HEDGEROW MANAGEMENT AND WILDLIFE

A review of research on the effects of hedgerow management and adjacent land on biodiversity

Contract report to Defra

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BACKGROUND AND INTRODUCTION

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BACKGROUND TO THE REVIEW

Summary of the problem

There is an extensive literature on hedgerows, much of which relates to wildlife. There are also reviews of various aspects of hedgerows, both general and specific, but until the first edition of this report was published (Barr *et al.* 1995) there had been no review which focused on the relationship between hedgerow management and wildlife. Osborn (1987) said *"FWAG* (Farming and Wildlife Advisory Group) *advisers are asked many questions on hedgerow management and, in the majority of cases, the advice given is based on educated conjecture, rather than drawn from scientific research".* As Hooper (1992) points out, the earliest papers on hedges (1800-1845) were often concerned with the need to remove hedges (they were seen by some as being too plentiful and too big). Up to 1960, most papers were concerned with the agricultural impacts of hedgerows, and only in the mid-1960s did interest shift to their wildlife value. Much of this early work with a more ecological focus was undertaken by Moore, Davis, Pollard and Hooper at ITE Monks Wood.

In the mid-1990s, a summary of the research context for hedgerows was expressed by the then Ministry of Agriculture, Fisheries and Food (MAFF) in the research specification for earlier versions of this review:

"Hedges are important for flora and fauna. They may be managed in a variety of ways according to the needs of the farm and sometimes local custom. The benefits of different management practices for wildlife can vary both as a result of the methods used and the timing of the operations. The nature of the adjacent land use can also have an important effect on the biodiversity of the hedge. MAFF provides grants for some forms of hedgerow management both as part of the Environmentally Sensitive Areas Scheme and the Farm and Conservation Grant Scheme. The wildlife value of hedgerows is also a consideration in other MAFF schemes such as the Habitat Scheme and set-aside. In order to inform the development of its policies, MAFF needs a report which pulls together the knowledge currently available on the wildlife value of hedges under different circumstances."

Although research done since then has gone some way to addressing some of the policy-related issues concerning hedgerows, there is now a need to re-assess the research direction and identify new priorities in the current policy climate.

Related research activities

Shortly before his retirement in 1992, Dr Max Hooper submitted a contract report to the then DOE entitled *'Hedge Management'.* This report remains unpublished but the authors of this review have been given permission to make use of it. Hooper's report goes some way to meeting the objectives of this review but focuses particularly on a hedgerow survey carried out in selected areas of England.

Important background information has also come from the results of the Countryside Surveys carried out by the Centre for Ecology and Hydrology (CEH), and its fore-runner organisations, in 1984, 1990 and 1998, supplemented by a specific hedgerow survey in 1993. These surveys, which were funded by MAFF and the Natural Environment Research Council (NERC), have shown that after a period of marked hedgerow loss between 1984 and 1990 (much of which was due to lack of appropriate management), there was no net loss between 1990 and 1998, although the quality of hedgerows (and associated vegetation) continued to decline. As a policy matter of importance to all Government Departments, it is important to know what the wildlife consequences of this trend may be.

OBJECTIVES OF THE REVIEW

The specific objectives of the review were laid out clearly in MAFF's original research specification, as follows:
"A review of previous and current research is required:

1. *To assess the impact of different forms of management on hedgerow biodiversity, e.g. closely cut, cut into an A-shape or square topped, laid or coppiced. The impact on wildlife value of non-management (i.e. development into relict hedges) also needs to be taken into account as does the timing of any management activities.*

2. *To assess the impact of immediately adjacent land use on hedgerow biodiversity, e.g. intensive arable, arable with uncropped land alongside the hedge, permanent grass, woodland, water-course.*

3. *To assess the relative importance of hedgerows for wildlife in different farming contexts, e.g. arable versus grassland, lowland versus upland. This will need to take account of varying local hedgerow practices, e.g. Devon pastoral compared with West Midlands/Marches pastoral.*

4. *To identify methods of enhancing biodiversity in hedges taking into account costs and practicability, and considering both individual hedgerows and combinations of hedgerows which might, for example, form a wildlife corridor.*

5. *To identify gaps in knowledge by an analysis of research needs against published and current research and to provide a prioritised list of future research requirements."*

These generic aims are as relevant today as they were when written in the mid-1990s.

In considering this last objective, it is worth noting Dr Hooper's comments made at the Wye College Hedgerow Symposium in 1992: *"After 30 years of studying hedges, I am more conscious of what I don't know, and what I am not sure about, than the extent of my knowledge."* This review of the literature can go some way towards identifying what is known but cannot, necessarily, provide all the answers.

INTRODUCTION TO THIS PUBLICATION

Approach

This publication is based on a contract report that was submitted to MAFF in 1995 and which was updated in 2000. The task of compiling that report was undertaken jointly by ADAS and the Institute of Terrestrial Ecology (ITE). Given the need for a rapid review of relevant literature, work was divided between the two research organisations with individual members of staff being given responsibility for different research areas, and hence different sections within the report. This approach risked duplication between sections and an 'editorial team' from both organisations took responsibility for combining contributions into a single report.

During the course of the review, authors extracted information from many hundreds of papers in scientific journals, magazines and elsewhere. They also read many hundreds more and, where appropriate, these have been included in the extensive bibliography section at the end of this report.

Content

The report starts with a review of hedge management, including its history, current status and costs. It then continues by examining what is known about the effects of hedge management on wildlife, including the effects of associated land use management. This main section of the report has been divided up according to major taxonomic groupings with a section devoted to each. Recommendations are made on further research needs within the final section of the review. The references are incorporated within a bibliography of publications which were consulted during the course of the review and, while these publications were not all directly relevant to the topic of management and wildlife (or duplicated material given elsewhere), they nevertheless may be useful to anyone needing information on hedgerows in general.

Updating the content

Since the original contract report was submitted, the information has been updated by section authors and, although some new research may have been reported during the publication stages, this report represents a reasonably comprehensive review of research information on hedgerow management and wildlife at the start of the 21st century.

HISTORY AND HEDGEROW MANAGEMENT

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THE RESEARCH ENDEAVOUR

The potential of air photographs for recording the incidence and character of English and Welsh field boundaries was demonstrated in a paper published in the German geographical journal, *'Erdkunde'*, based on an interpretation of wartime Luftwaffe prints (Hartke 1951). During the 1960s, British geographers used a combination of old agricultural textbooks and estate maps, as well as fieldwork, to study the origins, distribution and management of hedgerows, together with other types of boundary (Mead 1966).

Studies initiated by the Research Branch of the Nature Conservancy in the 1960s to gain a better understanding of the role of hedgerows as a wildlife habitat soon revealed the extent of their destruction, as a result of large-scale changes in the use and management of farmland. Dr M. D. Hooper found that over two-thirds of the hedges in one sample survey of the East Midlands had been lost in the previous twenty years. For three contiguous parishes in Huntingdonshire, the length of hedgerow declined from 70.8 miles, as interpreted from RAF air photographs of 1945, to 46.0 miles in 1963 and 20.0 miles in 1965, as recorded by field survey (Moore, Hooper & Davis 1967).

By comparing the species composition of hedges with maps and other forms of documentary evidence held in county record offices, Hooper suggested, as a rough guide for some parts of the country, that a hedge might gain about one species of shrub in a 30-yard length for every hundred years (Pollard, Hooper & Moore 1974). Local historians had for long suspected that older hedges were likely to be found on ancient farm and parish boundaries. Evidence from field archaeology suggests that some might even have Roman, or perhaps Bronze Age, origins. For both biological and historical reasons, a joint meeting of ecologists and historians, in 1971, pressed for priority to be given to the preservation of these long-established habitats, particularly at a time when farm amalgamation was proceeding apace (Anon. 1971).

In emphasising the importance of hedgerows as artefacts of earlier phases in the *'definition and control of space in the countryside'*, Morgan Evans (1994) has emphasised how entirely appropriate it would be to preserve them as part of the statutory planning process.

Developing interest in landscape ecology gave further impetus, both in Britain and the bocage landscapes of northern France, to studies of the edge-effect of hedgerows in a mosaic of otherwise open environments, and the inter-connectedness of hedgerows and their role as corridors or networks for the movement of organisms through the countryside (Chapman & Sheail 1994). The nature and significance of these functions reflected the width of the hedgerow, and composition of the three layers that comprised it, namely the tree, shrub and herb layers. A survey of the woody species of 2,300 hedgerows in Brittany established the importance not only of biogeographical factors and current management practices but, more importantly, former differences in husbandry (Baudry 1988).

PRESCRIPTIONS FOR HEDGE-MAKING

Some of the earliest published prescriptions are to be found in Anthony Fitzherbert's *'The booke of husbandry'* of 1568 and *'The profitable arte of gardeninge'*, published by Thomas Hill in 1672.

An insight into the variety of hedgerow species and their management is provided by the two sets of agricultural reports, compiled for most counties by the Board of Agriculture, during the period, 1790 to 1820. In Worcestershire, the new 'fences' were chiefly made of hawthorn (*Crataegus monogyna*), secured by post and rail, with stone being used on the Bredon and Cotswold Hills. The Essex fences contained a variety of woody species, including hazel (*Corylus avellana*), maple (*Acer platanoides*), ash (*Fraxinus excelsior*), oak (*Quercus* sp.), elm (*Ulmus* sp.), blackthorn (*Prunus spinosa*), whitethorn (hawthorn) and bramble (*Rubus fruticosa* agg.), with timber and pollard trees interspersed and growing in them at various intervals.

In Middlesex, the hedges were generally full of woody species, consisting mostly of hawthorn, elm and maple, with some blackthorn, crab apple (*Malus* *sylvestris*), briars (*Rosa* spp.) and damson (*Prunus domestica* ssp. *insititia*).

In his *'Review and Abstract'* of the Board's reports, William Marshall used extracts from the Hertfordshire volume to distinguish those hedgerows planted *de novo* on open ground and 'aboriginal fences', where the woodland on both sides had been cleared for farming. In the act of clearing, 'lines of native coppice wood were very judiciously left; not only as fences between enclosures, but as a supply of fuel, for the occupiers of the lands and their country neighbours'. Here, plashing was 'an invention of necessity', the taller sapling shoots being laid across the gaps and thinner parts to create a stock-proof fence.

The author of a paper on '*Hedges and hedge-making'*, published in the 'Journal of the Royal Agricultural Society' in 1899, looked for 17 qualities in a hedge. No species possessed so many of these qualities as the whitethorn or hawthorn. Since the thorns deterred all forms of livestock, the hedge could be cut into a very compact form, thereby ensuring its branches offered little refuge for birds and insects. It was only at high altitudes that the whitethorn had difficulty in establishing itself. The fact that it was the only shrub used as fencing along the entire length of the railways, through a great variety of soils, topography and climates, provided ample evidence of its adaptability (Malden 1899). Among the many changes in rural practice, brought about by the railways, Henry Stephens, in his 'Book of the farm', identified the most important to be the way in which hedgerows were established. The practice had been to plant the hedges on banks composed of material excavated from an adjacent ditch. Whilst this had the effect of immediately providing some kind of barrier, the sides of the bank inevitably fell away, exposing the rooting system. The railway companies had provided an 'excellent object lesson' in how the first consideration should be the welfare of the hedge. The quicks were planted on the level, with a ditch cut only where needed for drainage. However planted, the ground should be at least fallowed, limed and manured. In the first few years, the soil had to be kept 'stirred', so as to prevent the quicks from being choked by weeds (Scott 1883; Stephens 1890).

Much prominence has been given to the Prize Essays on hedgerows, published by the Royal Agricultural Society of England in the 1840s, that condemned hedges for taking up so much land, making the use of machinery difficult, acting as weed magazines and asylums of pests, impoverishing the soil and preventing the free circulation of air (Grigor 1845; Cambridge 1845; Turner 1845). It is likely, however, that the greatest threat to hedgerows was their mismanagement and neglect. If too much old wood was left, the heart of the hedge tended to become hollow as the younger growth on the outside smothered that of the inside. Wherever practicable, the wood was best cut with an upward stroke. Water would then run easily off the smooth surface. The vibration caused by a downward cut would cause the wood to splinter, leading to dampness and often considerable decay. Over time, it might become the chief cause of gaps in the hedge.

In broad terms, one of two management systems might be adopted. The more common was to train the hedge into an upright, triangular section, that followed closely the natural form of the hawthorn tree. It might reach a height of four or five feet, without ceasing to be thick and well-clothed at the very bottom. Not only did this produce an effective barrier for livestock, but whitethorn shoots were not seriously damaged by the shade cast by growth above them. The alternative method of management, and the one preferred by the railway companies, was to cut, rather than grow, the hedge into shape. It was first allowed to grow to a height of six to eight feet, and then 'wattled' at an angle of 40 degrees, stakes being left at two feet intervals, the wattling rods being hacked close to the ground, and woven in between the live stakes. The hacking encouraged a strong growth of young shoots from the base.

Through neglect, the hedgerows of parts of Essex and Suffolk, during the agricultural depression of the late nineteenth century, took on the appearance of lines of woodland, growing up to 25 feet in height, and encroaching onto fields and roadside wastes (Collins 1985). Commentators stressed the short-sightedness of such neglect. Once a weakness or gap developed, the whole purpose of the hedge was lost and remedial action might be costly. Re-planting on the site of a thoroughly-neglected or worn-out hedge was rarely successful. Whilst there was no actual evidence that injurious matter accumulated in the soil, it was usually presumed so. The only course was to remove and replace the top soil with fresh soil from nearby, mixed with well-rotted dung. On thin or barren soils, well-rotted turf or sod was useful. The most effective method of dealing with an overgrown, yet gappy, hedge was to plash it, the long rods being suitable for wattling. Any decaying stumps should be cut level with the ground, so as to encourage regeneration. If laid well, some judicious thinning and keeping the ground clear at the base should be enough to keep the hedge in shape for 20 to 40 years.

The thirteenth edition of *'Fream's Elements of Agriculture'*, published in 1949, found the most usual types of field division to be live hedges, the post and wire fence, and the post and rail fence. In most counties, experience had shown that the hawthorn made the most suitable hedge, planted in a double line 12 inches apart, with 18 inches between each quick. A hard pruning after 12 months in the ground encouraged strong growth. It would be ready for its first laying after ten years. Whilst it varied from district to district as to whether live or dead stakes were used, the aim was always the same, namely dense and healthy growth at the bottom and rigidity at the top. A stock-proof hedge also provided shelter from winds. Optimally, the hedge was cut once or twice a year into an A-shape, of not less than four feet at the base. Weed plants, particularly bramble, briar and elder had to be removed (Robinson 1949). If the post-war edition provided a distillation of centuries of experience in hedgerow management, the short paragraph in the fifteenth edition of *'Fream's Elements of Agriculture'*, published in 1972, emphasised the rapid decline in its relevance. Although they had a much longer life, hedges were three to four times more expensive than wire fencing which, in any case, was often required to protect the young hedge against livestock. The cost of planting might be reduced by using farm implements, as opposed to hand digging. Although tractor-operated trimmers might make subsequent trimming cheaper, there was no substitute for laying by hand every ten to 15 years if a good stock-proof fence was desired (Robinson 1972)

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DATA ON CURRENT HEDGEROW MANAGEMENT

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THE COUNTRYSIDE SURVEYS

The most recent literature describing hedgerows in terms of management, at the national scale, is based on data from the Countryside Surveys of 1990 (CS1990) (Barr *et al.* 1993) and 1998 (CS2000) (Haines-Young *et al.* 2000). From CS1990, two reports in particular focus on hedgerow issues. The first, '*Changes in Hedgerows in Britain between 1984 and 1990*' (Barr *et al.* 1991), looks at the change in hedgerow stock between these years and at the characteristics of hedges in both years. The second, '*Diversity in British Hedgerows*' (Cummins *et al.* 1992), concentrates mainly on the species composition of hedges and associated flora. Some information on hedgerow management is included in two outputs from the Countryside Surveys: '*Accounting for Nature: Assessing Habitats in the UK Countryside*' (Haines-Young *et al.* 2000) and '*Estimating hedgerow length and pattern characteristics in Great Britain using Countryside Survey data*' (Barr & Gillespie 2000). In the future, it is expected that more management information will result by aggregating data from county-based surveys, prompted by the publication of a standard handbook of field methods (Bickmore 2002).

The hedgerow characteristics recorded in the Countryside Surveys included species dominance (e.g. >50% hawthorn), height (e.g. >2 m), gappiness (e.g. gaps >10%), management (e.g. trimmed), shape (e.g. chamfered) and change (e.g. to line of relict hedge). These are all important in examining the management of hedgerows. For example, the individual woody species in the hedge may need more or less management depending on how fast it grows. Elder (*Sambucus nigra*) and sycamore (*Acer pseudoplatanus*), for example, grow quickly and need more active management than some other species. When looking at information recorded on height, hedges over two metres high tend to be those that are not managed. A hedge with filled gaps is showing signs of management, whereas one that is completely non-stock-proof and uncut may not be managed at all. The cutting regime of a hedge, one that has been trimmed recently compared to one that is derelict or uncut, for example, indicates the extent of management.

According to Countryside Survey definitions, where all forms of management have ceased and a hedge reaches its natural tree shape or when gaps break up a hedge to an individual line of trees or shrubs, then the feature can no longer be described as a hedge (and might be considered as, for example, a scattered line of shrubs). An overgrown, unmanaged hedge may be termed a 'remnant hedge' whereas an overgrown, unmanaged and very gappy hedge which has become a line of trees might be termed a 'relict hedge'. Remnant and relict hedges were quantified separately from 'true' hedges in the Countryside Surveys.

The stock of hedgerow length in England & Wales in 1998 was estimated to be 449,000 km (with a further 52,000 km being described as 'remnant' hedge) (see Table 1). This did not represent a statistically significant change from 1990. However, the length of remnant hedge did decrease significantly, by 21%.

The Northern Ireland Countryside Survey (which used a similar methodology to its Great Britain equivalent), estimated the stock of hedges to be 118,400 km (Cooper *et al.* 1997). There was a 4.5% decline in net length of hedges (and an additional 4,000 km decrease in earth banks) between the late 1980s and the late 1990s.

These statistics represent a complicated and dynamic picture of change between different field boundary types. Examination of GB Countryside Survey data suggests, for example, some remnant hedges became 'lines of trees' while others were restored to 'true' hedges.

The zero net change between hedge lengths in 1990 and 1998 suggests a balance between gains and losses which contrasts with the earlier interval between 1984 and 1990 which saw a decrease, in net terms, of about 23%. Figures from Barr *et al.* (1993) showed that a small proportion of this change, 6%, was due to hedges becoming incorporated into built landscapes (and hence lost to the countryside), with 35% due to hedge removal. Almost 60% of the decrease was due to a change in recorded boundary type, of which over one third (39%) was change to relict hedge. This is borne out by a corresponding increase (59%) in the number of relict hedgerows being recorded in 1990 compared to 1984, suggesting that there is a decline in hedge management on a national scale.

Of the total stock of hedges in 1990, some 75% had been recorded as hedges in 1984. A quarter of hedges gained come from relict hedgerows and over 20% were newly planted where no previous boundary of any type existed in 1984.

By comparison, of the total stock of hedges in 1998, 91% had been recorded as hedges in 1990. One third of hedges gained came from remnant or relict hedgerows and a quarter of hedges gained came from situations where no previous boundary, of any type, existed in 1990.

In management terms, this showed a continuing investment in planting new hedges as well as reclaiming hedges from other boundary types such as relict hedgerows or lines of trees.

The characteristics of hedges in earlier surveys were examined in Barr *et al.* (1991) and for CS2000 at http://www.cs2000.org.uk/M01_tables/reports/hedgecon98.htm. A summary from these reports for GB is given in Table 2.

The results from this table suggest that in Great Britain as a whole, the overall height and management regime of hedges remained reasonably constant between the three dates. When looking at gappiness however, the table shows that lengths of complete hedges had declined over the period 1984-90, with a corresponding increase in the number of hedges that are not stock-proof.
One of the aims of the work by Cummins *et al.* (1992) was to assess the effect of hedgerow management and change within hedgerows in the context of hedgerow diversity. The woody component of hedges from 259 paired plots surveyed in 1978 and 1990 were classified into one of 11 woody species classes (WSC) (e.g. hawthorn-dominant, blackthorn-predominant). The same three management categories as used in Table 1 were used to evaluate different types of hedge management for the five main WSCs, those that had more than 15 plots in a class. The percentage of hedges in each class in 1990 are shown by management characteristic in Table 3.

The proportion of hedges that had been cut within the past two years was greatest amongst elder/ hawthorn hedges (WSC 4c), but elder is a fast growing species that demands management attention if it is not to get out of hand.

In contrast, the lowest proportion of cutting and the highest proportion of unmanaged hedges was in the mixed-hazel class (WSC 5b).

As with the results for hedge lengths shown in Table 2, the differences in height and management are not marked between the classes, but there is a difference between the classes with regards to gappiness. Gaps were most frequent in mixed hawthorn (WSC 4b) and mixed-hazel (WSC 5b), possibly due to a lack of management or due to lower densities of thorny species, making it easier for livestock to break through. The elder/hawthorn class (WSC 4c) was the most complete, which may be due to the fast growing nature of elder blocking up the gaps. This class had no laid hedges and unlaid elder being easily penetrated, farmers may manage them by reinforcement with fencing.

Table 1 Hedgerow stock (1998) and change (1990-1998) in England and Wales, and in Scotland. Data from the Countryside Surveys.

