctive are common bird communities of hedgerow and woodland? Agric. Ecosyst. Environ. 84 (1), 79–92.
Garbutt, R.A., Sparks, T.H., 2002. Changes in the botanical diversity of a species rich ancient hedgerow between two surveys (1971–1998). Biol. Conserv. 106 (2), 273–278.
Gelling, M., Macdonald, D.W., Mathews, F., 2007. Are hedgerows the route to increased farmland small mammal density? Use of hedgerows in British pastoral habitats. Landsc. Ecol. 22 (7), 1019–1032.
Gosling, L., Sparks, T.H., Araya, Y., Harvey, M., Ansine, J., 2016. Differences between urban and rural hedges in England revealed by a citizen science project. BMC Ecol. 16 (1), 15.
Green, R.E., Osborne, P.E., Sears, E.J., 1994. The distribution of passerine birds in hedgerows during the breeding season in relation to characteristics of the hedgerow and adjacent farmland. J. Appl. Ecol. 31 (4), 677–692.
Griffiths, G.J.K., Winder, L., Holland, J.M., Thomas, C.F.G., Williams, E., 2007. The representation and functional composition of carabid and staphylinid beetles in different field boundary types at a farm-scale. Biol. Conserv. 135 (1), 145–152.
Haigh, A., O'Riordan, R.M., Butler, F., 2012. Nesting behaviour and seasonal body mass changes in a rural Irish population of the Western hedgehog (*Erinaceus europaeus*). Acta Theriol. 57 (4), 321–331.
Hannon, L.E., Sisk, T.D., 2009. Hedgerows in an agri-natural landscape: potential habitat value for native bees. Biol. Conserv. 142 (10), 2140–2154.
Heath, S.K., Soykan, C.U., Velas, K.L., Kelsey, R., Kross, S.M., 2017. A bustle in the hedgerow: woody field margins boost on farm avian diversity and abundance in an intensive agricultural landscape. Biol. Conserv. 212 (A), 153–161.
Hinsley, S.A., Bellamy, P.E., 2000. The influence of hedge structure, management and landscape context on the value of hedgerows to birds: a review. J. Environ. Manag. 60 (1), 33–49.
Hof, A.R., Bright, P.W., 2010. The value of agri-environment schemes for macro-invertebrate feeders: hedgehogs on arable farms in Britain. Anim. Conserv. 13 (5), 467–473.
Hof, A.R., Snellenberg, J., Bright, P.W., 2012. Food or fear? Predation risk mediates edge refuging in an insectivorous mammal. Anim. Behav. 83 (4), 1099–1106.
Homberger, B., Duplain, J., Jenny, M., Jenni, L., 2017. Agri-environmental schemes and active nest protection can increase hatching success of a reintroduced farmland bird species. Landsc. Urban Plan. 161, 44–51.
Institute of Grassland and Environment Research, 2000. Welsh ESA Field Margins and Hedges BD1605. Defra, UK [Online]. Available at: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=8002, Accessed date: 8 November 2016.
Jackson, J.I., 2001. Spatial and Temporal Dynamics of Plants Colonizing Species-Poor Hedgerows. University of Leicester.
JNCC and Defra, 2012. UK Post 2010 Biodiversity Framework. JNCC, Peterborough, UK.
Kohler, F., Thierry, C., Marchand, G., 2014. Multifunctional agriculture and farmers' attitudes: two case studies in rural France. Hum. Ecol. 42 (6), 929–949.
Koricheva, J., Gurevitch, J., Mengersen, K., 2013. Handbook of Meta-analysis in Ecology and Evolution. Princeton University Press, Oxford.
Kremen, C., M'Gonigle, L.K., 2015. Small-scale restoration in intensive agricultural landscapes supports more specialized and less mobile pollinator species. J. Appl. Ecol. 52 (3), 1365–2664.
La Coeur, D., Baudry, J., Burel, F., Thenail, C., 2002. Why and how we should study field boundary biodiversity in a agrarian landscape context. Agric. Ecosyst. Environ. 89, 23–40.
Lack, P., 1992. Birds on Lowland Farms. HMSO, UK.
Lacoeuilhe, A., Machon, N., Julien, J.-F., Kerbiriou, C., 2016. Effects of hedgerows on bats and bush crickets at different spatial scales. Acta Oecol. 71, 61–72.
Langellotto, G.A., Denno, R.F., 2004. Responses of invertebrate natural enemies to complex-structured habitats: a meta-analytical synthesis. Oecologia 139 (1), 1–10.
Lawton, J., 2010. Making space for nature: a review of England's wildlife sites and ecological network. [Online]. Available at: Defrahttp://archive.defra.gov.uk/environment/biodiversity/documents/201009space-for-nature.pdf, Accessed date: 14 February 2014.