(a) England and Wales	Stock in 1998			Change in stock 1990-98		
	Length ('000km)	SE ('000km)	% of 1998 stock	Length ('000km)	SE ('000km)	% change from 1990
Hedge	449.3	*21.2*	35.8	-0.4	*4.8*	0.0
Remnant Hedge	52.3	*4.3*	4.2	**-13.5**	*3.6*	**-25.8**
Wall	105.8	*12.8*	8.4	-2.7	*1.7*	-2.6
Line of trees/shrubs and relict hedge and fence	70.0	*5.1*	5.6	**15.5**	*3.1*	**22.1**
Line of trees/shrubs and relict hedge	83.4	*5.1*	6.7	**19.6**	*3.0*	**23.5**
Bank/grass strip	70.0	*7.4*	5.6	-1.9	*2.5*	-2.7
Fence	423.2	*16.9*	33.7	**25.6**	*8.9*	**6.0**
Total	1253.9	*32.1*	100.0	**42.3**	*8.4*	**3.4**

(b) Scotland	Stock in 1998			Change in stock 1990-98		
	Length ('000km)	SE ('000km)	% of 1998 stock	Length ('000km)	SE ('000km)	% change from 1990
Hedge	19.0	*4.4*	5.0	0.8	*0.8*	4.2
Remnant Hedge	5.3	*1.8*	1.4	-0.9	*0.5*	-17.0
Wall	87.1	*12.0*	22.8	-1.5	*1.6*	-1.7
Line of trees/shrubs and relict hedge and fence	11.1	*1.9*	2.9	**1.4**	*0.6*	**12.6**
Line of trees/shrubs and relict hedge	13.3	*1.9*	3.5	**2.4**	*0.7*	**18.0**
Bank/grass strip	12.4	*3.4*	3.2	0.8	*1.0*	6.5
Fence	233.7	*16.9*	61.2	8.6	*3.3*	3.7
Total	382.0	*21.6*	100.0	**11.7**	*3.2*	**3.1**

Figures in bold indicate a significant change ($p<0.05$).

Table 2 Hedgerow characteristics (%).

Characteristics		**1998 (%)**	**1990 (%)**	**1984 (%)**
Height Categories	<1 metre	3.3	2.1	6.3
	1-2 metres	50.3	59.0	51.7
	>2 metres	42.0	38.8	42.0
Management	Trimmed	n/a	55.1	55.1
	Uncut	n/a	34.8	34.1
	Derelict*	11.6	10.0	10.8
Gappiness	Complete	n/a	47.3	56.2
	<10% filled gaps	10.4	10.8	13.0
	>10% filled gaps	8.6	4.5	5.1
	Not stock-proof	43.3	37.4	25.7

Notes: n/a = not applicable (many of the previous categories were replaced in CS2000)
** Use of Derelict code in 1998 allocated features to a sub-category of 'hedge' summary group, 'unmanaged/incomplete hedge'. Thus the figure for Derelict in 1998 represents the total in this sub-group.*

Table 3 Hedgerow characteristics (%) in Woody Species Classes in 1990.

		Class 4a Hawthorn dominant	Class 4b Mixed hawthorn	Class 4c Elder/ Hawthorn	Class 5b Mixed - hazel	Class 6 Blackth'n predom.
Height	<1 metre	3	3	5	4	4
	1-2 metres	55	46	52	56	57
	>2 metres	43	51	43	40	40
Management	Trimmed	61	66	75	50	58
	Uncut	7	6	0	9	10
	Derelict	32	28	25	41	32
Gappiness	Complete	24	20	47	29	35
	<10% filled gaps	6	3	0	2	10
	>10% filled gaps	59	67	41	62	48
	Relict	12	10	12	7	7

HOOPER'S SURVEY OF HEDGEROWS IN 1990

The then Department of the Environment commissioned a report on the importance of hedges, both to farmers and the public, with particular emphasis on the environmental and wildlife implications of different types of management (Hooper 1992). The project involved reviewing literature, liasing with other researchers and carrying out a small sample survey of farmers to discover their attitudes and to identify landscape elements within their farms.

The survey was carried out in random 1 km squares in each of six of the Land Classes of the ITE Land Classification (Bunce *et al.* 1981). The six Land Classes (1, 3, 6, 10, 11, 16) were chosen to provide geographical coverage of lowland England, with a comprehensive range of lowland farm types in which hedges were the predominant field enclosure.

In all, 46 farms were sampled and 193 hedges were recorded. To assess the landscape features, including the hedges, each 1 km square was visited and landscape features over the whole square were noted. Five hedges in each square were recorded, with a detailed botanical survey of a central 20 m length in each being carried out. Hedges on stock farms in the study tended to be taller than those on arable farms. Arable farms and fields were on average larger (e.g. farms of 400 ha compared to 350 ha) and had fewer hedges than on stock farms (63% fields hedged, compared to 70%). Many more arable farmers had removed hedges (nearly 73%, compared to just under 40%). Where hedges were retained, over 64% of farmers saw them as having visual amenity. Nearly 74% of stock farmers retained hedges as a stock shelter, as did 40% of farmers who were predominantly arable. About 38% of farmers gave wildlife as a reason for keeping hedges. On average, the hedges surveyed had a verge under a metre wide, were on a bank (except in Land Class 11, tillage land of the east and central midlands), were about two metres high and had about 15 species of herb in their verge and bank (per 20 m length).

The study also identified two concepts of hedge: that of a 'key' hedge and that of an 'ideal' hedge. A 'key' hedge would be defined as one which by virtue of its position in space has an intrinsic value. Parish Boundary hedges, for example, would come into this category. These 'key' hedges may not, however, necessarily be of importance to wildlife other than providing a corridor for movement. Attributes which give value to a hedge for wildlife and landscape are controlled by hedge management, so an 'ideal' hedge would be defined as one which is currently managed to maximise wildlife and landscape benefits.

A hedge which is 'ideal' may not necessarily be a key hedge but a 'key' hedge can be made 'ideal' by improvement of its management. These improvements would normally include increasing the size of the hedge itself, adding trees and maintaining a grass verge.

The prime function of a hedge has always been as a stock barrier, so in examining the importance of hedges to farmers, the study looked at hedges for stock, shelter, game, trees, timber and field sizes. Public appreciation of hedges is the perceived benefits of wildlife, history and landscape and the study examined the hedges in relationship to birds, small mammals, invertebrates and plants as well as their use as corridors, and as historical and landscape features.

The study concluded that desirable hedge management benefiting both wildlife and landscape should include:

i. management to produce as large a volume of woody growth as is compatible with farming operations.
ii. hedge bottom management to produce an herbaceous, grassy strip about a metre wide on either side.
iii. hedge top management to allow sapling trees to grow.

HEDGEROW MANAGEMENT ATTITUDE SURVEY

A recent survey of hedgerow management was carried out by ADAS for MAFF (Britt *et al.* 2000), the main objective being to improve understanding of the attitudes of farmers and agricultural contractors to hedgerow management. This incorporated postal surveys of farmers and contractors, and a follow-up survey with on-farm interviews and hedgerow assessments.

This project found that most farmers trimmed hedgerows around arable fields in September/October or July/August, and hedges around grass fields or beside tracks in September/October or November/December. Relatively few hedgerows were trimmed in January/February. Hedgerows adjacent to arable fields were more likely to be trimmed in late autumn/winter where the soil was light. Although the majority of farmers thought that late autumn/winter was the best time to trim hedges, problems with soil conditions or growing crops were cited as the main reasons for not doing so.

Annual trimming of hedgerows to a box-shape, with a flail, was the management practice followed by a large majority of farmers. Almost 80% trimmed most of their hedgerows annually, although only 21% of farmers thought that this was ideal for maximising benefits to wildlife. Fast growing species (e.g. ash), possible difficulties for hedge-cutting machinery and the need to clear up debris were the main reasons for not adopting less frequent trimming, although farmers who already cut at two-yearly intervals or less frequently reported few problems.

More than half of all farmers said that they always prevented drift from spray and fertiliser applications reaching hedgerows; but over 40% of farmers sometimes or always sprayed weeds in hedge-bottoms.

The survey found that most farmers and contractors see hedgerows as an asset. Most farmers had made one or more changes in hedgerow management in the previous ten years, and most of these changes were positive, bringing management closer to environmental guidelines

HEDGEROW MANAGEMENT AND COSTS

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INTRODUCTION

The management of hedgerows has been carried out over the centuries in order to maintain their function. Bannister and Watt (1994) provide a summary of hedge management methods through the ages, which varied with the age of the hedge, state of growth, function and local tradition. The principle methods of management however, have been 'plashing' (laying), coppicing and trimming in various combinations and forms.

These methods have been recorded and reported over the years in books such as those by Pollard *et al.* (1974), the British Trust for Conservation Volunteers (Anon., 1975), and Menneer (1994) and in a range of advisory leaflets and booklets e.g. those from MAFF (1980); ADAS (1980, 1986, 1993); Farming and Wildlife Advisory Group (1983, undated); Countryside Commission (undated), RSPB (1988), and the hedge cutter manufacturer Bomford and Evershed Limited (undated).

Whilst these books and advisory leaflets reflect the accumulated experience and expertise of many years, it is only relatively recently that much systematic research has been carried out.

NEED FOR HEDGE MANAGEMENT

Historically, hedges had the main function of retaining stock, but also defined boundaries, and provided shelter to stock and crops and sources of by-products such as fruit and coppice material.

A survey by Hooper (1992) showed that farmers still regarded hedges as having the primary function of retaining stock, and over half those interviewed indicated they valued hedges for stock shelter. Although few hedges were still stock-proof and many were 'back-fenced', hedges were valued as visual barriers, which were thought to discourage stock 'break-outs'. Landscape value and visual amenity were valued by two-thirds of farmers interviewed, but only a third valued hedges for wildlife, and less than 10% mentioned benefits to game.

Although farmers have reported some concerns about hedges as a reservoir for weeds and pests (Macdonald 1984, Hooper 1992), a high proportion were found to be in favour of hedges, with the remainder neutral rather than against hedges.

A study of farmers' and contractors' attitudes to hedge management carried out by ADAS for MAFF (Britt *et al.* 2000) involved postal surveys of farmers and contractors and 'follow-up' visits for further interviews and assessments of hedges. It was reported that, for the farmers questioned, the most important factor in determining hedge management was the need to maintain a stock-proof barrier. Other factors mentioned, in order of importance, were farm tidiness, landscape value, stock shelter and wildlife.

Oreszczyn and Lane (1999) interviewed farmers and found them all to be proud of their hedges, even though some would have been considered by many people to be of poor quality.

In spite of these results, showing relatively positive feelings towards hedges, surveys (Barr *et al.* 1991; Barr *et al.* 1994) report net losses in hedgerow lengths in England and Wales. However the rate of hedge removal was shown to have declined over the survey periods (1984-1990 and 1990-1993), and the results of the CS2000 survey (Haines-Young *et al.* 2000) indicate that the declines have been halted. There is even some evidence that losses in England and Wales in the early 1990s have been reversed. CS2000 found evidence for a gradual degeneration of woody linear features, as some hedges become remnant hedges and some of these, in turn, become lines of trees or shrubs. But, unlike the 1980s and early 1990s, restoration and management has largely counteracted these trends. However, lack of management leading to the degeneration of hedges is still an issue. Over-management, associated with regular close trimming, has also been observed as a reason for hedgerow deterioration and loss.

Hedgerow management has evolved from the understanding that repeated cutting of woody shrubs stimulates new growth, resulting in a bushy structure and, where not managed, hedge shrubs will follow their natural inclination to grow into trees (Bannister & Watt 1994). Hedgerow neglect and dereliction has been observed periodically through the centuries, as summarised by Chapman and Sheail (1994). The decline in hedgerow quality and management standards over recent decades has been attributed to loss of agricultural function, continued hard mechanical trimming, intensification of agriculture, and the high cost of labour (Sturrock & Cathie 1980; Countryside Commission 1984).

In the UK Biodiversity Habitat Action Plan for ancient and/or species-rich hedgerows (Anon, 1995b), a target has been set to achieve 'favourable condition' for 50% of such hedgerows by 2005. The rejuvenation of hedgerows is encouraged in a range of agri-environment schemes across the UK.

OPTIONS FOR HEDGE MANAGEMENT

The main options for hedge management are laying, coppicing and trimming; with a variety of techniques available for each of these. Although these methods have been recorded and reported over the years, it is only relatively recently that concerns about hedgerow decline and the need to recommend restoration techniques have prompted much systematic research.

Farmers interviewed by Oreszczyn and Lane (1999) generally considered hedge management to be a peripheral activity to be carried out in quiet periods on the farm. Although the farmers wanted neat and tidy hedges, they were also looking for ease of management.

Hedge Cutting

Helps (1994) reported that the usual method of managing hedges was trimming with a flail cutter. This was also the standard management method used by the farmers questioned in the more recent MAFF-funded farmers' attitude survey (Britt *et al.* 2000), although Oreszczyn and Lane (1999) reported that the general public tend to dislike mechanical trimming.

The effects of mechanised cutting on the short term re-growth of hawthorn hedgerows has been studied by Semple, Dyson and Godwin (1994), over a three year period in farm hedges in Bedfordshire. The study concluded that flail cutters inflict more damage to hawthorn branches (of less than three years old) than a finger bar cutter or circular saw but that increasing the cut damage produces some beneficial effects i.e. it 'pushes' the position of new shoots further from the cut end, and may slightly increase the number of new shoots. The effect of repeated mechanical cutting of hedgerows and the effects on older and thicker wood require further work, however.

Bannister and Watt (1994 and 1995) investigated the effects of season and position of cutting on the first two years' growth of a newly planted hawthorn (*Crataegus monogyna*) hedge. They found that the combination of both vertical and horizontal cutting increased shoot length the following season, but vertical cutting alone decreased mean shoot length. A vertical cut in summer (August) increased thorn-tipped shoot numbers in the following growing season compared to a vertical cut in winter (February), although the latter resulted in longer shoots. Thus the type and time of cut will determine whether emphasis is given to a thornier hedgerow, or to one with longer bud-tipped shoots. However, it was pointed out that this work was carried out on juvenile plants with the treatments imposed for only two years, and the long-term effects of continuing the cutting regimes are unknown.

The same study also examined the effect of different cutting regimes on established hawthorn hedges in lowland England, and concluded that, as severe cutting decreased hawthorn shoot growth the following year, hawthorn hedges are probably best rejuvenated by gapping up with young plants. It was found over the three years of the study that an annual flail did not retard subsequent growth, but it was stressed that a longer-term assessment was needed. The study suggested that where a dense, compact hedge is required, a late summer cut is preferable, but this conflicts with the winter timing generally recommended for wildlife conservation.

A MAFF-funded project to provide guidelines for hedge management to improve the conservation value of different types of hedgerows, was started by IACR Long Ashton in 1996 and reported by Marshall *et al.* (2001a) and Marshall *et al.* (2001b). Part of this study investigated the effect of timing of cutting on berry production, noting that berries are an important food supply for many overwintering birds and other animals. It was found that, as most woody hedge species produce berries on 2nd year growth, a biennial or triennial cutting frequency leads to better fruiting than annual cutting. The timing of cutting was also found to be important, with February cutting allowing berries from the previous autumn to be carried into the winter. There was also some suggestion that cutting in September, when compared with February, could reduce bramble fruiting.

The effects of the timing and frequency of cutting on insects varied with the insect taxa studied, (Marshall *et al.* 2001a; Marshall *et al.* 2001b). Some taxa, such as psyllids, thrived best, in uncut sections of hedge, while others (e.g. Collembola) were more abundant in cut sections. Cutting in February was found to reduce populations of Lepidoptera, and possibly Diptera, when compared with cutting in September. The results concerning berry production and insect abundance lead the authors to recommend that not all the hedges on a farm be cut at the same time and that a relaxation from annual cutting would benefit biodiversity, (Marshall *et al* 2001b).

Increased hawthorn berry yields from reduced hedge cutting frequency were also demonstrated at a farm scale by Croxton and Sparks (2002).

Britt *et al.* (2000) reported that many English farmers were aware of the management currently considered to be best practice, but few actually followed this guidance. It was found that 79% of the farmers questioned trimmed their hedges annually. Reasons for avoiding a longer rotation included the possible inability of flail trimmers to cope with thicker wood, the need to clear cuttings and a perception that costs would probably be greater. Of the hedge trimming contractors questioned, 94% answered that they cut most of their clients' hedges annually. The timing of cutting varied, with most hedgerows around arable fields cut in the period July to October and most around grass fields cut between September and December. Although most farmers recognised that current advice was to trim in the period November to February, they felt that this was impractical, due to wet soils or the presence of growing crops.

Oreszczyn and Lane (1999) found that the farmers they contacted preferred small, neatly trimmed hedgerows, believing this to be a sign of care. However, they also found that members of the public and experts in hedgerow management both viewed harsh mechanical cutting as detrimental to wildlife (Oreszczyn & Lane 1999, 2000).

Traveller's-joy, or old man's beard (*Clematis vitalba*), is a woody climbing shrub capable of smothering hedges. Britt (1994) examined methods of controlling the plant and concluded that differing methods of mechanical trimming had no clear short-term effect on *C. vitalba* abundance. However, severing the stems at the base and treating the stumps with glyphosate gave effective control and a consequent improvement in hawthorn vigour. The use of different herbicides, the timing of application and the effects on different habitats were investigated by Clay and Dixon (1996). Imazapyr was found to be the most effective herbicide of those investigated when applied to cut stumps; however this herbicide is no longer available. Applying herbicide to growing plants and the effects on non-target plants were also considered and the cereal herbicide tribenuron-methyl (with the adjuvant 'Agral'), applied in July, was suggested as a potential selective treatment in hedges. It should be noted, however, that such use is not currently approved.

Hedge Planting/Replanting

Another survey funded by MAFF illustrated how the reasons for hedge establishment have changed since the days of the enclosure of land (Bickmore 2001). A postal study, followed by interviews, carried out as part of this project, found that hedges on farms are established for a variety of reasons, including aesthetics, grant availability, livestock shelter and wildlife.

Although 56% of farmers surveyed gave wildlife as a reason for establishing new hedges, there was little knowledge of how to maximise the value to wildlife – for example by choice of location or species.

Oreszczyn and Lane (1999) found that many farmers considered that planting or restoring hedges provides benefit for future generations.

The idea that mixed species hedges are of more benefit to wildlife than single species lines is long established. This has been recently reaffirmed by Hayes *et al.* ((2001); Marshall *et al.* (2001a); Marshall *et al.* (2001b); and Chamberlain *et al.* (2001).

A bank-top hedge planting trial by Asteraki *et al.* (1994) compared the establishment of hawthorn and blackthorn (*Prunus spinosa*), and examined the effect of fertilisers and peat mulch in harsh conditions and poor soils in mid-Wales. Overall mean survival was high, but hawthorn had higher survival than blackthorn in all treatments. Fertiliser treatments gave lower survival than the controls, possibly because of rapid grass growth on the bank tops.

Methods of repairing gaps in over-managed hawthorn hedges and establishing new hedges have been investigated by Henry (1993) and Henry *et al.* (1996) in Northern Ireland. Treatments applied were watering, fertilising with composted farmyard manure and replacing the soil, as well as an untreated control. Weed control using herbicides and hand weeding were used on all treatments. They found no significant increases in either the height or stem diameter among the four treatments, but the watered treatment displayed higher survival of quicks than the control. However the three months immediately post planting were much drier than average. The results did not support the concept of 'thorn sickness', a hypothesis which suggests that the soil in hawthorn hedges needs to be replaced if establishment of new quicks is to be successful. The authors also found that three-year-old '2+1' hawthorn transplants performed better than the larger, four-year-old '2+2' plants. Severe pruning, to 75 mm height, a few months after planting, produced significantly longer side shoots and did not impair survival. Planting at 45 degrees, as recommended by some authorities, did not produce significantly more side growth. This was considered to be a less practical option than upright planting, due to factors such as potential smothering with weeds and time required for planting.

The provenance of hawthorn plants has been found to produce significant differences in growth rates, morphology and disease resistance. Jones and Evans (1994) found that native Welsh hawthorn planted in mid-Wales grew faster; had a more appropriate morphology, including greater bushiness and thorniness, and was less prone to hawthorn mildew than Hungarian hawthorn.

Further work was carried out in mid-Wales, as part of a MAFF project, by the Institute of Grassland and Environment Research and ADAS (IGER 2000). It was found that hawthorns of local provenance established and grew better in Wales than Eastern European types. Significant growth differences were still seen 5 years after planting. Fencing was found to be imperative on the upland sites in this project, to prevent newly planted hedges being grazed. In the lowland sites grazed hedges survived more readily, but growth was reduced and the resulting hedge may not have been stock-proof.

With regard to provenance, Hayes *et al.* (2001), drawing on the above study, differentiated between upland and lowland hawthorn ecotypes. They suggested that growth and wildlife value are enhanced if the ecotype is matched to the site.

Research into the establishment of trees in hedgerows (Hodge 1990) has shown that planting transplants in tree shelters is generally the most effective and economic means of establishing trees in hedgerows. It was found that the use of natural shoots and saplings is generally unacceptable and impractical. The report recommended utilising natural gaps or cutting notches in the hedge, and controlling weeds by plastic sheet mulch or careful use of herbicides. The project also found that, for new hedge establishment, both height and stem diameter growth of hawthorn were significantly greater with plastic sheet mulch than with either no weed control or chemical weed control.

A study in Wales, by Wildig *et al.* (1994), evaluated the effects of three types of weed control on the survival and growth of a newly planted hawthorn hedge. It was found that mulching slightly enhanced the growth of young hawthorn plants; whereas propyzamide had no discernible effect, and glyphosate had an adverse effect on growth and survival of hawthorn (although the latter was presumably due to some inadvertent contact with the hawthorn transplants).

Henry (1993) suggested that black polythene was the most appropriate method of weed control, when compared with propyzamide during a study of hedge establishment in Northern Ireland. It was, however, thought that severely waterlogged sites may remain wet under the plastic, and may become anaerobic. The plastic may also become covered in leaf litter, so delaying or even preventing its degradation.

The use of polythene mulching was considered to be highly cost effective for the first 3 years after planting in the Welsh ESAs field margins and hedges project (IGER 2000). Not only were weeds controlled, but the soil was warmed and moisture was conserved, giving a 320% greater height increment in mulched hedges when compared with non-mulched lines. The results of this work suggest that the benefits of mulching are less discernible after three years and that, at this stage, the polythene should be removed to allow the ground flora to develop.

Further work on establishment techniques for hedges was carried out for MAFF by Catherine Bickmore Associates (1999). The objectives of this study were to undertake a representative survey of new hedges in England and Wales and compare the success rates of different establishment techniques. This work found that by their fourth season most hedges had established. In the first three seasons, enhanced growth was positively associated with bare earth and weed control, but thereafter there was little difference. The dilemma of the need to control weeds to enable good hedge establishment whilst trying to develop, or maintain, a good hedge ground flora for wildlife is acknowledged. It is suggested that by the fourth growing season competition is less likely to be a problem, so weed control should cease, allowing perennial grasses and herbs to develop for the benefit of wildlife.

The same study found that growth was suppressed by perennial grasses, and by locations on clay soils, old hedge banks and under trees. Growth rates suggested there was little benefit of using plants over 400 mm or under 300 mm in size, but it was pointed out that the sample was small. Aggressive weeds and browsing mammals were some of the main causes of gaps in newly planted hedges. A large proportion of hedges had a gappy basal structure, partly related to the use of tree guards. More bushy structures were associated with pruning. Just under a quarter of hedges had a poor overall assessment with lack of after care, weed suppression and browsing being contributing factors. Cultivation and weed control were associated with well established hedges.

Hedge Laying and Coppicing

Reif *et al.* (2001) describe coppicing on an 8 to 20 year cycle as a low cost maintenance operation, which is still one of the major management techniques used in Europe. Britt *et al.* (2000) reported that over half of the farmers who responded to their postal survey had laid hedges in the previous five years and 21% of the farmers questioned had coppiced hedges.

Henry, Bell and McAdam (1994) have examined the effects of laying, pollarding and coppicing with gapping up, as restoration strategies, on the flora and fauna of overgrown hedges. However there appears to have been little recent work examining the effects of these techniques on the structure of the hedge, although a MAFF-funded experiment at ADAS Drayton (Stratford-upon-Avon, Warwickshire) did consider this. The results of this experiment emphasised the difficulties of replanting, but indicated that coppicing can lead to rapid and successful regeneration of a hedge, particularly where blackthorn (which suckers readily - filling up gaps in the hedge) is a significant component of that hedge (Britt *et al.* 1996).

Marshall *et al.* (2001a) found that insect numbers in hedges increased significantly after laying.

McAdam *et al.* (1996) investigated the effect of different restoration strategies (coppicing, laying and pollarding) on the diversity of hedgerow ground flora. Coppicing significantly enhanced the diversity of the flora for the first two years after cutting. The subsequent decline in species richness was thought to be due to shading, and the authors therefore suggest that regular trimming of the sides of the hedge may be necessary to maintain a diverse flora. They further point out that such management may restrict the hedge's usefulness as a stock-proof barrier or as a provider of shelter.

Hedge-Bottom Vegetation

Where fertiliser and herbicide drift, and cultivation is too close to the hedge, the hedge-bottom vegetation is commonly impoverished in terms of species richness, and may become a potential source of pernicious weeds.

Britt *et al.* (2000) found that over 40% of farmers who responded to their attitude survey sometimes or always sprayed weeds in hedge bottoms. More than half of the respondents said they always prevented sprays and fertilisers contacting hedgerows, while 9% said they never did this.

Whilst there have been various studies addressing the management of the boundary strip and crop margin, work on the actual hedge-bottom vegetation is limited. Dunkley and Boatman (1994) investigated two options, natural succession and sowing various grasses, for restoring the hedge-bottom. Their preliminary results demonstrated that non-intervention can be an effective, if slow, option for restoration of perennial hedge-bottom vegetation. However there may be some trade-off between species diversity and weed control.

McAdam *et al.* (1994c) addressed the grassland situation, where increased sheep densities have led to restricted re-growth of managed hedges and reduced associated hedgerow flora diversity. Their study showed that protection from intensive grazing and fertiliser application was necessary to conserve the wildlife value of the hedge-bottom, but that there is little to be gained from fencing more than one metre from the hedge-base.

IACR, as part of the hedge management project reported by Marshall *et al.* (2001a) investigated techniques for improving the conservation value of species poor, weed dominated hedge-bottom flora. Treatments included the use of selective herbicides, cutting and fertiliser exclusion, and sowing an appropriate seed mix. It was demonstrated that reducing fertiliser deposition in hedgerows is useful for maintaining plant diversity. Resowing of hedge bases in arable areas was found to enhance plant diversity more significantly than fertiliser management. However, the establishment of sown vegetation in hedge bottoms in grassland was poorer than that in arable areas. In such grassland situations it is suggested that resowing may be a less practical and therefore a less effective method of restoration than in arable areas.

This project also showed that selective herbicides may be valuable in aiding the restoration of heavily weed infested sites, but that exclusion of fertilisers and cutting can also be beneficial in controlling weeds, notably cleavers (*Galium aparine*). Such treatment of hedge-bottoms with herbicide also increased the species diversity of true bugs (Heteroptera). There may, thus, be both ecological and agronomic benefits of such management, although it is pointed out that other weeds, such as common nettle (*Urtica dioica*) are known to be beneficial to insects.

Autumn cutting of the hedge bases was found to reduce the abundance of many taxa of invertebrates, (Marshall *et al.* 2001a). It was suggested that spring cutting, combined with removal of cut vegetation, could be the most beneficial strategy for plants and invertebrates, but doubts were raised as to the practicality of such an approach at the farm level.

COSTS OF HEDGE MANAGEMENT

The costs of hedge management have been subject to only limited research until recently, although there are a number of cost guides published that rely on informal survey. Nix (2003), for example, in the annually produced *Farm Management Pocketbook*, provides a guide to the cost of flail hedge trimming, hedge laying, coppicing and planting. The data are provided by the Farming and Wildlife Advisory Group (FWAG), from sources that include county FWAG personnel, local authorities and the British Trust for Conservation Volunteers.

Conservation advisers from various organisations usually have a good awareness of local costs, but these are rarely published.

Books on hedge management may include costings applicable at the time of publication. The British Trust for Conservation Volunteers (Anon. 1975) quotes costs for planting and managing a new hedge, and for managing a mature hawthorn hedge. These costs were based on those given by Pollard *et al.* (1974) together with information obtained from hedging contractors. Maclean (1992) provides actual examples of costed hedge planting schemes.

Cobham (1983), in discussing the Economics of Vegetation Management, provides data on the time inputs required for various hedge management operations including laying and trimming to different shapes. He points out that the cost can then be calculated to reflect whether the work is undertaken by permanent, contract or voluntary labour.

The cost of implementing the Habitat Action Plan for ancient and/or species rich hedgerows within the UK Biodiversity Action Plan (BAP) was estimated as £1.7M per annum in 2000, rising to £3.0M per annum by 2010. This would be in addition to the current public expenditure on hedges, estimated to be £2.5M per annum in 2000 (as reported in Mills, Winter & Powell 2000). Mills *et al.* (2000) also estimated that within their study county of Devon, implementation of this BAP would generate 27 new contractors jobs, along with extra jobs on farms (5.6), in supply industries (5), and in training (0.9). Hedge by-products and an increase in tourism would also generate more income from hedge restoration.

Mills *et al.* postulate that the expenditure suggested will meet 60% of the costs at the farm level, as hedge trimming will not be included. It is therefore concluded that the cost to the farmer of retaining and maintaining species-rich hedges is more than the financial benefits. Taking into account the factors above, it is estimated that the annual on-farm benefits of well-maintained species-rich hedges in Devon range from £230 to £412, while the costs range from £1,305 to £1,661. Furthermore, the authors suggest that the costs quoted to implement the BAP would be insufficient to meet the Plan's target in Devon.

Semple, Bishop and Morris (1994) assessed the impact on farm incomes of making changes to hedge management regimes to benefit the environment. Their research identified the cost of existing management practices for four common hedge types, and investigated the impact of changing those practices on cropped area, yields, and regular farm labour and machinery requirements. These findings were applied to three farm models to demonstrate the economic effect of changing hedgerow management practices in different farming systems. The study demonstrated considerable extra annual costs (including loss of cropped area and yield, and a greater number of hedge trimmer passes) when changing the management of the most common hedge type (one metre high, trimmed annually) to produce a more environmentally beneficial hedge, which is taller and wider. The inclusion of a verge also substantially increases the costs to the farmer.

This study was part of a wider contract report to the Department of the Environment (Hooper 1992) which also identified the typical costs of hedge laying and coppicing, and their typical annual costs when amortised over a 20 year cycle. The report also refers in general terms, to the savings in costs achieved by hedge removal. These savings are greatest where field size is small, and indicates the optimum as a square field of approximately 20 hectares.

Research on the economics of sustainable hedge cutting was commissioned by the Devon Hedgerow Group, and carried out by Silsoe College (Semple *et al.* 1995). This looked at the economic implications for the farmer of moving from annual flailing of hedges. Alternative management methods considered were: raising the height of cutting each year (incremental); incorporating trees into the hedges at 50 metre intervals; trimming the top every three years and the sides annually (3 + 1); and trimming the entire hedge back to its original size every three years. Four farm models were used to demonstrate the effect of these management practices on different farming systems; three were typical of Devon, and one of the arable Midlands.

The estimated annual direct costs of cutting a hedge every three years is less than half the cost of an annual cut. The 3 + 1 option also showed savings over an annual cut but the other two options were more expensive. The alternative management systems also had productivity impacts, with wider hedges reducing the field area in production, and taller hedges creating shade that reduces crop yield. In the Devon farm models, if the hedges comprise species with a slow growth rate, the combined productivity and direct annual costs are in general lower for the 3 + 1 and three yearly systems than for the annually trimmed hedge. For the Midland farm model, these two systems showed only a small increase in costs. The incremental system, due to the large hedge size, is the most expensive option independent of farm type and hedge growth rate. Leaving hedgerow trees also increased costs. Where gross margins are large, as with arable and dairy farms, and/or the hedge growth rate high, then the 3 + 1 option was found to be the most cost effective way of enhancing the environmental value of the hedges. However, costs were not always less than for the standard, annually trimmed hedge.

The effect of boundary features at the field margins on yields of winter wheat was examined by Cook and Ingle (1997), and this showed that aspect was a major factor in the yield effects, with the height and species composition also being important. The greatest yield reductions, and thus cost, were associated with an east or north facing tall (> 2m) hedge. Other estimates of cost are given by Helps (1994) and Doubleday (1994).

Marshall *et al.* (2001a) collected data on crop yields and times taken to trim hedges. The authors state that whilst these data provide useful insights they require validation on a greater range of hedges. They found no significant effect on grass or cereal yield when relaxing cutting regimes. By changing from annual to biennial or triennial cutting it is suggested that 40-50% of cutting time can be saved. This, coupled with the yield results, leads the authors to suggest that there are cost advantages in switching from annual to less regular trimming.

All these studies show a reduced annual direct cost of biennial or triennial cutting compared with an annual cut. The overall cost to the farm has been shown to vary with the farm and hedge types. This overall cost will be sensitive to variations in the gross margins of the enterprises i.e. the value of crop or livestock produce, less the direct variable costs of production.

The vast majority (98%) of contractors questioned as part of the survey by Britt *et al.* (2000) used hourly rates as their main charging method, with the average charge being £14.10 per hour. The farmers questioned in this project thought that the financial aspects of hedge management were very important. There were, however, differing views on the relative costs of annual, biennial or triennial trimming. Grants were welcomed and 48% of farmers said they would be 'very likely' to carry out work such as coppicing, laying, planting or gapping if more grant were available.

The survey of farmers carried out in the hedge establishment study by Catherine Bickmore Associates (1999) found an average price to establish a hedge of £4.48/metre, including plant protection. Planting and labour averaged £2.55/metre, with fencing on both sides of the hedge at £4.20. Economies of scale were shown in the cost of all materials. The balance between the cost of providing fencing or tree guards was related to plant density, with relatively little difference between the two costs at seven plants per metre for lengths over 1,000 metres. Typical contractor costs for hedge planting were found to range from £2.44/metre at four plants per metre with no protection to around £19/metre for seven plants per metre using spiral guards and livestock fencing. The report commented that little information was available on the costs and times required to establish a hedge.

PLANTS AND HEDGEROWS

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This section is the first in a series which considers the effects of hedgerow management and adjacent land use on different groups of organisms (taxa). In this section, the literature relating to aspects of hedgerow vegetation is reviewed and includes the hedge itself and its component woody species, the hedge-bottom flora and the immediately adjacent field margins.

IMPORTANCE OF HEDGEROWS FOR PLANTS

There are various perceptions on the importance of hedgerows for plants and these vary between commentators. In a study of lowland farms in England (Hooper 1992), about one third of farmers mentioned wildlife when asked about the value of hedges, but attitudes towards the vegetation associated with hedges is variable in the farming community. Many farmers see hedgerow plants, including some of the woody species, as unwelcome weeds, this despite the work of Marshall and others which shows that relatively few hedgerow species are to be found in the adjacent fields (see below under 'Adjacent land use and field margins'). The general public appear to have a more positive appreciation of hedgerow plants (Hooper 1992), but this may be limited to vegetation along roadside hedges and banks, which is often different to that between fields (e.g. Wilmot 1980). Natural historians and ecologists see the importance of hedgerows for vegetation in its own right (e.g. Bunce & Hallam 1991) and also as an essential habitat for fauna.

A good introduction to the ecology of hedgerows, including their importance to plants, is included in Dowdeswell (1987). Other references which highlight the importance of hedgerows include Hooper (1970a), Terrason and Tendron (1981) and Spellerberg and Gaywood (1993).

Of the research carried out on hedgerows, studies of the vegetation are relatively few (Boatman *et al.* 1994). After a period of relatively little research on hedgerows (see 'Background and Introduction'), several projects have been completed in the last decade, including those of McAdam's group and Hegarty in Northern Ireland e.g.. McAdam *et al.* (1994a); Hegarty *et al.* (1994); Elton, at Kingcombe Meadows Nature Reserve, Dorset, where the estate's hedgerow network has remained largely unchanged since c. 1840 (Elton 1994); and work at the University of Reading's farm at Sonning, where a hedge has been established and is being monitored in terms of value as a wildlife habitat, the effect of the hedge on the neighbouring crops and the effect of the crop management on the hedge e.g. Walsingham and Harris (1994).

Hedgerows as a habitat for plants

The most recent estimates of the length of hedgerows in Great Britain is c. 450,000 km and, after a period of decline (at the rate of about 18,000 km per annum between 1984 and 1990; Barr *et al.* 1993), this network is now relatively stable in terms of net change (Haines-Young *et al.* 2000). Much of the earlier losses were said to be due to lack of management of existing hedgerows, such that they became either rows of trees or stunted bushes.

Webb (1985) estimated that hedgerows occupy an area three times that of deciduous woodland in Ireland. If a similar calculation is made for Great Britain, the author estimates that the area of hedgerows might amount to about half that of broad-leaved woodland. Carlisle (1990) showed that 60% of broad-leaved trees in Northern Ireland are to be found in hedgerows, while results from a countryside survey in 2000 give an estimate of about 1.8M 'hedgerow trees' in Great Britain. Hooper (1992) suggested that, despite reported increases of non-woodland trees, the farmland stock of trees for timber is in decline, due to factors such as Dutch Elm disease, pesticides, fertilisers, soil management, acid rain (Forestry Commission 1991), and probably the replacement of these trees is being hindered by the use of flail mowers when sapling trees are present.

Clearly, hedgerows still constitute a large area of habitat for trees, hedgerow shrubs and ground flora, and provide a range of substrates and niches for plants and animals greater than in surrounding fields (Forman & Godron 1986) and especially for forest-edge species (Forman 1995). However, it is not appropriate to consider any of the component parts of the hedgerow system in isolation. Several studies (e.g. Hegarty & Cooper 1994; Cummins & French 1994) have shown that there is a positive correlation between the species diversity of shrubs in the hedge itself and diversity in the hedge-bottom flora. In agreeing that structurally diverse hedges support more species-richness, Spellerberg and Gaywood (1993) point out that this may not always be the ultimate goal.

Some five or six hundred plant species have been recorded in hedgerows, but only about half of these are sufficiently frequent to be thought of as hedgerow plants and practically all of them are found in other habitats such as woodland or grassland (Pollard, Hooper & Moore 1974) but in available studies, Forman and Godron (1986) say that no plant species is known to be limited to hedgerows; all species are found in nearby habitats. However, Hooper (1987) claims that the Plymouth pear (*Pyrus cordata*) is confined entirely to hedgerows. Of the c. one third of Britain's native plant species that have been recorded as occurring in hedgerows, only about 200 species occur sufficiently frequently to be regarded as hedgerow plants (Hooper 1968a). The Countryside Survey 1990 recorded over 40 species of woody shrub and about 270 herbaceous plants in almost 1,000 'hedge plots' (Barr *et al.* 1993). At a more local, but comprehensive, level, the Cornish Biological Records Unit (CBRU) hedgerow check list has 872 species and sub-species of plants and ferns, of which 518 are native, 32 being scarce, and 13 Red Data Book species (Menneer 1994). The NCC (1970) described 250 flowering plants and ferns as being recorded from hedgerows in Britain.

The relative importance of hedgerows for the conservation of these species is known only in general terms. Hooper (1968a, 1992) claims that a reasonable estimate is that the removal of all hedgerows would affect the total population of 20 species of plant very seriously, a further 20 species quite seriously and another 20 species to a significant extent. Further evidence of the importance of hedgerows to floristic diversity comes from the ITE/DOE study on the Ecological Consequences of Land Use Change (Bunce 1993) and the Countryside Survey 1990 (Bunce *et al.* 1994). Plots from linear features recorded in 1978, and again in 1990, showed that linear features contained a high proportion of all the plant species recorded in sample 1 km squares. Hedgerows and verges contributed most diversity in the lowlands, whilst in the uplands streams were more significant.

In the Countryside Vegetation System classification (Bunce 1999), 75% of the 565 (10 x 1 m) hedgerow plots recorded in Countryside Survey 1990 occurred in only eight of the 100 CVS classes, although there was some representation of 'hedge plots' in 29 of these classes (Baudrey & Bunce 2001).

Of those occurring in the eight classes, 40% were in classes characteristic of highly disturbed and fertile hedgerows and field boundaries, the majority of which were associated with cropped fields. Another 13% were classified as relatively species rich in the west of England.

Barr *et al.* (1994) have described a period of hedgerow loss in Great Britain between 1984 and 1990. Hooper (1992) questions whether these losses are of importance to the conservation of plants in a wider context and suggests that this depends upon the relative abundance of individuals of these species. For example black bryony (*Tamus communis)* is much more abundant in a number of habitats than, say, barberry *(Berberis vulgaris)* and, although a large proportion of individuals occur in hedges, hedge removal may not be as significant for this species as for barberry. In fact, the removal of hedges is unlikely to make any species extinct except, perhaps, Plymouth pear or one of the 'micro-species' of blackberry, rose or elm *(Rubus, Rosa* or *Ulmus*). In a few cases the removal of hedges might lead to the extinction of a species within a limited area such as an English county. This applies to species such as wild liquorice *(Astragalus glycyphyllos),* lesser periwinkle (*Vinca minor*) or wild service-tree (*Sorbus torminalis*) which are local, or to species common enough in one area but rare in another, like goldenrod (*Solidago virgaurea*), which is rare in the south-east, or wayfaring-tree (*Viburnum lantana*), which is rarer in the north. The main plant species found in hedges are apparently common in a number of other habitats and although removal of all the hedges in the country might cut the total population by up to 75% (Hooper 1987) one would still not have to travel very far to see an example, say, of oak (*Quercus* spp.), ash (*Fraxinus excelsior*) or blackthorn (*Prunus spinosa*).

Greaves and Marshall (1987) suggest that in defining the conservation objectives of a field margin, different species of plants and animals have different habitat requirements, which are often exacting and may conflict with each other. Nonetheless, the conservation interests are best served by those field margins which have the greatest species diversity of woody and herbaceous plants. This is achieved where a multiplicity of micro-habitats is present and where robust, dominant herbaceous plant species are discouraged. As animals are dependent on plants, many being very specific in their requirements, the diversity of animal species varies with the diversity of plant species.

The 'quality' of the vegetation in hedgerow habitats is said to be declining. Boatman and Theaker (1993) have documented a steady deterioration in the quality of the herbaceous vegetation in many arable field boundaries, from a mixture of tussocky grasses and perennial herbs, to flora composed largely of aggressive weedy species.

A similar pattern emerges from analysis of the Countryside Survey 1990 data (Barr *et al.* 1993), which showed an increase in plants typical of intensive grassland systems, at the expense of woodland and meadow species between 1978 and 1990.

The same study showed that there has been a significant decline in the diversity of hedgerow ground flora species in the pasture-dominated areas of Great Britain (Barr *et al.* 1993). Hooper (1968a) pointed out that little was known about regional extinctions of species and the same is largely true today, although knowledge about local flora is expanding, due to the activities of local Wildlife Trusts and others.

Species complement

Hedgerow vegetation is frequently described as varied, primarily because of differences in hedgerow origin and management (Delelis-Dusollier 1973; Roze 1981). The same is not true of all hedgerows: Tybirk *et al.* (2001) say that their research clearly show that there are no indications that today's average Danish hedgerow should be considered as important habitat for species of either regional, national or international conservation interests. A high species diversity in hedgerows is not only valuable as a refuge for different species, but also for the ecological processes in a system. The total species diversity is valuable for the hedgerow to work as a functioning ecological system (Sarlöv Herlin 2001).

Several authors have listed the ways in which hedgerows have been formed and the historical aspects are largely covered in Section 2 of this review. However, it is worth noting that, in broad terms, hedgerows were:

i. formed during clearance of ancient woodland as strips left between newly created fields or pastures (assarted) (e.g. Pollard 1973),

ii. created spontaneously as a result of stone clearance from fields which created stone banks in which shrubby species grew (*"accumulated over hundreds of years at the distance a person can throw a stone during cultivation of the field"*) (e.g. Reif 1983),

iii deliberately planted, often as a single species and usually hawthorn (*Crataegus* spp.), especially at the time of the Enclosures Acts (Muir and Muir, 1987, state that in the period 1750 to 1850 hedges were planted at the rate of about 2,000 miles each year). Internationally, planted hedgerows are usually dominated by a single species such as hawthorn or cypress (*Cupressus* spp.) in Europe, or Osage orange (*Maclura* spp.), pine (*Pinus* spp.) or willow (*Salix* spp.) in parts of the USA (Forman & Godron 1986).

Hedges originally assarted (cut out) from ancient woodland tend to be the most botanically diverse (Pollard 1973; Cameron & Pannet 1980). Greatest benefit to wildlife will come from allowing these botanically diverse hedgerows to expand (Deane 1989; Forman & Godron 1986).