Lecq, S., Loisel, A., Brischoux, F., Mullin, S.J., Bonnet, X., 2017. Importance of ground refuges for the biodiversity in agricultural hedgerows. Ecol. Indic. 72, 615–626.
Litza, K., Diekmann, M., 2017. Resurveying hedgerows in Northern Germany: plant community shifts over the past 50 years. Biol. Conserv. 206, 226–235.
Marshall, E.J.P., Maudsley, M.J., West, T.M., Rowcliffe, H.R., Barr, C., Petit, S., 2001.

'Effects of management on the biodiversity of English hedgerows', Hedgerows of the world: their ecological functions in different landscapes. In: Proceedings of the 10th Annual Conference of the International Association for Landscape Ecology, held at Birmingham University, 5th-8th September 2001. International Association for Landscape Ecology, Birmingham University, UK. Aberdeen, UK, pp. 361–365.
Mathews, F., Lovett, L., Rushton, S., Macdonald, D.W., 2006. Bovine tuberculosis in cattle: reduced risk on wildlife-friendly farms. Biol. Lett. 2 (2), 271–274.
Maudsley, M.J., 2000. A review of the ecology and conservation of hedgerow invertebrates in Britain. J. Environ. Manag. 60 (1), 65–76.
Maudsley, M., Seeley, B., Lewis, O., 2002. Spatial distribution patterns of predatory arthropods within an English hedgerow in early winter in relation to habitat variables. Agric. Ecosyst. Environ. 89 (1–2), 77–89.
McCollin, D., Jackson, J.I., Bunce, R.G.H., Barr, C.J., Stuart, R., 2000. Hedgerows as habitat for woodland plants. J. Environ. Manag. 60 (1), 77–90.
Merckx, T., Berwaerts, K., 2010. What type of hedgerows do Brown hairstreak (*Thecla betulae* L.) butterflies prefer? Implications for European agricultural landscape conservation. Insect Conserv. Divers. 3 (3), 194–204.
Merckx, T., Feber, R.E., Dulieu, R.L., Townsend, M.C., Parsons, M.S., Bourn, N.A.D., Riordan, P., Macdonald, D.W., 2009a. Effect of field margins on moths depends on species mobility: field-based evidence for landscape-scale conservation. Agric. Ecosyst. Environ. 129 (1–3), 302–309.
Merckx, T., Feber, R.E., Riordan, P., Townsend, M.C., Bourn, N.A.D., Parsons, M.S., Macdonald, D.W., 2009b. Optimizing the biodiversity gain from agri-environment schemes. Agric. Ecosyst. Environ. 130 (3–4), 177–182.
Merckx, T., Feber, R.E., McLaughlan, C., Bourn, N.A.D., Parsons, M.S., Townsend, M.C., Riordan, P., Macdonald, D.W., 2010. Shelter benefits less mobile moth species: the field-scale effect of hedgerow trees. Agric. Ecosyst. Environ. 138 (3–4), 147–151.
Merckx, T., Marini, L., Feber, R.E., Macdonald, D.W., 2012. Hedgerow trees and extended-width field margins enhance macro-moth diversity: implications for management. J. Appl. Ecol. 49, 1396–1404.
M'Gonigle, L.K., Ponisio, L.C., Cutler, K., Kremen, C., 2015. Habitat restoration promotes pollinator persistence and colonization in intensively managed agriculture. Ecol. Appl. 25 (6), 1557–1565.
Moorhouse, T.P., Palmer, S.C.F., Travis, J.M.J., Macdonald, D.W., 2014. Hugging the hedges: might agri-environment manipulations affect landscape permeability for hedgehogs? Biol. Conserv. 176 (0), 109–116.
Morandin, L.A., Kremen, C., 2013a. Bee preference for native versus exotic plants in restored agricultural hedgerows. Restor. Ecol. 21 (1), 26–32.
Morandin, L.A., Kremen, C., 2013b. Hedgerow restoration promotes pollinator populations and exports native bees to adjacent fields. Ecol. Appl. 23 (4), 829–839.
Morandin, L.A., Long, R.F., Kremen, C., 2014. 'Hedgerows enhance beneficial insects on adjacent tomato fields in an intensive agricultural landscape. Agric. Ecosyst. Environ. 189 (0), 164–170.
Morandin, L.A., Long, R.F., Kremen, C., 2016. Pest control and pollination cost-benefit analysis of hedgerow restoration in a simplified agricultural landscape. J. Econ. Entomol. 109 (3).
Mountford, J.O., Parish, T., Sparks, T.H., 1994. The flora of field margins in relation to land use and boundary features. In: Boatman, N. (Ed.), Field Margins: Integrating Agriculture and Conservation. British Crop Protection Council, Farnham.