The subsequent development of the hedgerow, and changes in plant species diversity, are well documented by Forman and Baudry (1984). They point out that no long-term study of a hedgerow has been conducted; therefore, our understanding of hedgerow development is mainly limited to general hypotheses. In planted and spontaneous hedgerows, species diversity must increase at least for a time as birds and wind bring in new propagules. In early stages these will be largely field and forest-edge species that live in open and semi-open conditions. Later as the hedgerow trees become taller and the shrub layer denser some invasion of forest-interior species is expected. Because of the longer life span and size of the late successional tree species, they occupy and out-shade the diverse shrub vegetation (Schulze & Gerstberger 1993). Thus, in this case, ageing hedges lose their biodiversity.

The remnant hedgerows in contrast would initially lose species, at least some forest interior species, due to the increase in wind, light and temperature following cutting of the adjacent area. This relaxation effect (Diamond 1972), presumably, would be rapidly counterbalanced by an increase in species as open-field and forest-edge plants colonise the hedgerow. One might expect less rapid change over the following few years or decades, with the remnant hedgerow maintaining a high diversity of open-field, forest-edge, and forest-interior species.

Planted and spontaneous hedgerows would continue to change rapidly at least until large trees had developed over several decades or more.

Schulze and Gerstberger (1993) suggest that if the hedge is not maintained (cut every 20-30 years) then the invading forest species will not supply palatable leaves, nectar, fruits and shelter for the insect and bird fauna.

In terms of the species which form part of the colonisation process, Dowdeswell (1987) lists elder (*Sambucus nigra*), hazel (*Corylus avellana*), field maple (*Acer campestre*) and dogwood (*Cornus sanguinea*) as good colonisers, with ash, rose and blackthorn occupying a middle-position in terms of colonisation. Other woody species are slower to spread in. Deane (1989) states that the ground flora of grasses and broad-leaved plants will also change underneath new scrub.

On reverted arable land, annual weeds will invade, to be followed by coarse grasses and flowers. Plants characteristic of woodland such as dog's mercury (*Mercurialis perennis*) and primrose (*Primula vulgaris*) will follow much more slowly, if at all (Peterken 1974; Helliwell 1975).

Colonisation will depend on the ecological requirements of the species concerned. Grubb *et al.* (1996) have looked at the light and soil requirements of seedlings of ten European tall-shrub species and beech (*Fagus sylvatica*) under experimental conditions and discuss their results in relation to the roles of the various species during secondary succession, and their regeneration niches. Similarly, Kollmann and Reiner (1996) have examined the shade tolerance and response to light of seedlings of six shrub species during establishment beneath scrub (in Germany) and conclude that light availability is the dominant factor for the growth and survival of seedlings.

As Forman and Baudry suggest, such maturation processes are more theoretical than real in many landscapes due to human influences, but species conservation in hedgerows must consider the possibilities of re-colonisation of existing hedgerows and/or colonisation of new ones. Colonisation is a function of the regional species pool and of species dispersal ability, and the later is often constrained by landscape structure (Burel & Baudry 1994a).

Hooper's Rule

One of the few universal hypotheses that has emerged from hedgerow research has been 'Hooper's Rule'. This formalises the general notion that planted hedgerows will become more (shrub) species-rich with time and states that approximately one new species will become established in every 30 yards of hedgerow, every 100 years (Hooper 1970a). While the rule may hold true in much of eastern and middle England, dominated by planted hedges in arable landscapes, many authors have suggested that there are clear, often regional exceptions (Helliwell 1975 - in Shropshire; Cameron 1984; Rackham 1986; Heatherington 1986 - in Warwickshire; Condon & Jarvis 1989 - in western Ireland). Dowdeswell (1987) suggests that the rule is "subject to a considerable margin of error". Muir (1996) mounts a formidable attack on the strict interpretation of the rule and points to the absence of any credible scientific mechanism for such recruitment.

Cummins and French (1994) note that the species diversity of a hedge is likely to depend on its position in the landscape, for example whether it is near to sources of seed such as woodlands. Forman and Godron (1986) suggest that intersections, or nodes, provide better habitat for plants than other parts of the network. Wilmot (1980), noting that hedges next to roads had more hedge species than those between fields, recommends that Hooper's rule only be used once local relationships have been established. It is unlikely that the specific equation can be fitted to hedges in northern Britain, because the potential for species diversity is less than in the south of the country.

Hooper himself (1994), notes the limitations of the rule, but it is generally agreed that older hedgerows tend to have accumulated more woody species (e.g. Deane 1989) and, in its wider sense, the rule has proved useful in many studies and has become a standard in the teaching of hedgerow ecology.

It is not appropriate to note a full list of shrub and ground flora species, found in hedgerows, in this review. However, although much descriptive work has been done, there is scope for more ecological description and interpretation of the vegetative components of hedgerows and, for example, their functional types and 'ecological value'. Boatman *et al.* (1994a), in a survey of arable field boundaries across the south of England, described differences between species occurring in a high number of quadrats, in relation to the number of boundaries which would be expected to tend towards a uniform distribution within boundaries (e.g. false oat-grass (*Arrhenatherum elatius*), rough meadow-grass (*Poa trivialis)*, common nettle (*Urtica dioica*), creeping bent (*Agrostis stolonifera*), couch (*Elytrigia repens*) and barren brome (*Anisantha sterilis*)), and those giving a low ratio, which would tend to have a clumped distribution (e.g.

white dead-nettle (*Lamium album)*, creeping thistle (*Cirsium arvense)*, perennial rye-grass (*Lolium perenne*)). The majority of the former group were polycarpic perennials, with two exceptions, cleavers (*Galium aparine)* and barren brome. Most share certain common characteristics; they are competitive (C, CR or CSR strategists; Grime 1974) and successful colonisers, characteristic of high soil fertility and often associated with disturbance. They are tolerant of moderate shade, but not of defoliation.

Hedgerows as corridors

As Forman and Godron (1986) and Forman (1995) have pointed out, it has been suggested that hedgerows are important corridors that facilitate the movement of plants and animals across agricultural landscapes (Sinclair *et al.* 1967; Pollard *et al.* 1974; Helliwell 1975; Forman & Godron 1991; Forman 1983; Baudry & Burel 1984; Merriam 1984). There has been a long-running debate on this with, for example, Sinclair *et al.* (1967) and Merriam (1984) concluding that only a few plants and small mammals move along hedgerows efficiently, while Helliwell (1975) states that plants do not travel through hedgerows. In a restricted study aimed at this topic, Fenner (1996) found no evidence for movement of 'woodland species' along hedgerows adjacent to woodland, but concluded that results for 'woodland-edge species' required further examination. Ouberg (1993) has found evidence for limited movement of some vascular plants along hedgerows in the Dutch Rhine System. Burel (1996) found no such evidence in Brittany and speculates that hedge width may be an important contributory factor.

In 1984 Forman and Baudry reviewed the published work and gave no firm conclusions on the movement of plants in hedgerows. Similarly, Dawson (1994), in an extensive review of the theoretical basis and empirical evidence for habitat corridors, revealed few good studies. He concludes that, while the idea that a network of corridors enables large-scale movement is attractive, it remains untested. While the preconditions for corridors (such as hedgerows) to act as useful conduits can occur, 'all-purpose' corridors do not exist. Hooper in his report to the Department of the Environment (1992) refers to island biogeography in relation to woodlands (Moore & Hooper 1975) and notes the discussion of the possibility that hedgerows and other linear features in the landscape could act as 'green corridors' for the movement of species from one site to another, thus cancelling out the deleterious consequences of population instability (such as the likelihood of extinction of species in small isolated habitats). However, in Canadian landscapes of fragmented forest, Fritz and Merriam (1996) conclude that plant movement along 'fencerow' corridors, between isolated forest patches may be constrained by architectural differences between fencerows and forest edges.

As Hooper has pointed out, until relatively recently, plant 'movement' has been a plausible hypothesis without any scientific foundation. There has been evidence of movement [of animals] from a wood into adjacent hedgerows (e.g. Wegner & Merriam 1979) and, to an extent, there has been evidence (e.g. Krebs 1971) of movement from a hedgerow into a wood. Buckley and Knight (1989) suggest that the most 'interesting' and 'attractive' woodland ground flora species are poor colonisers. This supports earlier observations by Rackham (1986), Pollard *et al.* (1974) and Brown (1995). What is lacking is concrete evidence of movement from wood to wood along a hedge, in preference to movement <u>across</u> a field. However, some evidence is now accumulating to show that this is at least probable (for animals).

More recent analysis of Countryside Survey data has found no evidence for hedgerows acting as corridors for plants (French & Cummins 2001) and especially not for woodland indicator species (where hedgerows present a relatively hostile environment) (Smart *et al.* 2001). Using a novel Habitat Preference Index (HPI) approach, McCollin *et al.* (2000) reach the same conclusion, stating that the environments of hedgerows are more similar to woodland edges than interiors; qualitative differences between the environmental characteristics of hedgerows and woodlands are such that certain woodland plant species are highly likely to be limited in their capacity to use hedgerow networks.

Conversely, in a small study in north Somerset, Boots (2001) found that a number of plant species were only present in hedgerows connected to woodlots and that the hedgerows connected to woodlots were more species diverse than hedgerows unconnected to woodlots. The woodlots post-date the hedgerows and may have influenced the presence of woody species found in connected hedges.

Burel and Baudry (1994a) stress, yet again, that research carried out within the framework of landscape ecology emphasises that hedgerows cannot be considered as isolated landscape elements. Hedgerow species diversity can only be understood as resulting from landscape scale processes. If management practices at the hedgerow scale are very important to maintain habitat quality, landscape design and management to assure a high connectedness within the network, as well as connections with sources of forest species, are major influences on species colonisation of available habitats. Diquelou and Roze (1997) describe how agricultural activity has resulted in damage to the hedgerow network in parts of Brittany, resulting in a loss of diversity in term of corridors.

The possibility of plants 'moving' along hedgerows, which is likely to be controlled by plant dispersal mechanisms and niche availability, needs further research to inform a long-standing debate.

EFFECTS OF MANAGEMENT

As discussed in the earlier section on 'History and Hedgerow Management', hedges in Great Britain have been managed at least since the 16th Century, and the appearance of the lowland British landscape today is heavily influenced by the degree to which hedgerows have been managed. However, it should be remembered that hedgerows in other countries may be treated differently; North American hedges are quite different in that they are usually unmanaged and are commonly tree height and four to 15 m wide (Forman & Godron 1986).

The appearance of British hedgerows may be determined by a variety of factors, including:

- the law (which dictates that roadside hedges are to be trimmed regularly);
- local tradition (which may influence the style of management);
- the use to which the hedgerow is put (whether as a stock-proof barrier, or for shelter, game management or landscape value);
- the socio-economic characteristics of the landowner or farmer (i.e. whether the farmer has the resources to manage hedgerows regularly) and, increasingly,
- the interests and activities of local wildlife conservation groups (who may enter into tree-marking schemes).

Within any one of these broad categories, there may be different styles of management. For example, for game management, hedgerow requirements differ for 'showing' partridges (where tall hedges are required) and for partridge nest sites (Doubleday 1994).

This part reviews what is known about the effects of hedgerow management on vegetation and is divided into sections dealing with woody species and ground flora.

Woody component

Hedge species composition and health

Early prescriptions for hedgerow management were devoted to ensuring the sustainability of the shrub and tree species that comprise the hedge itself. Management of the hedge-bottom was related to weed control. It is only relatively recently that interest has focused on managing the hedgerow for plant species with wildlife conservation in mind. There are numerous references in the literature, and guidebooks available, on prescriptions for hedgerow management. Early work showed that although management regimes (and soil types) had effects on the frequency of individual species, overall density remained unaffected (Hooper 1994). Dowdeswell (1987) stated that, perhaps surprisingly, methods of [hedge] maintenance seem to have less effect on hedge composition than was once supposed.

Broadly, the species diversity and composition of a hedge will be determined by its original composition and by any subsequent colonisation and extinctions (Cameron & Pannet 1980a). The addition of species to a hedge after creation may also result from deliberate planting, especially of trees. The original composition and colonisation will in turn depend on a complex of natural and human factors.

Correlative studies

Of the earlier field survey studies Pollard, Hooper and Moore (1974) attempted to examine species complement in relation to management. They had shown that the degree of management affected the nesting of birds and it was expected that the same might be true of other aspects of hedgerow ecology such as colonisation by shrubs and climbers. Their results were equivocal with some climbers, e.g. bittersweet (*Solanum dulcamara*) and white bryony (*Bryonia dioica*), being more common in unmanaged hedges but others, such as bramble and cleavers, being more abundant in managed hedges. Samples elsewhere showed that other species, rose and honeysuckle (*Lonicera periclymenum*), could be more abundant in managed hedges.

The work done in ESAs in Northern Ireland by Hegarty and Cooper (e.g. 1994) show that unmanaged hedges contained significantly higher mean cover values of blackthorn, grey willow (*Salix cinerea)* and gorse (*Ulex europeus)*. Other species, such as hawthorn, ash and dog rose (*Rosa canina)* were also more common in managed hedges. Hooper (1976), in England, also found that ash, elm (*Ulmus procera)* and sycamore (*Acer pseudoplatanus)* were twice as common in unmanaged hedges than in those regularly managed. These results are amplified in Hegarty's thesis (1992): hawthorn was highly correlated with complete hedges whereas gorse was characteristic of 'gappy' hedges. Of all the tree and shrub species, hazel (*Corylus avellana)* was the most characteristic species of tall hedges, followed by grey willow, sycamore and ash. In contrast, the mean cover values of gorse and hawthorn were negatively correlated with hedge height. Unmanaged hedges were associated with shrubs such as blackthorn and grey willow. Managed hedges contained ash and hawthorn. The mean cover value of dog rose was significantly positively correlated with hedge width.

Correlative studies are useful in developing hypotheses but, since they are often based on a 'snapshot' in time, details of hedge life-cycles and history remain largely unknown and there is a need for longer-term observational and experimental work.

Direct management effects on woody species

As Bannister and Watt (1995) have noted, the effects of different methods of cutting hedges have been reviewed (Maclean 1992), but current information is driven from experience and observational studies rather than from experimental evidence. The literature contains relatively few comments on the effects of different management regimes on individual species. However, Wolton (1994) notes that ash and hawthorn are quite resistant to flailing, but others like hazel and blackthorn succumb quickly. Since an estimated 97% of farms use flails for hedge trimming (Britt *et al.*, 2000), it seems likely that the species composition of managed hedgerows is likely to change.

Bannister and Watt have completed some rigorous experimental work on the effects of cutting on the growth of hawthorn (1995). The effects of the position and timing of cutting on shoot growth of young *Crataegus monogyna* plants in newly-planted hedges were studied. Total shoot length was unaffected by cutting. In general, a combination of both vertical and horizontal cutting produced a hedge with long, bud-tipped shoots. The timing of cut was important: a horizontal cut in summer resulted in fewer but longer shoots whereas a vertical cut in summer produced more thorn- tipped shoots. A vertical cut in winter resulted in longer shoots than one in summer and reduced the number which were thorn-tipped. Management style of farm hedges could be characterised by various growth parameters. Hand-cut hedges had numerous short shoots and many older-wood branches per unit area, whereas unmanaged ones had a greater leaf area and longer shoots. Summer-flailed hedgerows were characterised by a smaller leaf area, although this may have been partly due to cleavers (*Galium aparine*) infestation. The use of the flail on the current season's growth did not significantly retard growth the following year.

Carter (1983) stated that, where machines are used, there is still a need to use hand tools to remove "*rubbish*" such as elder or briar and Pollard *et al.* (1974) observed that those hedges managed by layering have more black bryony, and those managed by trimming have more rose and honeysuckle. It is interesting to note that competition-standard hedge laying requires climbers and ramblers to be dug out, thus changing the species complement and reducing diversity. Helps (1994) says that a mixed hedge may need to be cut back every year because of vigorous species such as bramble (*Rubus fruticosus agg.*), traveller's-joy (*Clematis vitalba*) and elder - whereas a pure hawthorn hedge may need cutting less frequently.

Very little has been published on the effects of repeated cutting on hedge structure, diversity or longevity since Stephens wrote his book in the middle of the last century (Wolton 1994). However, work at Wye (Banister & Watt 1994) has redressed this situation in relation to hawthorn.

The management of hedgerows in relation to fruit (berry) production has been the subject of recent work by Sparks at CEH Monks Wood and Maudsley at IACR Long Ashton. Both studies note that unmanaged hedgerows are far more productive than managed ones, suggesting "an order of magnitude" difference (Sparks & Martin 1999, Croxton & Sparks 2002). From a comprehensive study, examining the effects of contrasting hedge management regimes on the associated flora and fauna of different hedgerows, Maudsley *et al.* (2000) showed that annual cutting (in either September or February) was shown to have significant negative impacts on the berry production of woody hedge plants. They also conclude that the growth of some species (e.g. buckthorn, *Rhamnus cathartica*) is negatively affected while some 'scrambling type' plants, such as bramble (*Rubus fruticosus*), responded positively to regular trimming in late winter.

In their guidelines for hedge management, Marshall *et al.* (2001a) say that there is no consistent evidence that timing of cut affects hedge size. However, hedge volume increases with time since last cut. Differences in growth are apparent between hedge types. There is evidence that hedge size continues to increase after 10+ years, but that the *rate* of increase declines.

In the same guidelines, and in Marshall *et al.* (2001b), the researchers conclude that for mixed species hedges, there are differences in the response to cutting between the different hedge shrub species. Hawthorn and dog rose re-grow strongly immediately after cutting, and appear to be tolerant of regular cutting, whereas other species such as spindle and buckthorn are positively responsive to being left uncut for longer (2+ years). Blackthorn grows extremely vigorously each year if left uncut, and may encroach on other hedgerow plant species and adjacent farmland. Scrambling hedge species such as bramble and black bryony decreased in abundance with time left uncut.

Hedges may be valued for the growing or mature trees within them (Hooper 1992). Hedgerow trees as a timber resource has been a significant issue for many years (e.g. Anon. 1955) and attempts have been made from time to time to record their number and state (e.g. see Peterken & Allison 1989 pages 40-43; Barr & Whittaker 1987). Most have been small sample surveys, carried out by various methods and the statistical significance of the results is suspect (Hooper 1992). Whether or not hedgerow trees are now of value as a timber resource may be doubted, but trees are undoubtedly of significant value as a landscape feature and for birds, bats and other animal groups. Little research is reported on the value of trees, nor on the best ways of managing hedgerows with trees in mind (e.g. optimal spacing of hedgerow trees, choice of species), but they do form part of the vegetative component of hedgerows and should not be omitted from research endeavours.

There has been an increasing interest in veteran (or ancient) trees during the past decade. This has been largely driven by the recognition that Britain has the largest and best array of extremely old trees in North-West Europe, and they form an irreplaceable gene pool of native stock, with valuable characteristics including growth forms and longevity. These trees also make a unique contribution to the quality of the landscape. Many species of insects, lichen, plants and fungi have co-evolved to be dependent upon ancient trees and the dead wood habitat within them, some of which are now rare and endangered. They also provide an important habitat for bats and several species of birds (including, for example, owls and tree sparrows). Within the existing agricultural landscape, veteran trees are most frequently found individually as markers along old boundary banks and occur in long-established hedgerows and riverbanks. They also occur in scattered groups in parkland and remnant pasture woodland. Interest has been generated and maintained through the activities of organisations such as The Ancient Tree Forum, The Tree Council, The Woodland Trust, and English Nature, and attention focussed on their value and vulnerability through the Veteran Trees Initiative. To date, little scientific research has been directed at this important habitat type although Kirby and Yeo (2000) suggest that more information is needed on their extent and on ways in which they might best be protected.

Diversity of woody species

The desirability or otherwise of a high diversity of species in a hedgerow is dependent on the use of the hedge and on the viewpoint of the user. For straightforward farming purpose a single-species, well managed hedge may be ideal as a stock-proof boundary, whereas for wildlife or landscape purposes, a species-rich hedge may be more welcome. It has been a generally accepted ecological principle that high species diversity is a 'good thing' in order to maintain a larger gene pool and allow natural processes to be buffered against man-made threats. From a wildlife conservation viewpoint, the desirability of a diverse flora may depend on the 'quality' of the constituent species.

As stated in the previous section, the species diversity of a hedge will be determined by its original composition and by any subsequent colonisation and extinctions (Cameron & Pannet 1980). The addition of species to a hedge after creation may also result from deliberate planting, especially of trees, and the original composition and colonisation (and hence diversity) will in turn depend on a complex of natural and human factors.

Lewis *et al.*, 1999 carried out a study of 211 hedges near Cardiff, South Wales. They found significant positive correlations between woody species diversity and taller, wider and longer hedges. They also found that parish boundaries had the highest number of woody species, then roads/tracks, with farm hedges being the poorest.

The role of hedgerow management in determining diversity of hedgerow woody species is not clear. In studies over many years, Hooper and colleagues (e.g. Hooper & Holdgate 1968; Hooper 1992) consistently found no relationship between hedge management and tree and shrub species diversity but, rather, that "*apart from the over-riding influence of a planter's personal preferences we can identify only two major factors affecting the diversity of a hedge: soil type and age*". Similarly, Cummins *et al.* (1992), in their analyses of plot data from all parts of Great Britain, could find no correlation between the management of the hedgerow itself and species diversity, either within or beneath the hedge.

However, studying hedges in the ESAs of Northern Ireland, Hegarty, McAdam and Cooper (1994) found strong links between a variety of management factors and species diversity - showing that hedge management and height had most influence on tree and shrub species diversity. They also observed that hedges cut by flail had significantly greater number of tree and shrub species, than hedges managed by any other method. Complete hedges (with less than 10% gaps) had significantly more species in the tree and shrub plots and boundary strip plots, than gappy hedges. Taller and wider hedges were associated with greater tree and shrub diversity and woodland species were positively correlated with hedge height.

Hegarty (1992) in a more extensive hedge survey in Northern Ireland found that the effects of hedge management and the associated hedge structure diversity were most strongly correlated with the number of tree and shrub species, with unmanaged, tall, wide hedges supporting the greatest number of tree and shrub species. In fact, the variable which was significantly the best predictor of the mean number of tree and shrub species was the percentage of gaps in the hedge, followed by hedge height. There is a need for research to assess the apparent discrepancies in the work done to date, and especially to examine the effects of temporal management cycles, regional differences in farming practices and the influence of other correlators (e.g. land use management).

Other studies of hedge diversity have been few, but Wilmot (1980) noted that, in one parish in Derbyshire, hedges next to roads had more hedge species than those between fields, and that while subsoil was related to the number of woody species, recent management was not.

Both Helps (1994) and those involved in a discussion session at the Wye Conference in 1992, have suggested that some variation in hedgerows is likely to occur automatically, as a result of differences in slope, aspect, accessibility which gives variation in hedge height and shape, as well as botanical variation in hedges and field margins. However, the relationship between geographical scale and hedge diversity (i.e. whether all the hedges on one farm, or in one parish, are managed in the same way) needs further research.

Hedge bottom flora

Species composition

Until recently, studies of the herb flora of hedgerows were relatively few (Boatman *et al.* 1994). Pollard (1973), Helliwell (1975) and Peterken and Game (1981) have studied the status and potential colonisation of woodland herbs in hedgerows and other regional studies have been conducted in, for example, Warwickshire (Cadbury, Hawkes & Readett 1971) and Wiltshire (Grose 1957). In a floristic analysis of animal habitats in rural Quebec, Jobin *et al.* (1996) found that the herbaceous layer of dominant species of hedgerows were similar to those in woodlands. The ideal management regime for ground flora has not been elucidated. In a discussion session of an ITE Monks Wood Symposium on Hedges and Hedgerow Trees (Hooper & Holdgate 1968), Dr Hooper was asked what was the best width and height for a hedge. He suggested that for plants a narrow, well managed hedge was "quite adequate". However, in their book, 'Landscape Ecology', Forman and Godron (1986) say that forest herbs are sensitive to hedgerow width - need wider hedges (but their study in the USA used balsam (*Impatiens* sp.) and avens (*Geum* sp.) and classified narrow hedges as being less than 8 m!). Similarly, in a study of the Swavesey fen grasslands, forbs typical of partial shade (e.g. ground ivy (*Glechoma hederacea)* and upright hedge-parsley (*Torilis japonica*)) were positively correlated with hedge dimensions. Tall herbs that were eliminated by cultivation or intense grazing survived, protected by the larger hedges e.g. hemlock (*Conium maculatum)* and common nettle. In contrast, species which were negatively correlated with hedge size were generally intolerant of woody shade (Mountford *et al.* 1994).

Dowdeswell (1987) has said that the most powerful factor affecting the survival and spread of different hedgerow species is the nature and extent of management. Where this is absent, taller plants are at an advantage. These include the taller grasses, such as couch, cock's-foot (*Dactylis glomerata*), Yorkshire fog (*Holcus lanatus*) and false oat-grass; large umbellifers (Apiaceae), like cow parsley (*Anthriscus sylvestris*) and hogweed (*Heracleum sphondylium*); and other strongly growing species, such as the meadow buttercup (*Ranunculus acris*). Frequent cutting, flailing or grazing encourages the finer-leaved grasses, notably common bent (*Agrostis capillaris*) and the fescues (*Festuca* spp.). It also favours rosette-forming species, like creeping buttercup (*Ranunculus repens*), greater plantain (*Plantago major*) and dandelion (*Taraxacum* spp.).

In studies of field margins, Boatman *et al.* (1994) referred to species whose occurrence was significantly affected by the type of adjacent hedge. Only creeping bent was significantly more frequent where no hedge was present. Cow parsley, cleavers, ivy, hogweed and common nettle were more common where hedges were present; and ground ivy was most common next to tall hedges (higher than two metres). Several species were more frequent where hedges were present, in comparison with boundaries containing only herbaceous vegetation. Ground ivy and ivy characteristically occur in shaded or partially shaded habitats, and do not persist in unshaded tall herb communities. Cleavers benefits from bare soil beneath hedges where it can germinate and establish free from competition, and from the hedge itself as a structural support.

As the forgoing suggests, and as Clements and Tofts (1992) have pointed out (in reference to studies in the USA which show a correlation between diversity and hedge width), no single structure is favoured by all species.

Other authors refer to the importance of the hedge shape: Moorhouse (1990), for example, notes that while A-shaped hedgerows are easily managed, shed snow and do not self-shade, they may shade out ground flora. Coppicing has a negative effect on shade-loving plants (Deane 1989).

Amongst the most intensive studies on the relationships between management and ground flora species composition are those undertaken in Northern Ireland by McAdam, Hegarty *et al.*, work at Long Ashton, the GB Countryside Survey 1990 (Cummins *et al.*) and work in France by Baudry, Burel and Le Coeur.

In Northern Ireland, Hegarty and Cooper (1994) found that a woodland flora characterised the species-rich hedges, whilst competitive grasses dominated the species-poor hedges. Hedge management in general did not seem to have a significant influence on the mean number of species found in hedgerow plots, but did affect the variation in abundance of plant species (Hegarty, McAdam & Cooper 1994). Unmanaged hedges contained significantly higher mean cover values of ground flora species such as sweet vernal-grass (*Anthoxanthum odoratum*) and the moss *Thuidium tamariscinum*. Managed hedgerows contained more competitive-ruderal species such as cleavers and common nettle. Coppiced hedges had the greatest number of ground flora species (agreeing with findings in McAdam, Bell & Henry 1992). Hedge width was the most significant predictor of the diversity of hedgerow ground flora, with total nitrogen content the next.

Hegarty's thesis (1992) gives much more detail of the species involved (including relationships with height, width and 'gappiness' of the hedge) but the overall conclusion of this work confirms that woodland species perform best in large, shade-giving hedges and aggressive, competitive species were found in more highly managed situations (where they were better suited to a harsher environment).

In a partial repeat survey (5%) of Professor Ronald Good's surveys of Dorset in 1931 and 1939, Button (2003) has shown that whilst species richness has remained similar, the number of 'Dorset notable' species declined from an average of 3 per stand to 1 per stand.

Resulting from recent experimental work, Marshall *et al* (2001a), in their guidelines for hedge management, state that hedge base habitats generally contained very high botanical diversity, higher than in the shrubby part of the hedge. However, no significant effects of hedge cutting on botanical diversity in the hedge base are apparent. At one site, hedge coppicing and laying both increased the species diversity of hedge base plants, presumably in response to ground disturbance and increased light levels. However, there were no differences between these treatments and control plots by the end of the experiment. Analysis of the composition of hedge-base floras at different sites shows that different hedgerows have distinct hedge-base plant communities. Differences appear to be largely determined by adjacent land-use. Arable hedgerows are less diverse than grassland ones, although uncropped field margins next to the hedgerow may increase botanical richness in the hedge base. In summary:

- Hedge base habitats can be botanically rich.
- Coppicing and laying can increase plant diversity in the short-term.
- Adjacent land-use and field operations are important in determining plant composition of hedge bases.

Le Coeur *et al.* (1997), working in Brittany, showed that local shrub and tree structure explained most of the variation in adjacent field margin ground flora but that adjacent land use was also important.

Jobin *et al.* (1997), examining the effects of agricultural practices in southern Quebec, found that the diversity and vegetation cover of the herbaceous layer of hedgerows and woodland edges were lower on sites at which herbicides had been sprayed in recent years, probably due to herbicide drift during application on adjacent fields. Herbicide use and tillage had an impact on the species composition of the cultivated fields: there was a higher proportion of annual and introduced species in cultivated fields subjected to herbicide use and tillage than in fields that were not regularly treated or tilled. The species that were found only in non-crop habitats were primarily native and perennials, few of which were weed species, whereas a high proportion of the species found only in cultivated fields were annual and introduced species, several of which were considered weeds.

By contrast, in their analysis of Countryside Survey data, Cummins *et al.* (1992) and French and Cummins (2000) found no statistical relationship between the occurrence of particular types of hedge-bottom species groups and management factors. However, the analyses used data from all of Great Britain and there is scope for a much more detailed examination of the data in relation to individual species and biogeographical zones.

Ground flora species diversity

Marshall and Smith (1987) gave a concise ecological perspective relating to the diversity of hedge bottom species:

- ground vegetation needs to be managed to interrupt succession to shrub and tree cover;
- diverse habitats tend not to exhibit dominance by one or two species at the expense of others (c.f. brome-dominated hedges)
- optimum growth conditions (i.e. few limiting factors and high fertility) favour dominance and low diversity
- bare ground is typically colonised by prolific seeding annuals.

Therefore we should accept that some form of regular maintenance is necessary to keep shrubs in check.

The question is what form of management will favour diversity. Perhaps due to the lack of research in former years, opinion is mixed. For example, Doubleday (1994) recommended that hedges *"should be kept reasonably short (about 2 m) in order to avoid impoverishing the ground flora by shading it out"*. In contrast to this, Hegarty (1992) in Northern Ireland noted that species-rich ground flora groups were significantly associated with the tallest and widest hedges and that the greater the structural diversity of a hedge, the more likely it was associated with a species-rich flora.

Dover and Sparks (2001) carried out a study of green lanes (un-metalled tracks with field boundaries on either side; boundaries can be grass banks, hedges, wood edge or stone walls) in Cheshire. Their studies have clearly shown that, for plants and butterflies, green lanes are superior to other field boundary habitats. The likely reasons include: the enhanced shelter and modified microclimate found in green lanes; their historical continuity; their lower agricultural inputs, compared with adjacent field boundaries; relatively low management regimes; and high structural diversity. These results show that priority should be given to maintaining and enhancing green lanes as part of any farm management plan.

Evidence from correlative studies

Other correlative studies also appear to be contradictory: in analysing Countryside Survey 1990 data. Cummins *et al.* (1992) found that management of the hedge had no significant effect on species diversity, either within or beneath the hedge. But Baudry (1988) and Burel and Baudry (1990) noted that the presence of forest species was related to hedgerow width in hedges in New Jersey and Hegarty (1992), in a survey in Northern Ireland, also found that the species diversity of ground flora plots was most strongly influenced by hedge width. In a survey of ESAs in Northern Ireland, Hegarty *et al.* (1994) found that, although hedge management in general did not seem to have a significant influence on the mean number of species found in hedge plots, coppiced hedges (cut with a circular saw) had the greatest number of ground flora species (agreeing with findings in McAdam, Bell & Henry 1992).

Other studies

Reporting early results of a long-term experiment looking at hedgerow restoration strategies (laying; pollarding; coppice, with same-species inter-planting; coppice, with different species inter-planting), Henry, Bell and McAdam (1994) found that all treatments showed increased numbers of plant species, when compared with the control treatment. Coppice treatments had the highest numbers of species, probably due to increased light levels.

Menneer (1994) reported some local, but intensive, observation studies in Cornish hedges. In a survey of the hedges along either side of a one-mile length of road , Carter (unpublished report) showed a 70% reduction in species diversity following use of a flail (twice a year - May/June and July/August) - from 188 spp in 1971 to 57 in 1989. Rare species were reported to have gone and the ratio of annuals/ biennials to perennials changed from about 15% to 100%. After flailing was reduced to a single annual cut, taking place later in the year, species started to return and by 1994 had increased to 103. Similarly, Murphy (1985) found a reduction from 163 plant species to 117 between 1971 and 1985 with finger-bar trimming.

Other observations include a small-scale study by Baudry (reported as *pers. comm.* to Forman and Godron 1986) which showed that the number of herbaceous species was more than twice as great on the sunny side of a hedge to those on the other. Mosses were restricted to the shady side. Most species on the sunny side were open field species, while those on the shady side were woodland species. Forman and Godron (1986) also noted that the inclusion of a fence in the hedgerow complex may attract birds and will increase botanical diversity. Similarly, herbs at the hedge-bottom are very much affected by the management of the hedgerow complex (i.e. including hedgebanks, verges and ditches) (Hooper 1992).

Recent work, reported in Marshall *et al.* (2001b), showed some success in establishing treatments to increase species diversity and reduce weed populations; these comprised cutting, selective herbicides, excluding fertilisers and re-seeding perennial vegetation. Results showed that highest botanical diversity is achieved through re-sown vegetation, especially in arable situations. Cleavers and barren brome in the hedge-bottom were most effectively reduced through the application of selective herbicides.

Conclusions

As the foregoing suggests, and as Clements and Tofts (1992) point out (in reference to studies in the USA which show a correlation between diversity and hedge width), no single structure is favoured by all species, leading to the conclusion that rich habitats support a diverse species assemblage. Hegarty's thesis (1992) suggests that low species diversity in hedgerows in Northern Ireland is associated with lowland well managed farms with fertile soils and that high species diversity is associated with the opposite situation. The diversity of the hedge-bottom flora is therefore likely to be associated with a host of factors, including environmental parameters, position in the landscape, active or passive management of the hedgerow and of the surrounding land.

The recent experimental work at IACR Long Ashton (Marshall *et al.* 2001a) was specifically commissioned by Defra to provide definitive answers to the debate over the effects of hedge management on wildlife. As stated above, they could find no lasting effects of hedge cutting, or other forms of hedge management, on the botanical diversity of the hedges they studied..

ADJACENT LAND USE AND FIELD MARGINS

Effects of hedgerows on adjacent land

It is not appropriate in this review of management and wildlife to detail the literature relating to the physical effects of hedgerows on crops and neighbouring land use. However, it is important to note that a farmer's decision on the management of a hedgerow, and the subsequent consequences for wildlife in the hedge, may result from his or her understanding of the effects the hedge is having on the land. There is a healthy literature on the effects of hedges on wind speed and shelter effects (e.g. Jensen 1954; Lewis 1966; Marshall 1967; Shepherd 1968; Pollard *et al.* 1974; Brandle & Hintz 1988; Bruckhaus & Buchner 1995; Sparkes *et al.* 1998) and some information on hedgerows as snow barriers (e.g. Naaim-Bouvet *et al.* 1998) but, as Hooper (1992) has said, further research is needed on the arrangement and pattern of hedgerows if the mechanisms and effects are to be properly understood.

The other main area of debate concerning effects of hedges on adjacent land, and one nearer to the interests of this Review, is whether hedges act as a refuge for agricultural weeds. Doubleday (1994) stated that *"hedges, particularly badly managed* [sic] *hedges, can act as a reservoir of weeds which can cause problems to arable crops"*. In his survey of lowland farms, Hooper (1992) found that about a third of farmers he interviewed in 1990 were worried by the possibility of invasion of weeds and other pests from the hedge. Such invasions may have significant cost implications. In an examination of the distribution, abundance, and economic importance of field bindweed (*Convolvulus arvensis*) and hedge bindweed (*Calystegia sepium*) in the continental USA, Boldt *et al.* (1998) have estimated that the value of crop losses due to field bindweed in the USA to be more than $377 million per year.

Research in this area has been limited but Deane (1989) noted that shrub species that grow fastest from the hedge are those that sucker readily, such as blackthorn and English elm. These may move out at a rate of one metre per year, where conditions suit. Rambling species such as dog rose, bramble, honeysuckle, black and white bryony and traveller's-joy will follow at varying speeds. The work of Marshall and colleagues (e.g. Marshall 1986; Marshall & Smith 1987; Marshall 1989) over several years suggests that only 25% of hedge bottom species also occurred in the field at 0.5 m from the hedge - i.e. very few species were invading the crop. In more recent work in Essex, Marshall and Arnold (1995) demonstrated that most perennial species of field margins are not adapted to successful establishment in field crops. They recommend that management of margins should encourage such perennial species, with an occasional cut to control woody plants. Carnegie and Davies (1993), reporting on a survey of 32 headlands and field boundaries in Scotland, found that about half of the 101 recorded plant species were found exclusively in the field boundary and no more than one metre into the crop. A further 35 species were recorded up to 5 m into the headland and 17 were confined to the headland. In very few sites was there evidence of significant spread of invasive species into the crop.

Further work on weed species invasion is being undertaken at the School of Plant Sciences at Reading University and has shown the positive effects of nitrogen fertiliser on the growth of barren brome (*Anisantha sterilis*) in field boundary vegetation (Theaker *et al.* 1995a) and described evidence for the origin of field infestations of the same species (Theaker 1995b). From the same study, Row *et al.* (1996) showed that both barren brome and cow parsley, although limited in their ability to disperse seeds, nevertheless may provide important sources of weed infestation. There is little doubt that the two main culprits are cleavers and barren brome, and methods for the control of weed species is discussed later in this section (see 'Adjacent Land Use and Field Margins': sub-section on 'Field margin management').

Interestingly, Boatman and Theaker (1993), in their work on restoring hedgerow ground flora, have suggested that while barren brome is a weed of the hedgerow and field margin, cleavers is self-sustaining in fields and, in fact, may invade hedgerows.

A recent study of field boundaries in Canada (Jobin *et al.* 2001) confirmed that weed abundance was lowest in natural woody hedgerows compared with planted windbreaks and herbaceous field margins. The authors concluded that natural hedgerow preservation would be an efficient conservation strategy, from both a wildlife and an agronomic perspective.

The extent to which the hedge-bottom is truly a reservoir of weeds has been questioned, and is frequently more a consequence of poor field margin management rather than the presence of a hedge *per se* (Hooper 1992). Where land abandonment occurs (rare in Britain), unmanaged hedgerows expand into fallow fields, being good sources of woody colonisers, and are progressively incorporated within the shrubby successional stages of older fields (Burel 1996).

Effects of adjacent land on hedgerows

Links with land use

Several studies (e.g. Pollard & Relton 1970; Burel & Baudry 1990) have emphasised that hedgerows should not be studied in isolation as there are clear interactions with surrounding land use (Clements & Tofts 1992).

In their study of Countryside Survey 1990 data, correlating vegetation plot data with surrounding land use data, Cummins and French (1994) show that both very intensive land management, and no management at all, are deleterious to the number of herbaceous species in hedge-bottoms.

The same authors are cautious about the use of these data and say that, due to the 'snapshot' nature of surveys, the effects of land use on diversity can only be inferred; direct cause/effect relationships cannot be determined. This is particularly so with the woody species and there are many possible explanations for the few differences that there are between land-uses.

For example, hedges with few woody species are more prevalent in arable landscapes than one would expect statistically, but this could be because only monotypic hedges are planted there, or the hedges are younger and have not yet been invaded by other species. However, hedges are long-lived and their composition of established woody species is unlikely to be related to factors which fluctuate on a relatively short time scale e.g. land-use changing from pasture to cereals. More substantial inferences were drawn about the effects of land-use on herbaceous species because a direct comparison could be made between the vegetation in the hedge-bottom and that of the adjacent land. The species associations in most hedge-bottoms resembled those of the adjacent land-use, rather than the woodland-type vegetation expected in an 'unaffected' hedgerow.

There is some evidence that the intensity of management of the hedge is related to that of the surrounding land i.e. farmers who manage land intensively may also manage their hedgerows intensively. Parish and Harris (1991), in reporting the Swavesey Project, support the idea that intensive hedgerow management goes with intensive land use management. Similarly, Hegarty and Cooper (1994) discuss regional differences in the composition, structure and management of hedges in Northern Ireland, with the relatively unmanaged hedges of County Fermanagh (which were associated with the greatest species diversity) being farmed less intensively than lowland areas where hedge management was more intensive. Burel (1996) reports the results of an intensive study of three sites (each c. 500 ha.) in Brittany, which indicate a strong link between agricultural practices, hedgerow composition and field size.

In the pastoral landscape of Britain, farm animals may have a detrimental effect on hedgerow flora. In a study of field boundaries on Anglesey (Partridge 1999) damage by sheep was identified as a major threat to hedgerows. Many guides on hedgerow establishment and management advise the use of fences to prevent access to the hedge by farm stock.

Effects of adjacent crop management

Since wildlife interest in hedges began, there has been interest in agricultural activities associated with neighbouring crops. Forman and Godron (1986) suggest that herbicides and insecticides drift into the hedgerow and "doubtless kill many insects and some plants and vertebrates". Fertilisers from fields are said to enter hedgerows and favour some species such as nitrogen loving plants (nitropholous) at the expense of others (Ellenberg 1939, 1978; Piggot & Taylor 1964; Tuxen 1967; Kopecky 1969; Braakhekke-Ilsink 1976; Ruthsatz & Haber 1981).

Marshall (1988) stated that disturbance factors, such as fertiliser contamination, spray drift, close cultivation, mulching and burning may all affect the flora. Close cultivation may also affect shrub root growth. However, in reporting results from the Boxworth Project, the same author (Marshall 1992) suggested that herbicide drift was of little significance on the boundary flora, although this may have been because the flora had already become modified as a result of previous management practices. Marshall then goes on to suggest that other factors, such as habitat structure and closeness of cultivation may have been more influential.

There is experimental evidence that hedges intercept pesticide spray drift (B. N. K. Davis, pers. comm., cited in Hooper 1992). Tsiouris & Marshall (1998) described how patterns of granular fertiliser deposition differed markedly between a pneumatic boom applicator and a spinning disk machine, both of which were tractor-mounted. The pneumatic applicator gave relatively even distribution across the boom width. A spinning disk gave more variable deposition and significant amounts were spread further than the expected 12 m overlapping pattern.

In work designed to assess the effects of hedges on spray deposition and on the biological impact of pesticide spray drift, Davis *et al.* (1994) showed how hedgerows are very effective at intercepting drift and create a shelter zone of up to 15 m in adjacent crops. However, in strong winds, protection afforded to sensitive species may be limited and severe damage may be inflicted over considerable distances. In similar, microcosm-based studies, Marrs and Frost (1997) found highly variable results in the performance of different species groups to spray drift. However, there was little effect more than 8 m away from the point of application.

In a 5-year experiment, Jones and Haggar (1997) studied the impact of nitrogen and organic manures on yield, botanical composition and herbage quality of two contrasting grassland field margins in Wales. The forb component of both ecosystems had been drastically reduced by the high N treatment, to less than half of their original level. The organic treatments on the other hand showed signs of developing species-rich communities, while at the same time providing a relatively high yielding and nutrient-rich field margin sward of high mineral content.

Longley *et al.* (1997) measured pesticide spray drift deposition into field boundaries and hedgerows in summer and showed that the incorporation of a conservation headland reduced deleterious effects on hedgerow flora and associated insects.

McAdam *et al.* (1994b), looking at field margin flora change in response to grassland management practices, found that grazing and fertiliser use significantly reduced species diversity of ground beetles and plants, relative to all other management treatments.

In his partial repeat of Good's survey of Dorset hedgerows, Button (2003) demonstrates a very significant increase in Ellenberg fertility scores for nitrogen, from 1931/9 to 2002. Button says that the likely factors responsible are changes in agricultural practice leading to increases in soil nutrients, as well as changes in highway, verge and hedge management.