Muller, G., 2013. Europe's Field Boundaries: Hedged Banks, Hedgerows, Field Walls (Stonewalls), Dead Brushwood Hedges, Bent over Hedges, Woven Hedges, Wattle Fences & Traditional Wooden Fences. Kunstverlag Stuttgart, Neuer, Germany.
Natural England, 2009. Agri-environmental Schemes in England in 2009: A Review of Results and Effectiveness. Defra, London, UK.
Natural England, 2012. The Value of Nature: How Environmental Stewardship Can Benefit Farming. Natural England, UK.
Natural England, 2013. Section 41 Species - Priority Actions Needed. Spreadsheet. online Natural England Available at: http://publications.naturalengland.org.uk/file/6518755878240256.
Natural England, 2016. Countryside Stewardship: Mid Teir Options, Supplements and Capital Items. Natural England, UK.
Norton, L.R., Maskell, L.C., Smart, S.S., Dunbar, M.J., Emmett, B.A., Carey, P.D., Williams, P., Crowe, A., Chandler, K., Scott, W.A., Wood, C.M., 2012. Measuring stock and change in the GB countryside for policy – key findings and developments from the Countryside Survey 2007 field survey. J. Environ. Manag. 113 (0), 117–127.
O'Brien, J., Elliott, S., Hayden, T.J., 2016. Use of hedgerows as a key element of badger (*Meles meles*) behaviour in Ireland. Mamm. Biol. 81 (1), 104–110.
Oreszczyn, S., Lane, A., 2000. The meaning of hedgerows in the English landscape: different stakeholder perspectives and the implications for future hedge management. J. Environ. Manag. 60 (1), 101–118.
Pollard, K.A., Holland, J.M., 2006. Arthropods within the woody element of hedgerows and their distribution pattern. Agric. For. Entomol. 8 (3), 203–211.
Power, E.F., Kelly, D.L., Stout, J.C., 2013. Impacts of organic and conventional dairy farmer attitude, behaviour and knowledge on farm biodiversity in Ireland. J. Nat. Conserv. 21 (5), 272–278.
Reeve, N., 1981. A Field Study of the Hedgehog with Particular Reference to Movements and Behaviour. University of London.
Roy, V., de Blois, S., 2008. Evaluating hedgerow corridors for the conservation of native forest herb diversity. Biol. Conserv. 141 (1), 298–307.
Russ, J.M., Montgomery, W.I., 2002. Habitat associations of bats in Northern Ireland: implications for conservation. Biol. Conserv. 108 (1), 49–58.
Sanderson, F.J., Kloch, A., Sachanowicz, K., Donald, P.F., 2009. Predicting the effects of agricultural change on farmland bird populations in Poland. Agric. Ecosyst. Environ. 129 (1–3), 37–42.
Sheridan, H., Keogh, B., Anderson, A., Carnus, T., McMahon, B.J., Green, S., Purvis, G., 2017. Farmland habitat diversity in Ireland. Land Use Policy 63, 206–213.
Slade, E.M., Merckx, T., Riutta, T., Bebber, D.P., Redhead, D., Riordan, P., Macdonald, D.W., 2013. Life-history traits and landscape characteristics predict macro-moth responses to forest fragmentation. Ecology 94 (7), 1519–1530.
Smal, C., 1995. The Badger and Habitats Survey of Ireland. Department of Agriculture, Food and the Marine, Dublin.
Sparks, T.H., Croxton, P.J., 2007. The influence of timing and frequency of hedgerow cutting on hawthorn flowering and berry yields: preliminary results. Asp. Appl. Biol. 82, 103–106.
Sparks, T.H., Martin, T., 1999. Yields of hawthorn *Crataegus monogyna* berries under different hedgerow management. Agric. Ecosyst. Environ. 72 (2), 107–110.
Sparks, T.H., Parish, T., 1995. Factors affecting the abundance of butterflies in field boundaries in Swavesey fens, Cambridgeshire, UK. Biol. Conserv. 73 (3), 221–227.
Staley, J.T., Sparks, T.H., Croxton, P.J., Baldock, K.C.R., Heard, M.S., Hulmes, S., Hulmes, L., Peyton, J., Amy, S.R., Pywell, R.F., 2012. Long-term effects of hedgerow management policies on resource provision for wildlife. Biol. Conserv. 145 (1), 24–29.
Staley, J.T., Bullock, J.M., Baldock, K.C.R., Redhead, J.W., Hooftman, D.A.P., Button, N., Pywel, R.F., 2013. Changes in hedgerow floral diversity over 70 years in an English rural landscape, and the impacts of management. Biol. Conserv. 167, 97–105.