Hald *et al.* (1994), in a study involving 26 experimental fields with paired permanent plots, sprayed and unsprayed, noted that after four years, seedling numbers, seedling species numbers and seeds were all higher in unsprayed plots. Also, hedgerows next to unsprayed plots had higher species diversity, usually occasioned by an increase in annuals. Net crop yields in the unsprayed plots were reduced by 9 to 18%. In a study of biodiversity surrounding a point source of nitrogen pollution in northern England, Kovar (1997) showed that hedgerows play an important role in the landscape in filtering acid pollutants, including N compounds. They also served as a captivity storage for N in this type of agricultural landscape. The biodiversity of the hedgerow herb layer showed a clear dependence on the distance from the N source. Hedgerow orientation and adjacent land use had a lesser effect.

Species movements

There is little in the literature about plants moving from the adjacent land into the hedge-bottom. Presumably this is not common because available niches are rare. However, Boatman and Theaker (1993) have suggested that cleavers is self-sustaining in fields and, in fact, may invade the hedgerows. Menneer (1994) considers that some species are in hedge-bottoms because of neighbouring land cover (e.g. heathland) and when these habitats are lost, then so are some species in the hedge (non-sustaining species) while others remain (self-sustaining) as a reservoir.

In Northern Ireland Bell, McAdam and Henry (1994b) have studied the effects of four treatments: (i) unmanaged; (ii) fertilised and rotationally grazed with sheep; (iii) a 2 m wide strip ploughed along the hedge-base and sown with a game cover crop, the remaining 8 m harvested for silage; and (iv) as for the previous treatment except that the ploughed strip is left unmanaged to permit colonisation by natural flora. The species diversity of the flora and fauna were monitored to determine which management option maximises the wildlife value of the field margin. Early results of this long-term trial indicated the detrimental effects of sheep grazing and fertilisation on the field margin flora.

Boatman *et al.* (1994) gave a useful summary of the effects of adjacent land on hedgerows: those hedgerows next to arable fields typically have a ground flora which is impoverished to a greater or lesser extent, largely due to the impact of agricultural operations in the adjacent field, and is often dominated by a few species of coarse herbs such as common nettle, false oat-grass, and hogweed. Co-dominant with such species are others which have the potential to become arable weeds e.g. the perennials rough meadow-grass, creeping thistle, couch, field bindweed and the annuals barren brome and cleavers. Farmers therefore often view hedgerows as a reservoir of weeds, and treat them accordingly, though they may unwittingly encourage the very species they are attempting to control. Conservationists, particularly botanists, often view the hedgerow ground flora with a similarly jaundiced eye; regarding the species present as common, widespread and not 'interesting'. Consequently, recent research has often been directed at attempts to replace existing vegetation with a species mixture considered more 'desirable', rather than at the management of the indigenous flora (Smith & MacDonald 1989; Marshall & Nowakowski 1991). Such an approach may provide benefits in terms of weed control, if only by widening the verge and providing an incentive to more careful management. The association between species characteristic of mown or grazed grassland and verge width probably indicates the presence of wide grass verges which are kept regularly mown, a policy deliberately adopted by a few arable farmers. The negative association between barren brome, cleavers and couch and verge width indicates that these species at least are kept in check by this practice. An alternative approach, controlling weed species by the use of selective herbicides which do not damage non-target species, gives good results in the short-term but its effectiveness in the longer-term (over periods of two years or longer) has yet to be fully tested. (Boatman 1989, 1992). There may be some scope for complimentary use of these two approaches (Marshall & Nowakowski 1991).

Field margin management

The perceived and real problems of agricultural weeds spreading from hedgerows into adjacent crops have been reviewed above and reference to work on possible solutions was made in the previous section.

Having showed that traditional spraying of field margins in an attempt to control weeds has proved largely unsuccessful (e.g. Boatman 1994), several research groups have examined the effects of introducing field margin management into normal agricultural practice. This approach was summarised by Cummins and French (1994): the effects of land-use can be ameliorated by introducing wide headlands which can then be subjected to different management regimes from the remainder of the land (e.g. Smith & MacDonald 1992). This practice would be particularly valuable in croplands where hedge-bottoms have a markedly poor flora. However, if a more diverse ground flora is to be re-established within, say, one metre of the hedge then the headland should be considerably wider than this so that the one metre strip itself is effectively buffered from land-use practices (Davis *et al.* 1990). Even then, the seed bank of herbaceous species may be so depleted in some arable areas that a non-weedy hedge-bottom flora may not develop without assistance e.g. by seeding with appropriate wild species.

Other studies have been reported by Boatman (e.g. 1992), Smith *et al.* (1993), Sparkes *et al.* (1994) and Kleijn *et al.* (1997). The whole subject area formed the theme for a conference of the British Crop Protection Council in 1994 and was fully reported in the BCPC Monograph No. 58, edited by Boatman. Work in hedgerows in Northern Ireland has included examination of field margins (e.g. Hegarty 1992), showing relationships between plant species and hedge characteristics and Marshall and colleagues (e.g. Marshall & Nowakowski 1994) have carried out research into the choice of wildflower and grass seeds for use in field margins. The Game Conservancy Trust (undated), in its guidelines for the management of field margins, notes that conservation headlands may provide a refuge for rare and declining plants.

RECOMMENDATIONS

In the course of this review, the author has noted several specific recommendations or ideas for further research.

Ideas for new research themes have included:

- **hedge management and shape** - Carter (1983) called for more basic research on different management methods and the value of these for wildlife in the long term. There is also a need to know the ideal hedge shape for different plant species.

- **colonisation** - Hooper (1994) asked a series of questions: Why are some hedges rich in tree and shrub species and others not? What is the mechanism of acquiring new species? If it is succession, are there associated soil changes, or is it the rate of death of originally planted shrub species that let new species in? And what controls which new species? Is that controlled by availability in neighbourhood and attractiveness of fruits to birds?

- **connectivity** - Burel and Baudry (1994) suggest that one might expect that new hedgerows connected with older ones will have a faster increase of species diversity, though, to our knowledge, this has not been demonstrated.

- **choice of species** - Boatman (1994) calls for research to give a greater understanding of the factors affecting botanical composition and, combined with research into the habitat requirements of beneficial or otherwise desirable animal taxa, should enable the development of management techniques to utilise this potential more effectively whilst minimising any adverse impact on agriculture.

- **'quality' and value** - as early as 1968, in a discussion session of the *Hedges and Hedgerow Trees* Symposium at Monks Wood, Boote suggested that the key problem was to translate wildlife, amenity and aesthetic values into values which could be appreciated by those who took the decisions.

  Similarly, Tofts and Clements (1994) in describing their HEGS system (a methodology for the evaluation and grading of hedgerows), make the point that there needs to be agreement amongst ecologists on evaluation. Hooper (1987) raises questions of conservation interest in relation to scale (e.g. what's rare in Norfolk might be common in England as a whole).

The literature is full of prescriptions for the 'correct' management of hedgerows and adjacent land. To what extent these prescriptions are based on the results of scientific research, keen observation, ecological theory or sound common sense, is unclear. In terms of recommendations for further research, it is perhaps sufficient to say here that any research results from further work should be compared with 'current thinking', as given in these many prescriptions.

INVERTEBRATES AND HEDGEROWS

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THE INVERTEBRATE FAUNA OF HEDGEROWS

Most British invertebrates are of woodland origin and many find hedgerows a good substitute for woodland edges. However, hedges are a comparatively young vegetation form and no strictly 'hedgerow' species of invertebrates have yet developed. Despite this, hedgerows contribute greatly to invertebrate biodiversity in intensively managed farmland.

As a linear habitat, hedges have a large surface : volume ratio and this results in a high leaf surface index, two to three times higher than in woodland. Foliage consumption in hedges has been shown to be much higher than that in woodland, and in some cases it falls within the range measured in farmland and grassland ecosystems (Zwolfer & Stechmann 1989).

Biomass production in the hedgerow starts in the spring with the sprouting of new shoots and opening of flowers. Many hedgerow shrubs come into leaf early in the year, well before most forest trees. This early growth, combined with early flowering, provides a valuable food source for insects in spring. Feeding and associated growth in the populations of phytophagous (plant eating) insects takes place in early summer, followed by an increase in entomophagous (insect eating) insects from mid-summer. Late summer and autumn fruit production has less importance for invertebrates than for mammals and birds. The major periods of hedgerow productivity ensure an additional food supply for the invertebrate fauna before and after the main production period of the surrounding open farmland. Hedgerows, therefore, contribute to the continuity of biological production processes in farmed landscapes (Zwolfer & Stechmann 1989).

The number of invertebrates which feed on a particular shrub or tree is related to the length of time it has been part of the native flora. For example, Brooks (1980) has reported that oak (*Quercus* sp.), hawthorn (*Crataegus* sp.), elm (*Ulmus* sp.) and ash (*Fraxinus excelsior*), all native species that are common components of British hedges, are associated with 284, 149, 82 and 41 insect species respectively. According to Kennedy and Southwood (1984), hawthorn has over 200 insect or arachnid species associated with it. Recent introductions, in comparison, tend to have low numbers of invertebrate species associated with them, although they report that holly (*Ilex aquifolium*) may have as few as ten species associated with it. Hedgerows, in general, are known to support a tremendous diversity of invertebrates; with over 1,500 insect species having been recorded at some time, living or feeding in hedgerows (Anon. 1995).

Hedgerows contribute more to the wildlife of the general countryside than would an equivalent extent of woodland (Kirby 1995). Their value is recognised by the Habitat Action Plans being produced by each county for Ancient/Species Rich Hedgerows. For example the Worcestershire Biodiversity Action Plan lists stag beetle (*Lucanus cervus*), brown hairstreak butterfly (*Thecla betulae*), orange-tailed clearwing moth (*Synanthedon anthraciniformis*), a jewel beetle (*Agrilus sinuatus*), and a flea beetle (*Altica brevicollis*) as being invertebrate species of particular conservation interest associated with this habitat within the county.

Molluscs

The age of a hedgerow also has an important bearing on the number of invertebrate species present. A study of the snail fauna in 'relic hedgerows' of known age, in three English counties, found a correlation between the number of snail species and the age of the hedgerow. 20th century hedgerows had 1.4 to 2.0 snail species; 16th to 19th century hedgerows 5.4 to 6.8 species; and 11th to 16th century hedgerows 7.0 to 9.9 species (Cameron *et al.* 1980).

In another study, 21 species of land molluscs were recorded in nine diverse habitats in St. Ives, Cornwall. Of these 16 were present in hedgerows, two more than in woodland and scrub combined, indicating the diversity of the hedgerow habitat (Menneer 1994). For groups with limited dispersal, such as snails, connection to a source habitat has a positive correlation with species diversity (Maudsley 2000). As well as vegetation structure and plant species diversity, distribution of fauna has also been correlated with plant species composition and, particularly for snails, hedgerow origin (Pollard *et al.* 1974, cited in Forman & Baudry 1984).

Spiders

Maudsley *et al.* (2002) sampled spiders in hedge bases and foliage and found no significant relationship between spider abundance and hedge density or width. Although the hedge bases generally supported a greater range and diversity of invertebrates than the hedge shrubs, many spiders were found in these shrubs. Shelter from wind may also influence the abundance of spiders in hedge foliage and may be determined by hedge orientation or vegetation density. Ysnel and Canard (2000) investigated the relationship between structure of spider communities and an index of hedge ecological quality. They found that species richness and composition of dominant spider species were the same for hedges of different quality. They also found that foliage orientation may be another factor, and should be taken into account when comparing spider communities inhabiting hedges.

Insects

Summer insect diversity in a hedgerow was shown, by Forman and Baudry (1984), to be higher than in an adjacent bean field and pasture, though the density was highest in the pasture. The most abundant orders present were (starting with the most abundant): Hymenoptera (wasps, ants and bees), Diptera (flies), Hemiptera (bugs), Coleoptera (beetles), and Thysanoptera (thrips).

Another study investigated the distribution of flying insects in an organic rye field, an adjacent hedgerow and a woodland edge. The largest number of taxa (123) was found alongside the hedgerow, compared to 118 at the woodland edge and 94 in the centre of the field (Hradetzky & Kromp 1997). Thomas and Marshall (1999) found that carabid diversity was lowest in the crop, low in crop edges and highest in the hedge at their study site.

Springtails (Collembola)

Alvarez *et al.* (1997a) showed that epigeic springtail (Collembola) population dynamics within arable fields were greatly affected by the proximity of a hedgerow. Where a hedgerow was present, more species and a greater overall abundance were recorded near field edges in crops of spring sown barley or vining peas. Alvarez *et al.* (2000) carried out a similar study looking at recolonisation by Collembola. They found that the abundance of some species of springtail in the field was reduced by hedgerow barriers which shows that hedgerows could be important source habitats for colonisation or recolonisation of arable fields.

Bumblebees (Hymenoptera: Apoidea)

Croxton *et al.* (2002) investigated the vegetation communities within 15 green lane sites and in adjacent field margins. Species richness was found to be significantly higher in the green lanes. Bee numbers were also found to be significantly higher within the green lane habitat than they were on the other side of the hedges, adjacent to the field margins – this difference was related directly to the abundance of flowers within the habitat.

True bugs (Hemiptera: Heteroptera)

Species such as hawthorn shieldbugs, lacebugs, common barkbugs, forest bugs and common green capsids are commonly found on hawthorn and oak hedges. Much of the research on these insects has been on distribution in relation to hedge diversity. Maudsley *et al.* (1997) and Marshall *et al.* (2001a) looked at different hedge types in England and Wales, and found that a mixed hazel hedge in Wales was most species-rich in Heteroptera, and that there was a positive relationship between the number of plant species at each site and the number of Heteroptera species. The arable sites had fairly low species diversity for both plants and Heteroptera, which may have been due to the effects of intensive agriculture on hedgerow biodiversity. Species richness of this group was dependent on floristic diversity of the hedge, and both the hedge and hedge-bottom were found to be important in determining composition of Heteropteran communities. Some species of Heteroptera found in hedgerows are restricted to specific host plants, but most are generalists. Many are highly mobile and Maudsley (2000) found that Heteroptera were less affected by lack of physical connections with source habitats compared to less mobile species groups. Moreby and Southway (2001) investigated invertebrates, including Heteroptera, in hedges and arable fields surrounding them and found that for some Heteroptera, the hedge boundary contained the greatest species diversity.

The majority of studies on the invertebrate populations of hedgerows have concentrated on beetles (particularly the ground beetles; family Carabidae) and butterflies.

Ground beetles (Coleoptera: Carabidae)

Beetles of the family Carabidae in hedgerows are considered to be primarily woodland species. The main reason for the concentration of research on this family is probably their role as important predators of crop pests such as aphids. Pollard

(1968d) compared the carabids of an arable field and a neighbouring hedgerow with those of a woodland glade. His results indicated that hedgerows provided a habitat for species that are restricted to dense cover, or those requiring shelter when crop cover is incomplete or absent. Different carabid species have been shown to have different habitat preferences. Maudsley *et al.* (2002) found that although carabids were mainly found in litter and the upper part of the soil profile, their distribution and species composition was also influenced by soil water content and monocotyledon material, possibly due to overwintering site selection. They found that there was a differentiation between vertical layers as well as a horizontal differentiation. In their study of carabid communities in woodlands and woody linear features, Petit and Usher (1998) found that communities found in woods and hedgerows displayed the same species diversity and were both characterised by the presence of forest species. They found that the main factors constraining carabid communities were grazing intensity and soil type.

The effect of field boundaries on carabid distribution has also been studied. Holland *et al.* (2001) found that the greatest carabid diversity was located around field boundaries (where boundaries comprised of a hedge with a herbaceous/grass bank). These boundaries were used for over-wintering and provide a different habitat from the crop and better foraging resources.

From a landscape context, a study in western France found a significant relationship between landscape structure and carabid communities. Forest-dwelling species were found to be more abundant in dense hedgerow networks surrounded by permanent grasslands. Where the landscape was more open, small and mobile species were more abundant (de la Pena *et al.* 2003). Petit and Burel (1998) studied the effect of landscape history on populations of a carabid beetle (*Abax parallelepipedus*) in a hedgerow network. They found that distribution was related to connectivity of the landscape, but that there may be a time lag between changes in the landscape and reaction to these changes.

Butterflies and moths

Butterflies are considered to be of importance not only because of their aesthetic appeal, but because they can act as indicators of the quality of farmland habitat. There are 54 species of butterfly found in lowland Britain, 23 of these breed in hedgerows, 15 commonly.

Of the 31 British butterflies which are originally woodland species, 15 breed in hedgerows. This is true of only seven of the 22 ‘open country’ species. The one species originating in shrub vegetation also breeds in hedgerows. Hedgerows support more species of butterfly than habitats such as unimproved permanent pasture and unimproved tall grassland (Thomas 1984, cited in Dover & Sparks 2000), so are an important habitat for butterflies.

Hedgerows are of recognised importance for a number of butterfly species including the brimstone (*Gonepteryx rhamni*), which feeds on buckthorn (*Rhamnus cathartica*); the black hairstreak (*Satyrium pruni*) and brown hairstreak, which are dependent on blackthorn; the white-letter hairstreak (*Satyrium w-album*), on elm (*Ulmus* spp.); and the orange-tip (*Anthocharis cardamines*) and green-veined white (*Pieris napi*), on crucifers in the hedge bottom. The brown hairstreak seems to be confined to hedgerows (Dowdeswell 1987).

The commonest butterfly colonists of hedgerows are found in the family Satyridae (the ‘browns’), whose larvae feed on a range of common grasses. The distribution of different species in this family indicate the importance of all of the component parts of the hedgerow habitat. Most closely associated with the shrub layer is the hedge brown or gatekeeper (*Pyronia tithonus*). The grassland immediately adjoining the hedge is occupied by the ringlet (*Aphantopus hyperantus*). The meadow brown (*Maniola jurtina*) is an insect of open grassland, whose main requirement is that the grasses on which its larvae feed should remain undisturbed throughout the year. Formerly, its distribution in well established fields was widespread, but with a change in agricultural practice towards more short-term leys it has been forced onto the strip of uncultivated land between the hedge and crop. The speckled wood (*Pararge aegeria*) is also found along hedgerows (Dowdeswell 1987).

Of the smaller British Lepidoptera 53 species are listed as having hawthorn as a food-plant. Twelve are solely dependent on it, five being general leaf feeders, five leaf miners and two berry eaters (Elton 1966).

Studies by Menneer (1994), in Cornwall, have indicated that fourteen species of butterfly are able to sustain their populations totally within the hedgerow habitat - one third of the total number of Cornish species. Approximately twelve other species are said to regularly visit hedges. About 150 of the larger moth species are usually self-sustaining in association with Cornish hedges (Menneer 1994).

The abundance and distribution of butterflies in hedgerows can be related to a number of factors. Geographic location, habitat quality, adjacent land use, environmental conditions and management, as well as shelter, insolation, nectar plant quality and plant species richness are important factors (Dover 1996). Dover (1999) found that (although differences were not significant), short hedges held more butterfly species than grass banks and similarly, Dover (1996) found that fewer butterflies were associated with grass banks and farm tracks adjacent to field boundaries where there was no shelter. Butterflies were more common at intersections of hedges and woodland where there was more a more stable microclimate (in terms of shelter, elevated temperature and humidity).

Studies on the effect of shelter in open countryside have shown that the protection provided by hedgerows, and in particular green lanes, is sought by butterfly populations (Dover *et al.* 1997). Sparks *et al.* (1999) also found that most species were most abundant in green lanes compared to grass verges and hedged verges. They also found individual species differences, with species such as speckled wood which are normally found in woodland being associated with lanes with a low width:height ratio (due to the shading effect). In Norfolk, Sparks and Anderson (1999) found that a double hedged green lane supported a high density of butterflies such as meadow brown, ringlet and small veined whites, compared to other parts of the lane. They also found that as wind speed increased, the green lane became a more valuable habitat, particularly for the ringlet butterfly. Dover *et al.* (2000) also found that green lanes had higher butterfly abundance and diversity, and the interiors were particularly important because of lower levels of disturbance, reduced pesticide and fertiliser inputs and rich source of nectar.

Some species, particularly those with stronger flight abilities such as the large white (*Pieris brassicae*), brimstone and small tortoiseshell (*Aglais urticae*) are less constrained by lack of shelter (Dover 1996).

Ouin and Burel (2002) investigated whether butterfly diversity was influenced by landscape heterogeneity (in western France). They found that landscapes with different quantities and qualities of various herbaceous elements did not support the same butterfly communities. Compared to grasslands, linear herbaceous elements provided higher butterfly diversity.

THE VALUE OF HEDGEROWS FOR INVERTEBRATES IN DIFFERENT AGRICULTURAL LANDSCAPES

Ancient and Planned Countryside

Lowland Britain can be divided into two principal landscape types (Rackham 1986): the 'Planned countryside', forming a triangle from the East Riding of Yorkshire to the northern half of East Anglia and across the Midlands to Dorset, and the 'Ancient countryside' comprising the remainder of the lowland area. Planned countryside contains more straight, species-poor, Enclosure Act hedges than Ancient countryside, whose hedges are generally older, richer in species and more sinuous (Clements & Tofts 1992).

A good example of field boundaries in the Ancient ('unplanned') landscape is the 'Cornish hedge', as described by Menneer (1994). These are often 2500-5000 years old, older than hedges in most other parts of Britain. They differ from the more typical thorn hedges in being stone-faced with a subsoil core with, or without, woody vegetation on the top. In plant distribution the Cornish hedge often resembles a vertical flower meadow; in contrast to the thorn hedge, which is nearer to linear woodland. Hedges in many parts of Devon and south-west Wales are similar in form to Cornish hedges. This type of hedge provides suitable habitats for a greater range of invertebrates than planned countryside hedges.

In exposed conditions, such as those prevailing across much of Cornwall, hedgerows provide effective shelter for many invertebrate species, particularly flying insects. Of particular importance are the many 'green lanes' which may be too narrow for road traffic and, where not overgrown, provide a particularly sheltered environment for invertebrates (Menneer 1994).

One illustration of the recognised value of hedgerows to wildlife in the Ancient countryside is the listing of all of the 4,000 km of hedgerows present in the Dartmoor Natural Area as key habitats in that area's Biodiversity Profile (Anon. 1997b).