Staley, J.T., Amy, S.R., Adams, N.P., Chapman, R.E., Peyton, J.M., Pywell, R.F., 2015. Re-structuring hedges: rejuvenation management can improve the long term quality of hedgerow habitats for wildlife in the UK. Biol. Conserv. 186 (0), 187–196.
Staley, J.T., Botham, M.S., Chapman, R.E., Amy, S.R., Heard, M.S., Hulmes, L., Savage, J., Pywell, R.F., 2016. Little and late: how reduced hedgerow cutting can benefit Lepidoptera. Agric. Ecosyst. Environ. 224, 22–28.
Staley, J.T., Botham, M.S., Amy, S.R., Hulmes, S., Pywell, R.F., 2017. Experimental evidence for optimum hedgerow cutting regimes for brown hairstreak butterflies. Insect Conserv. Divers. http://dx.doi.org/10.1111/icad.12239. (in this issue).
Sutton, R.K., 1992. Landscape ecology of hedgerows and fencerows in Panama township, Lancaster County, Nebraska. J. Nat. Soc. Sci. 73.
Tsiourus, S., Marshall, E.J.P., 1998. Observations on patterns of granular fertiliser deposition beside hedges and it's likely effects on the botanical composition of field margins. Ann. Appl. Biol. 132, 115–127.
UK Biodiversity Steering Group, 1995. Biodiversity: The UK Steering Group Report Volume 2. HMSO, London, UK.
van de Poel, J.L., Dekker, J., van Langevelde, F., 2015. Dutch hedgehogs *Erinaceus europaeus* are nowadays mainly found in urban areas, possibly due to the negative effects of badgers *Meles meles*. Wildl. Biol. 21 (1), 51–55.
Walker, M.P., Dover, J.W., Hinsley, S.A., Sparks, T.H., 2005. Birds and green lanes: breeding season bird abundance, territories and species richness. Biol. Conserv. 126 (4), 540–547.
Walker, M.P., Dover, J.W., Sparks, T.H., Hinsley, S.A., 2006. Hedges and green lanes: vegetation composition and structure. Biodivers. Conserv. 15 (8), 2595–2610.
Walsh, A.L., Harris, S., 1996. Foraging habitat preferences of vespertilionid bats in Britain. J. Appl. Ecol. 33 (3), 508–518.
Webb, J.R., Drewitt, A.L., Measures, G.H., 2010. Managing for species: Integrating the needs of England's priority species into habitat management. In: Part 1 Report. Natural England Research Reports, Number 024. Natural England, UK.
Weibull, E.C., Ostman, O., 2003. Species composition in agri-ecosystems. The effect of landscape, habitat, and farm management. Basic Appl. Ecol. 4 (4), 349–361.
Whittingham, M.J., Evans, K.L., 2004. The effects of habitat structure on predation risk of birds in agricultural landscapes. Ibis 146, 210–220.
Whittingham, M.J., Krebs, J.R., Swetnam, R.D., Thewlis, R.M., Wilson, J.D., Freckleton, R.P., 2009. Habitat associations of British breeding farmland birds. Bird Study 56 (1), 43–52.
Wickramasinghe, L.P., Harris, S., Jones, G., Vaughan, N., 2003. Bat activity and species richness on organic and conventional farms: impact of agricultural intensification. J. Appl. Ecol. 40 (6), 984–993.
Winkler, B., Mathews, F., 2015. Environmental risk factors associated with bovine tuberculosis among cattle in high-risk areas. Biol. Lett. 11 (11).
Wolton, R., 1994. Hedges in decline? Enact 2.
Wolton, R., 2009a. Hazel dormouse *Muscardinus avellanarius* (L.) nest site selection in hedgerows. Mammalia 73 (1), 7–12.
Wolton, R.J., 2009b. Priority BAP Species Associated With Hedgerows: Paper in Preparation for UK Hedgerow Habitat Action Plan. Hedgelink Steering Group, UK.
Wolton, R.J., Morris, R.K.A., Pollard, K.A., D, J.W., 2013. Understanding the combined biodiversity benefits of the component features of hedges. In: Report of Defra project BD5214. Annex C: Review of How Well Existing Environmental Stewardship Provisions Meet Key Hedge Management Requirements for Biodiversity, With Suggestions for Change. Bright Angel Consultants, Lincolnshire.
Wright, J., 2016. A Natural History of the Hedgerow, and Ditches, Dykes and Dry Stone Walls. Profile Books Ltd, London, UK.
Wuczyński, A., 2016. Farmland bird diversity in contrasting agricultural landscapes of southwestern Poland. Landsc. Urban Plan. 148, 108–119.
Young, R.P., Davison, J., Trewby, I.D., Wilson, G.J., Delahay, R.J., Doncaster, C., P., 2006. Abundance of hedgehogs in relation to the density and distribution of badgers. J. Zool. 269 (3), 349–356.