There has been no recent regional study of hedgerows, equivalent to that carried out in Cornwall by Menneer, within the Planned countryside. However, some comparable data may be obtained from local studies on the impacts of development schemes on the wildlife of hedgerows in the vicinity (e.g. Williams 1996) and from local biodiversity studies.

The parish of Shapwick in Somerset has been the subject of a long term historical and archaeological study which has shown that Shapwick has a range of hedgerows of different ages, from ancient through to enclosure. A recent study of the invertebrate fauna (Clements & Alexander 2004) has shown positive correlations between both the presence of Ancient Woodland Indicator Species and total numbers of saproxylic invertebrates and hedgerow age as evinced by historical evidence. It was concluded that old hedgerows are an important habitat resource for these fauna, and can support good numbers of nationally and regionally scarce and local species.

The role of hedgerows in invertebrate dispersal - corridors and networks

Wildlife corridors

Hedgerows can act as corridors for the movement of populations and so increase the connectivity of different parts of the farmed landscape. Joyce *et al.* (1999) found that *Nebria brevicollis* (a carabid beetle) showed higher activity at hedgerow intersections and that gaps in the hedgerow and the hedge-bottom were readily crossed. There was also movement along the hedgerow, indicating it was used as a corridor. Work by Dover (1990) suggested that 98% of butterfly movements were along field boundaries as opposed to across crops indicating their importance in agricultural landscapes as corridors for movement between habitats. Long distance recaptures of released carabid beetles along a hedgerow and field margin suggested a corridor effect for these structures in a study by Thomas *et al.* (1997). The loss of landscape features, such as hedgerows reduces migration and dispersal possibilities for the majority of animal species, thereby decreasing biodiversity.

A study by Burel and Baudry (1990), looked at hedgerow networks (in Brittany) as habitats for forest invertebrate species and the implications for the colonisation of abandoned land. It concluded that hedgerows can be relatively good reservoirs of forest species in agricultural landscapes and that their presence will increase the rate of colonisation of abandoned land. However, this process may still take an extremely long time in the case of animals with low rates of dispersal.

The control of biodiversity in hedgerow networks was examined in a review by Burel and Baudry (1992). Landscape variables such as distance from woodland and 'connectedness' between favourable habitats were found to control the spatial distribution of forest carabid species. The most favourable conditions for the migration of forest carabids were the presence of two parallel hedges bordering a lane or, for a single hedgerow, a dense herbaceous layer and the presence of tree cover. Some species formed small localised populations in hedgerow network nodes, such as lane intersections or small areas of woodland attached to hedgerows. These hedgerows were then used for dispersal. Connectivity between small wooded habitats was shown to be necessary in order for populations to be maintained at the landscape level, as individuals dispersed from local populations using only hedgerows. Where progressive removal of hedgerows occurred, this led to a decline in the abundance of forest carabids. For a time the carabid assemblages in remaining hedgerows are a 'memory' of those in the previous landscape until, eventually, the isolated population becomes extinct.

The conclusions of this study emphasised that individual hedgerows cannot be considered in isolation and that where hedgerow removal or planting takes place a network should be maintained.

Further studies (Charrier *et al.* 1997) confirmed the influence of hedgerow 'quality' in determining the efficiency of linear woody elements as dispersal corridors for forest carabid species. They concluded that the value of lanes bordered by two hedgerows was as high as that of woodland, and suggested that such lanes should be preserved to ensure connectivity migration between local carabid beetle populations.

Hedgerows as semi-permeable barriers

Hedgerows may not function only as corridors, but also negatively as semi-permeable barriers in the landscape. However, the consequences of this barrier effect on species conservation are poorly understood. Field margins may significantly reduce the dispersal of carabid beetles between fields and increase the isolation of butterfly populations. Recent work (M Maudsley, *pers. comm.*) studying the activity of the carabid beetle *Pterostichus melanarius* showed that a hedgerow acted as a significant barrier to dispersal between fields. 20% of recaptures were of beetles released in opposite halves of the same field whereas only 5.75% of recaptures were from releases on opposite sides of a hedgerow.

Another study, carried out by Fry and Robson (1994) in southern Norway, indicated that hedgerows can have a negative role in the dispersal of butterflies - as margins of tall vegetation formed barriers to butterfly movement. Their observations showed that butterflies often fly parallel to a hedge and then cross when they reach a gap. It was concluded that this barrier effect reduces dispersal, increasing the isolation of fragmented populations. However, the authors suggested that this effect could be used in a positive way, with a combination of extended field margins and tall hedges being employed to direct butterfly movements over agricultural land, for example between patches of uncultivated meadow (Fry & Robson 1994). It may be necessary to provide functional gaps in hedgerow networks to allow the dispersal of certain species. However, such gaps may be insurmountable obstacles for other species using hedgerows as corridors, and so a conflict of interest arises. This may be resolved through an improved understanding of the needs of different groups of species (Fry 1994).

Conservation headlands were shown by Dover (1997) to slow down butterfly movement along hedges and make hedgerows less effective corridors by providing distracting resources. This issue is however inconclusive and more detailed research is required.

THE IMPACT OF HEDGEROW MANAGEMENT ON INVERTEBRATES

As well as providing a valuable source of food, the hedgerow habitat is attractive to invertebrates because it can provide:

a) suitable microclimates;
b) a framework for landing, mating or attachment (e.g. spiders webs or pupal cases), and
c) protection from predators, extremes of climate, or harmful agricultural operations (Zwolfer & Stechmann 1989).

The management of hedgerows largely controls the various parameters of hedgerow 'structure' (e.g. width, height, and vegetation density and stratification), and determines to a large extent, how valuable hedgerows are to invertebrates.

Effects of hedge cutting

The high variability in insect distributions (compared to plants) in hedgerows makes it more difficult to detect management effects. However, several studies have investigated possible effects. Sotherton *et al.* (1981) undertook a study of the arthropod fauna of nine Hampshire hedgerows, in three management categories. Supporting data from similar hedgerows in Northumberland were also reported with the results of Sotherton's study. The hedgerow management categories were:

- uncut (not cut for more than five years, but still stock-proof)
- cut (cut about eight months prior to sampling) and
- 'remnant' (individual bushes and trees).

Significantly more suckers (Psyllidae), Lepidopterous larvae, shield bugs (Pentatomidae) and leaf beetles (Chrysomelidae), and consequently more herbivores as a group, were present on remnant hedges than other types. No significant differences were found between numbers of carnivorous insects, as a group, between hedge types - but there were significantly more flower bugs (Anthocoridae) and harvestmen (Opiliones) on remnant hedges than on cut hedges. There were no significant differences between the numbers of saprophagous insects (i.e. those feeding on decaying matter) occurring on each hedge type. The total number of taxa recorded was greatest on the cut hedges, indicating that the effects of hedgerow management through regular cutting is not necessarily detrimental to invertebrate diversity. The authors hypothesise that it may be the timing and intensity of management, coupled with the mobility and re-colonising ability of a particular herbivorous species, that will determine numbers of that species on hedges clipped within the previous twelve months (Sotherton *et al.* 1981).

A number of studies (Marshall *et al.* 2001a, b and c and Maudsley *et al.* 2000) have investigated the effect on invertebrates of different timings and frequencies of hedgerow cutting. Hedges were cut in February or September on annual, biennial or triennial cycles and the effects on invertebrates, berry production and hedge-bottom flora were assessed. Cutting hedges at less frequent intervals had positive effects on vegetation, berry abundance and habitat quality for birds and mammals. In terms of frequency and timing of cutting, invertebrates showed mixed responses. A number of groups were more abundant on uncut sections (e.g. psyllids), certain groups were enhanced by trimming (e.g. Collembola, Thysanoptera) and for some taxa, cutting in February was detrimental. For example, plots cut in February supported lower numbers of Lepidoptera larvae (and Diptera, though not to the same extent) than those cut in September. Cutting late in winter will result in the removal of insect eggs laid during the autumn. Although later winter cutting was not good for invertebrates, it was more beneficial for birds and small mammals (due to the provision of berries). A relaxation in cutting would benefit vegetation structure, composition and berry abundance on hedgerows, but frequent cutting may be beneficial to invertebrates and regular management was not necessarily detrimental to all wildlife. Annual cutting could result in increased invertebrate diversity due to stimulation of new growth and therefore increased food resource for herbivorous insects. The most desirable strategy would therefore seem to be, on the basis of this research, to cut hedges at different times, in a farm-scale rotation.

Most hedges are trimmed annually, using a flail (Hooper 1992; Britt *et al.* 2000), usually in late summer or autumn. However, some hedges, particularly those beside public roads, may be trimmed more than once a year. The adverse effects of such practices on the invertebrate fauna have been recorded in a long-term (34 years), large scale observation by Menneer (1994) in Cornwall. A ten year period in which Cornish hedges were flailed twice every summer (May/June and July/August) saw a reduction in butterfly species present, from 24 to three, and in moth species, from 68 to 19. Later, after a three year period of reduced intensity trimming, Menneer reported the return of 14 of the previously recorded butterfly species, and a slight increase in the number of moth species present.

The brown hairstreak butterfly, in particular, has been severely affected by modern methods of hedge cutting. Oviposition of this species takes place on farmland hedgerows, on any unshaded *Prunus* bush - the majority of eggs being placed on projecting young stems, where they remain from late summer until May. The brown hairstreak was locally distributed in the past, when hedges were cut by hand. However, with the advent of mechanical hedge trimming, and the consequent increased intensity and frequency of cutting, the brown hairstreak is now a rare species, absent from all unwooded southern regions of Britain where hedge trimming is intensive (Thomas 1991).

The shape to which a hedge is cut may also have a bearing on the invertebrate fauna within the hedgerow habitat, although the preferred shape appears to be a matter for debate. Most hedges are rectangular, but Maclean (1992) has argued that maintaining a flat top on a hedge results in the accumulation of trimmings below the hedge, and the formation of a mulch which is generally detrimental to wildlife. For this reason, Maclean preferred either an A-shaped hedge (which may also have the advantage of a wider base), or a rectangular hedge with a 'chamfered' top. Maudsley *et al.* (2002) found that staphylinids benefited from a wider hedge-base, possibly because it would provide a less-disturbed habitat. However, Deane (1989) and others have argued that an A-shaped hedge may be detrimental to insects.

Taller hedges, providing a greater degree of shelter, are frequently said to be beneficial to hedgerow invertebrates, but most research has been mainly concerned with subsequent effects on the distribution of crop pests and beneficial insects in adjacent crops (Lewis 1969; Bowden & Dean 1977). However, Sparks *et al.* (1994), showed a positive correlation between hedge height and butterfly species richness. Fewer butterfly species were present in transects containing no hedges, or hedges less than two metres tall, compared with transects with hedges taller than two metres.

Results from research elsewhere, however, suggest that hedge height may be less important than hedge density in determining the local distribution of butterflies; and that the effect of shelter, as well as other measures of habitat quality, are important for butterflies (Dover *et al.* 1997). Butterfly numbers were recorded in 1995 and 1996 on hedges managed in three ways; uncut, laid and coppiced. Unlike other studies (such as Sparks and Parish 1995), significantly fewer butterflies were recorded along the uncut hedges than in the other treatments. This may have been because the hedges were young. Uncut plots have sparse ground flora and these as well as the base of the hedge were grazed, leaving little protection from the elements (Sparks *et al.* 1996).

There seems to be a consensus in the literature that only a small proportion of the total length of a hedgerow should be actively managed in any single year. Management options suggested include managing a maximum of one third of the total length of any hedgerows on a farm in a single year. However, no scientific data to illustrate the value of such a management regime at farm scale (or larger) has been found.

Some conclusions on desirable hedgerow management were reached in an unpublished report, by the Institute of Terrestrial Ecology, for the Department of the Environment (Hooper 1992). Hedgerows were also classified by Hooper into types on the basis of management. The desirability of each type was listed. The most desirable was an unmanaged hedgerow up to four metres high and four metres wide, with a considerable growth of bramble at the sides, but this was recognised as being unacceptable to farmers! The classic 'well managed hedge', up to 2 m high, but often only 1.5 m high or wide, and 'A' or box-shaped was listed as the most acceptable to farmers, but was thought to be less beneficial to wildlife. A hedgerow up to four metres high and two metres wide, with only its sides trimmed, was suggested as a possible compromise.

Effects of hedgerow restoration, replanting and protection

Other commonly encountered methods of hedgerow management include restoration, replanting and protection from grazing animals. Petit and Burel (1998) discussed the results of a study which showed that populations of forest species may survive in hedgerow networks for some decades after landscape changes have taken place. This time lag may provide a period in which restoration of connectivity using these methods can take place, allowing species distribution.

A study in Northern Ireland, by Henry *et al.* (1992), investigated the effects of a range of restoration techniques on the micro-fauna of overgrown and unmanaged hawthorn-dominated hedges. Untreated sections of hedge were compared with sections which were either laid, cut to a height of 1.5 m, or coppiced (with gaps being planted). In the early stages of the experiment, unmanaged hedgerow sections had fewer invertebrate Orders present than any of the other three treatments, although only the laid treatment had significantly more. The authors suggested that hedge laying had immediately created a dense structure suitable for a wide range of invertebrates, but that this may be the case for a relatively short time. In later stages of hedge development, the coppiced treatments are likely to become a more suitable habitat for more insect groups.

Marshall *et al.* (2001a and c) found that restoration of hedges involving an increase in plant diversity (gapping-up with new shrub species or hedge base restoration) had a positive knock-on effect on invertebrate diversity. Layed hedges provided a greater diversity of herbaceous plant species in the verge, and provided large insect populations early summer (after the initial year). This could provide more abundant resources for insectivorous bird species so this practice is particularly important for enhancing insect numbers and diversity. Maudsley *et al.* (2000) also found that Hymenoptera and Diptera were more abundant in layed plots than in cut plots at some sites. Coppicing on the other hand was found by Marshall *et al.* (2001a) to be detrimental to invertebrates, at least for the first year.

The protection of existing hedgerows from damage by, for instance, livestock can improve its suitability as a habitat for invertebrates. For example, wire fencing is stated to be an important factor in the preservation of the wildlife and structure of Cornish hedges (Menneer 1994). The presence of wire fencing discourages livestock from damaging the face of the hedge or the hedge-bottom, and also ensures that the flail does not cut too closely.

The replanting of hedgerows can affect their suitability for invertebrates. As mentioned previously, the species of plants used can greatly affect the number of invertebrate species supported by a hedgerow. Plant species characteristic of the local area should be preferred. Concern has been expressed at the use of planting material which does not originate from local sources (e.g. Jones 1994), and further work in Wales (IGER 2000) has shown significant differential invertebrate herbivory between individual hawthorn provenances. Their findings reinforce the possibility of further unknown 'knock-on' consequences for indigenous wildlife of planting alien material.

In many parts of Devon, Cornwall and Wales hedgebanks are stone-faced with a topsoil core. Some local authorities (e.g. Dyfed County Council) may request that wall builders, when reinstating walls, re-use all soil saved from the former wall to ensure that some of the invertebrate population is transferred (Maclean 1992).

Effects of hedge-bottom management

A number of insect groups are known to make use of hedge-bottom vegetation, in at least part of their life-cycle, and to benefit from a well developed ground flora (Boatman *et al.* 1992). It has been established that most overwintering by insect adults and larvae occurs in the hedge-bottom, including groups found in the hedge shrub layer during the summer.

Hedge-bottoms may be subject to a variety of forms of management - depending on adjacent land use, the traditions of the area and the perceptions of the individual farmer. These can range from no management (in neglected hedgerows) or an occasional trim at the same time as the hedge is cut, to deliberate annual applications of herbicides. Boatman *et al.* (1992) report that surveys of farmers at agricultural shows have shown that a large proportion (around 60%) of farmers use herbicides in their field boundaries. No further details of the extent of these surveys, or explanation of the type and degree of herbicide usage, was given in this reference. A more recent survey (Britt *et al.* 2000) found that some 40% of farmers sometimes or always sprayed weeds in hedge-bottoms. In between the two extremes of management are various degrees of disturbance arising from active hedge-bottom management (e.g. frequent cutting) or other farm operations on adjacent areas, such as cultivations, or pesticide and fertiliser application (Boatman *et al.* 1992).

A study by Reidel (1995) examined the distribution of hibernating predatory beetles in field boundaries. Field inhabiting carabids, as a whole, showed a clear preference for the grass strip immediately adjacent to the cultivated area. However, the small number of captured species that are known to fly showed no such preference, and were distributed further into the hedgerow. The conclusion of this study was that dispersal by the majority of carabid species is by walking and that, on reaching the first appropriate site for overwintering, there is no further stimulus for immigration into the hedgerow interior. Reidel recommended that the outer edge of the field boundary should be carefully preserved when soil cultivations are carried out.

Cormie (1998, cited in Marshall *et al.* 2001c) found that in order to retain suitable habitat for overwintering invertebrates, cutting hedge-bottom vegetation in spring would be more appropriate than cutting in autumn, but this may not be a practical option. Marshall *et al.* (2001c) also found that fertiliser reduction can maintain plant diversity, though it can be difficult to achieve. Problem weeds can be controlled using selective herbicides since insect diversity is reduced where herbaceous flora is dominated by annual weeds. The authors found that use of selective herbicides was effective against cleavers and barren brome which resulted in increased insect diversity. However, some species found in hedge-bottom vegetation, which are considered to be agricultural weeds (such as common nettle, *Urtica dioica*), are actually important hosts for insects such as Heteroptera.

Spraying hedge-bottoms can be particularly damaging to the invertebrate fauna of a hedgerow (Hooper 1992). In commercial farming practice, herbicides are sometimes used to eradicate or manipulate the flora at the base of hedges. The effect of this on carabid beetle and spider communities was assessed in a study by Asteraki *et al.* (1992) on a hawthorn hedge and adjacent grassland. The use of a non-selective (i.e. 'total') herbicide reduced the number of carabid species present. Spiders were also affected by the treatments, but to a lesser extent.

An experiment to simulate the removal of the hedge-bottom flora was carried out by Pollard (1968b), in order to ascertain its effect on the invertebrate fauna of a hawthorn hedge. The study was carried out over three years. Some sections of the hedge-bottom were maintained free of vegetation and these were compared with untreated sections. The fauna was divided into three categories: phytophagous, entomophagous and miscellaneous. A reduction in the total numbers and biomass of all three categories was recorded, in herbicide treated sections, in the second and third year of the experiment. The most marked effect was the reduction in the number of predators. This occurred in all three years of the study.

A further study (Pollard 1968c), on the same hedgerow, looked at the effect of similar treatments on ground beetles (Carabidae). It was found that removal of the hedge-bottom flora changed the abundance of many carabid species. This effect was attributed to changes in the microclimate of the hedge-bottom. Species restricted to the hedgerow were greatly reduced, whereas species characteristic of bare soils were found more frequently in sections of hedgerow from which the ground flora had been removed.

The spraying of hedge bottoms to kill common nettle (*Urtica dioica*) is listed as one of the contributory factors in the contraction of the range of the peacock (*Inachis io*) and small tortoiseshell (*Aglais urticae*) butterflies (Dowdeswell 1987). The impact of direct application of herbicides to the hedge-bottom flora on butterfly populations is by immediate loss of larval food plants or nectar sources and also by the more gradual development of a species poor plant community. Accidental drift of fertilisers into hedge bottoms also reduces the floristic diversity which is crucial for overall butterfly diversity (Longley & Sotherton 1996).

Research by Joyce *et al.* (1997) looked at the biodiversity and mobility of invertebrates in hedgerows in Hampshire, using repeated applications of a pyrethroid spray. They found around 200 species of invertebrate in the hedgerows sampled (the most dominant being Araneae, Coleoptera, Diptera, Homoptera, Heteroptera and Hymenoptera). Populations before and after spraying were compared for these 6 orders. Apart from Coleoptera, populations one month after spraying had not returned to pre-spraying levels. The only families that returned to levels equivalent to before spraying were Carabidae, Chrysomelidae and Staphylinidae (all in order Coleoptera). Although the numbers were not as great as pre-spraying, Araneae and Homoptera did recolonise the sprayed area. Recolonisation rates were fastest for Coleoptera and Araneae. Coleoptera may colonise first because they are generally ground-residing so may only climb into hedgerow vegetation to feed. They can also use alternative food sources if necessary as they are opportunistic feeders, and being based in the bottom of the hedge may have avoided the pesticide.

THE EFFECT OF ADJACENT LAND USE ON INVERTEBRATES IN HEDGEROWS

Much of the ecological research carried out in agricultural landscapes focuses on non-cropped areas, such as hedgerows, which may be considered as 'islands' within a hostile or neutral matrix of farmland. However, hedgerows are not true islands. For instance, many species can utilise adjacent farmland (e.g. some carabid beetles that overwinter in hedgerows) - so that the field matrix has a permeability, that allows exchanges between different landscape elements. The interactions between hedgerows and adjacent land use play an important role in maintaining biodiversity (Burel 1996). The quality of the narrow hedgerow habitat and, particularly, its suitability for invertebrates, is greatly affected by inputs from adjoining fields and land-use immediately adjacent to the hedge (Maclean 1992).

Burel *et al.* (1998), cited in Baudry *et al.* (2000) looked at adjacent landscapes that differed in hedgerow density. They found that for some groups of species (e.g. Diptera: Dolichopodidae, Empididae and Chiropodidae), species number decreased from dense to open landscapes. For carabids however, species number did not vary significantly (though body size did decrease from dense to open landscapes).

Field boundaries can directly influence invertebrates found within the uncropped edge as well as in the adjacent arable field (Moreby & Southway 2001). A field headland with a hedge boundary can contain higher densities of beneficial invertebrates such as Heteroptera compared to a similar field adjacent to a non-woody edge such as wire fences. Species with limited dispersal tended to be found in hedgerows rather than in the field. Martin *et al.* (2001) found that, when released in cultivated habitats, forest carabid beetles moved towards woody habitats. However, this was not conclusive, as in some enclosures, they did not show any preferences between woodland and cultivated areas.

Field margins

A hedgerow can be described as a thin strip of woodland and, similarly, the adjacent field margin can be likened to a strip of meadow. A gradual transition between habitats from, for example, grassland via tall herbs and scrub to the hedge, provides many more niches for invertebrates than an abrupt boundary, even though there may be no additional plant species present (Kirby 1992). Field margins, including features such as walls, ditch banks and wet ditches, enhance invertebrate diversity by increasing the variety of micro-habitats available (Dennis & Fry 1992).

Sparks *et al.* (1994), recorded more butterfly species where a verge, or a ditch, of more than one metre in width was present, compared with boundaries containing verges, or ditches, less than one metre wide.

A study by Sotherton (1985), examined the distribution and abundance of overwintering polyphagous predatory beetles in four types of field boundary. The presence of a bank in the boundaries increased the number of overwintering predators present. It was suggested that banked boundaries may be better drained, with a consequently lower risk of predators becoming frozen. The vegetational characteristics were also thought to be important, particularly the density of tussock grasses. The results suggest that predatory beetles are attracted more by hedgerows than by grass strips along wire fences, and that the maintenance of hedges on a raised grass bank would be of greatest benefit (Sotherton 1985).

A study of the dispersal of two carabid species, *Pterostichus melanarius* and *Harpalus rufipes*, showed that the predatory *P. melanarius* was most abundant in hedgerows and field margin habitats in June, but dispersed into adjacent cereal fields in early July; suggesting that these habitats are important sources for field colonisation by this species. In comparison the mainly phytophagous *H. rufipes* showed very little change in distribution, due to its diet being available in the hedgerow (Thomas *et al.* 1997).

Field boundaries remain the primary uncropped habitats available to butterflies on arable farmland, but most have been degraded by modern farming methods (Feber *et al.* 1994). Butterfly populations and species diversity in field margins, however, can be enhanced by careful and sympathetic management. For example, the high number and variety of butterflies recorded in one study was attributed to several factors including the presence of hedgerows and their associated shrubs, a rich hedge-bottom flora, and the fact that this was gradually grazed in late summer, rather than forming part of the hay cut (Hooper 1992).

Part of hedgerow research by McAdam *et al.* (1994), in Northern Ireland, compared the impact on carabid diversity of various grass field boundary management practices. Hawthorn hedges formed the boundaries between the grass fields. Four different treatments were imposed on the land on each side of the hedge. These were:

1. Fertilised and rotationally grazed with sheep

2. Two metre strip adjacent to the hedge ploughed and sown with game cover
3. Two metre strip adjacent to the hedge ploughed and left unmanaged
4. Unmanaged control.

Two years after the imposition of the alternative management treatments (2 to 4), there were significantly more beetle species present in all of them than in the 'fertilised and grazed' treatment. Populations of four key indicator species - *Abax parallelepipedus*, *Clivina fossor*, *Leistus fulvibarbis* and *Pterostichus melanarius,* were found to be reduced by grazing/fertilising, particularly in late summer. The findings indicate the importance of the field margin as a source of biodiversity in grassland, most species having been found in the hedgerow, hedge-bottom and within 0.5 m of the hedge-bottom. The importance of protecting the field margin from grazing and fertiliser application was indicated. The authors also concluded that, from the wildlife perspective, there is little advantage to be gained in fencing further out than 1 metre from the hedge (McAdam *et al.* 1994).

Dover (1999) compared different field margin types (grass banks, short hedges, tall hedges and wood edge) and found that although differences were not significant, short hedges held more species and grass banks held the fewest. Another study on green lanes and hedges found that although there was no difference between grass banks and hedgerows in terms of species richness or abundance, hedgerows did have significantly different species richness and abundance than the field-side or interior of green lanes (Dover *et al.* 2000). Dover (1996) conducted a study around five arable fields, bounded by hedges, grass banks, gardens, roads and a railway line. Most butterflies were found to be associated with hedgerows and wood edges, especially at intersections.

Extended field margins

Studies of the effects of establishing 'extended field margins' have tended to concentrate on the margin itself and the adjacent cropped land, with little information being collected on the effects on invertebrate populations in hedgerows. The only invertebrates for which any substantial amount of data has been found are the butterflies.

Dover *et al.* (1990) stated that butterfly populations may benefit substantially from consistently low pesticide usage in field margins, especially on farms where the majority of cereal fields have conservation headlands. These headlands may increase butterfly densities through the provision of nectar.

Feber *et al.* (1994) compared the effects of different types of boundary strip on the meadow brown butterfly; showing that the presence of an extended grassy boundary strip significantly increased the abundance of meadow brown adults, when compared with narrow, unmanaged boundaries exposed to herbicide drift or direct applications. Other forms of management of the grassy boundary strip also affected butterfly abundance, summer mowing having a particularly deleterious effect. The authors conclude that restoration and conservation management of field margins benefits the common grassland or hedgerow butterfly species most - as they are not unduly demanding in their habitat requirements, but have suffered as a result of agricultural intensification and poor field margin practices. This, and other studies have shown that increasing boundary width can result in increased butterfly densities.

The structure and complexity of field boundaries affect the quantity and deposition patterns of drifting pesticides. In a study examining summer pesticide spray drift into field boundaries (Longley *et al.* 1997) tall grasses in the hedge-bottom were found to filter out drifting spray droplets, thereby reducing the volume of chemical reaching the opposite side of the hedgerow. In an associated experiment the absence of tall vegetation in the hedge-bottom (or in the field), led to higher levels of field boundary contamination during autumn spray applications. The adoption of unsprayed headlands, of at least six metres' width, significantly reduced such contamination, especially when spraying was carried out at low wind speeds (Longley & Sotherton 1997b).

It may be concluded that such 'conservation headlands' act as a protective buffer zone against pesticide drift, which may be especially valuable where hedgerows have good floristic diversity or where new hedgerows are being established. However, unsprayed headlands need to be maintained over consecutive years to be of long term value.

ENHANCING INVERTEBRATE DIVERSITY IN HEDGEROWS

One way of achieving greater invertebrate diversity is to increase hedgerow floral diversity. This increases the potential range of host-specific invertebrates. A hedge rich in tree and shrub species is also likely to have a more extended flowering season than a species-poor hedge. This is particularly beneficial to nectar and pollen-feeding invertebrates and, therefore, to their predators (Clements & Tofts 1992).

Marshall *et al.* (2001a and 2001c) looked at ways of increasing botanical diversity of hedge-bottom vegetation in order to increase the associated invertebrate fauna. Of the different methods used, re-sowing with a perennial seed mix proved to be most effective, particularly on the arable site (compared to grassland). Fertiliser reduction can also help to maintain plant diversity, though may be difficult to achieve. In order to increase the botanical diversity to retain suitable habitat for overwintering invertebrates, cutting hedge-bottom vegetation in spring would be more appropriate than cutting in autumn. They also found that insect diversity was reduced in herbaceous flora dominated by annual weeds and that this flora must be managed in order to enhance biodiversity in hedgerows.

The presence of trees in hedgerows has been shown to increase invertebrate biodiversity by such obvious means as the provision of an increased number of available niches. Old trees are especially important as they provide a substrate for epiphytic mosses and lichens, on which a range of small invertebrates feed and live. Dead trees and timber also provide habitats for a range of invertebrates not encountered elsewhere. When hedgerow trees are felled as large a stump as possible should be left, which may then take 10-20 years to rot. When clad with ivy, these stumps provide a late-summer nectar source for many insects (Menneer 1994).

Spatial distributions of flying Diptera were studied by Peng *et al.* (1992), who trapped flies at three levels and two distances from an emergent hedgerow tree. The distribution showed dramatic differences, with all families except one being caught more frequently close to the tree. The tree appeared to act as a centre of biological attraction, and would be likely to provide a food source, mating station, swarming marker or shelter. The authors concluded that hedgerow trees are an important influence on the distribution and local concentration of the dipterous fauna of lowland Britain, with a major impact on other species such as birds and bats. Such trees greatly increase the faunal diversity of lowland Britain.

A study for MAFF (IGER 2000) compared the effect on hedge structure and fauna of planting different provenances of hawthorn and mixed species hedges (birch, rowan, sessile oak, hawthorn, blackthorn, European gorse and heather). The different hawthorn provenances showed variable growth rates and differing degrees of invertebrate herbivory. In the mixed species hedge, combinations of oak, hawthorn and gorse attracted the most diverse invertebrate taxa. In general, where there was more than one shrub species present, there was a greater diversity of invertebrates.

CONCLUSIONS

In conclusion, the potential of hedgerows to maintain or increase invertebrate abundance and diversity in the agricultural environment has been confirmed in a number of studies.

The huge range of invertebrate groups or species present in hedgerows means that recommending specific management techniques to be used in all situations is likely to disadvantage some species. Overall, a diversity of hedgerow management at both the farm and landscape scale is most likely to benefit biodiversity as a whole. However, some management options have obvious beneficial effects which can help to mitigate against the effects of modern farming practices. These include maintaining or establishing a diverse hedgerow flora by minimising herbicide and fertiliser applications and livestock grazing damage, perhaps by the use of extended field margins or fencing. Obviously the application or drift of insecticides into hedgerows must be avoided.

Rotational hedge management at the farm scale allows the development of a range of hedge types and associated habitats. Some hedges may be trimmed annually, with others being allowed to grow with just their sides being trimmed.

The timing of cutting may be critical. There is some evidence that summer cutting can be favourable to some invertebrate groups, but this practice is likely to be detrimental to other invertebrates (as it is to small mammals and birds).

At the landscape scale the aim must be to avoid the isolation of hedgerows from other favourable habitats such as woodlands, extensively managed grasslands, etc. Isolation can occur by the direct removal of hedgerows or by the degradation of existing hedgerows. The most favourable conditions for the maintenance of biodiversity in hedgerow networks are achieved by the presence of green lanes, dense herbaceous growth and hedgerow trees.

AMPHIBIANS, REPTILES AND HEDGEROWS

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GENERAL BACKGROUND AND THE IMPORTANCE OF HEDGES

British herpetofauna is generally considered to include six species of amphibians, (common frog (*Rana temporaria*), common toad (*Bufo bufo*), natterjack toad† (*Bufo calamita*), smooth newt (*Triturus vulgaris*), palmate newt (*Triturus helveticus*), great crested newt (*Triturus cristatus*)), and six species of reptile, (common lizard (*Lacerta vivipara*), sand lizard† (*Lacerta agilis*), slow worm (*Anguis fragilis*), grass snake (*Natrix natrix*), adder (*Vipera berus*), smooth snake† (*Coronella austriaca*)); rare species are indicated by a dagger. There is very little published work on the ecological importance of hedges to these species.

It is difficult to define the importance of hedgerows to this group of species because they are not very apparent in a terrestrial habitat and because of the difficulty of observations within dense hedgerows. The use of hedgerows, as suggested by most surveys, is likely to be greatly underestimated. 31% of all herpetofauna records in the Biological Record Centre contain some habitat description and H. Arnold (pers. comm.) has summarised the records taken within hedgerows. Less than 0.4% of records for each of the amphibians are from hedgerows. Very little habitat information is recorded for the rare reptiles and only 0.3% of adder records are from hedgerows. However, just under 2% of grass snake records and just under 3% of both slow worm and common lizard records were made in hedgerows.

Amphibians

Research on amphibians has concentrated on their breeding sites in water bodies. Pond density has declined dramatically this century as their importance in farming has dwindled. Pond density is likely to be greatest in pastoral systems, woods and gardens and hence the concentration of amphibians in these habitats.

A summary of known sites of the great crested newt in Huntingdonshire (Cooke 1984) confirms the paucity of locations in arable systems. However, a 2 ha garden 'island' in an otherwise arable landscape is described as one of the more heavily populated sites for great crested newts in Britain (Cooke 1985, 1986).

Trapping at this site revealed that adults made much use of arable land prior to harvest and that trappings were greater in damper weather. Both young and adult newts were caught in the hedge dividing the gardens from the arable land. These results suggest a terrestrial need by Great crested newts for adequate vegetation cover (either in the crop or in the hedgerow) and that movement is increased in damper conditions. Studies at De Montfort University suggested that hedges were of lesser importance than gardens but those with a wide base and thick vegetation were more significant than poorly managed, gappy hedges (R. Oldham, pers. comm.).

Swan and Oldham (1993a) have published the results from a common amphibian survey containing 11 thousand records, just under half of which included detailed habitat information. Survey sites were mainly ponds which were reported as existing in a low density in both upland and arable lowland. The authors stated that predominantly arable landscapes were hostile to frogs and great crested newts. Some adverse effects of hedgerows for frogs and toads were suggested by linear discriminant analysis. This may, in part, be caused by other related factors, such as shading and water depth. However, an examination of the appendices to that report suggest that where records exist in an arable situation the proximity of a hedge is important for frogs, toads and palmate newts. More detailed analysis of the data from the surveys would be valuable.

The natterjack toad is currently restricted to some coastal and inland heath sites and hedgerows are of no value to this species. Indeed as the natterjack occurs mostly in open poorly vegetated habitats, the presence of hedges with dense ground vegetation may lead to increased colonisation by, and subsequent competition with, common toads (e.g. Denton & Beebee 1994).

Smith (1971) stated that hedgerows offer protection to toads hibernating on dry banks under hedges.

C. Reading at CEH Dorset (pers. comm.) has studied both the grass snake and the common toad. He suggests that toads are likely to avoid hedges with no ground flora or debris. Hedges do not have to be wide, but ground cover is important both to provide shelter and as a source of prey insects. Adjacent ditches are thought to be of benefit, indeed wet ditches have been observed to function as migration routes for breeding toads (M. J. S. Swan, pers. comm.). Studies at De Montfort University using trapping and radiotracking has reinforced the view that hedgerows are important refugia for common toads (R. Oldham, pers. comm.).

R. Oldham at De Montfort University (pers. comm.) suggested that hedgerows are capable of supporting a high density of amphibians. Ground cover is thought to be vital. It is questionable whether amphibians are dependant on hedgerows as corridors but use is made of agricultural land where suitable vegetation cover exists and, indeed, in some circumstances, hedges may act as obstacles. A ditch within a hedgerow will be of benefit but will not be essential. Hedgerows may be important refugia during cold or exceptionally dry spells.

Reptiles

Reptiles like a mosaic of diverse terrestrial habitats; in arable landscapes diversity may be created by hedges. Two of Britain's rarest reptiles (smooth snake and sand lizard) are mainly restricted to heathland habitats, though in continental Europe they are more common and make more use of hedgerows (e.g. Street 1979). The remaining reptiles are variously described as using hedgerows as part of their habitat (e.g. Smith 1971). Moore (1968) indicated that all six reptiles breed in hedges but only one (unstated, but presumably the common lizard) is commonly found breeding in hedges.

Smith (1971) reports that the slow worm hibernates in holes in dry banks, including those banks contained within hedgerows.

C. Reading at CEH Dorset (pers. comm.) has investigated the movement of grass snakes. This work is done mainly in a pasture/woodland landscape. Grass snakes commonly occur on vegetated banks within hedges. Grass snakes do make occasional use of arable fields and seem to use hedges as corridors between hibernating and breeding areas on a farm and for hunting. As for toads, hedges do not have to be wide but ground cover appears to be important and toads often form the prey of grass snakes. Adjacent ditches are again likely to be of benefit. Prestt *et al.* (1974) suggested that the grass snake remains in close proximity to water, but this may not be the case in summer after amphibian dispersal.

Prestt (1971) reported similar findings for the dispersal of the adder. He reported movement of adders between hibernation areas (thickly vegetated dry elevated ground) and summer areas (along the sides of ditches in river meadows) using linear features including hedges. A seasonal movement of 1-1.5 km was reported.

Swan & Oldham (1993b) in a report on a survey of reptiles state that reptiles were most frequently encountered in woodland, moorland and grassland and rarely in arable. Of the common reptiles, the grass snake was most likely to be associated with arable land. Hedgerows are not specifically mentioned in the report though they were included in site description categories.

An undated British Herpetological Society leaflet stressed that hedgerows were important for the conservation of reptiles. Common lizards use hedgerows, feeding on insects and spiders. The adder is also described as being associated with hedgerows.

THE EFFECTS OF HEDGEROW MANAGEMENT ON AMPHIBIANS AND REPTILES

Though the evidence is largely circumstantial it appears that Britain's herpetofauna make little use of a purely arable landscape. There is little direct information on the effect of hedgerow management on these species. However, a hedgerow complex with a dense ground flora that contains a dry bank and a ditch are much more likely to be used. For amphibians these will have to be within 0.5-2 km of a pond, preferably within pasture. The two common snakes seem to make use of the hedgerow complex as a corridor for dispersal, as a food source and as a site for hibernation. Other reptiles will use dry banks within hedgerows for hibernation and as feeding areas. In continental Europe hedgerow banks may be warm enough to encourage breeding of the smooth snake and sand lizard.

With the paucity of information on this group of species it is difficult to suggest appropriate hedge management techniques. Hedgerow height does not appear to be important, although a dense ground flora must be retained. The incorporation of dry banks and ditches within the hedgerow complex will be of benefit and a continuous hedgerow network will be of value to the dispersal of at least the two common snakes.

BIRDS AND HEDGEROWS

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THE IMPORTANCE OF HEDGEROWS TO BIRDS

General

Hedges provide a resource for many birds, for nesting, song perches, roosts, food supply, shelter from predators and for movement. Lack (1992) summarises much of our current knowledge on habitat use by birds in a lowland arable landscape. Of 55 species of birds considered, 27 routinely use hedges for nesting and feeding and a further 16 will nest and feed in hedges if populations are high. Earlier work by Moore (1968) suggested that of 91 lowland terrestrial species of birds, 65 bred in hedges (23 commonly so).

A large proportion of the British avifauna is thus to be found in hedges. In some situations hedges may have the attributes of woodland edge (e.g. Inglis *et al.* 1994), whilst in landscapes of low woodland density they may provide the only suitable habitat for woodland bird species. A diversity of habitats is required for bird species diversity. Non-productive areas are usually very important for wildlife. These non-productive areas include field edges, hedges, scrub and some woodland. Hedges probably hold a greater number of breeding birds than any other feature in farmland (Lack 1992) and as such are vital for bird conservation in farmland. However, no species, except perhaps the cirl bunting (*Emberiza cirlus*), is restricted to a purely hedgerow habitat. In his study of an English parish, Wyllie (1976) concluded that bird populations are generally tree and hedgerow dependent.

A study of an arable farm in Hampshire (Fuller 1984) recorded 52 nesting species. Songbird territories averaged 21/km^2 in crops, 969/km^2 in woodland and 13/km length of hedgerow. The latter figure suggests a greater density of birds in hedges than in woods per unit area of woody material. Elsewhere the relative densities of birds in hedgerow and woodland are compared (e.g. Krebs 1971; Inglis *et al.* 1994; Fuller *et al.* 2001) but this comparison depends largely on how the area of the hedge as a habitat is defined.
The general decline in farmland birds has received much attention (e.g. Fuller *et* al. 1995; Gregory & Baillie 1998; Mason 1998) and the relative importance of woodlands and hedgerows for birds has been discussed (Fuller *et al.* 1995).

Cracknell (1986) studied foraging behaviour of birds in the same Hampshire area as Fuller (1984). Many species, for example chaffinch (*Fringilla coelebs*), whitethroat (*Sylvia communis*), dunnock (*Prunella vulgaris*) and blackbird (*Turdus merula*) foraged close to the hedgerows. A study by the RSPB of the cirl bunting suggested that the species rarely forages more than 30 m from a hedge in winter. These studies demonstrate the importance of hedges as a base for foraging into the adjacent crop.

There is little doubt that hedges are used by small birds as corridors, for movement between habitats, for example between woods (e.g. Haas 1995), but it is difficult to definitively prove the reluctance of birds to cross large open areas. Blackwell and Dowdeswell (1951) reported that an open playing field acted as a barrier to the movement of blue tits (*Parus caeruleus*). Published work on wildlife corridors has been reviewed by Spellerberg and Gaywood (1993), Dawson (1994) and Beier and Noss (1998).

Small birds undoubtedly use hedgerows for protection from birds of prey (Hull 1998) and from nest robbing. Dense hedgerows will inevitably offer greater protection. Nest predation in hedges may be higher than that in woods for some species (Gassman & Glueck 1993; Chamberlain *et al.* 1995; Eybert *et al.* 1995; Major *et al.* 1999)).

Hedgerow removal

O'Connor (1987) reported that a greater density of field boundaries led to a greater areal density of birds; in fact 24 out of 57 examined birds were reported to be more numerous when field boundary density was greater. It is not surprising, therefore, that the drastic reduction in the density of hedgerows that has occurred post-war has generally been detrimental to bird species (Williamson 1971; Bull *et al.* 1976; Lack 1987).

On occasions, the reduction has had a lower-than-expected effect when populations have been below capacity, resulting in a greater density in the remaining hedges. A range of response by individual species to hedge removal has been observed; Lack (1987) reported that the great (*Parus major*) and blue tits fared worst whilst the yellowhammer (*Emberiza citrinella*) was least affected of the common species because of its preference for arable crops. However, even yellowhammer numbers have been shown to be related to hedge density (Kyrkos *et al.* 1998). Fuller *et al.* (2001) suggested that species richness was only adversely affected when hedge density fell below c. 8 km/km^2. Gillings and Fuller (1998) suggested that habitat loss might be of secondary importance to loss of habitat quality. It has even been suggested that hedgerow loss may reduce predation rates (Eybert *et al.* 1995).

Hedge types and bird species richness

It would be naive to believe that a single structure or type of hedge will be ideal for all bird species. Each species has its own preferences. Lack (1992) suggested that woodland birds (e.g. chaffinch) were most associated with tall hedges, whilst birds associated with scrub (e.g. dunnock and yellowhammer) were less fussy. Some species (e.g. corn bunting (*Emberiza calandra*) and skylark (*Alauda arvensis*)) were more abundant in the absence of trees and hedges. Songbird territories in Fuller's (1984) study were twice as numerous in tall hedges compared to short hedges and similar preferences were shown in the later work of Cracknell (1986). O'Connor (1987) reported that in lower hedges, nests produced fewer young and Parslow (1969) briefly reported a lower success rate in shorter hedges, possibly due to predation by rats. More recent work (Fuller *et al.* 1997) confirms the link between hedge density and species richness at the landscape scale.

O'Connor (1987) suggested that tall wide hedges would promote a hedge base flora, important for many species (e.g. yellowhammer and whitethroat (Stoate & Szczur 1994)). Osborne (1982, 1984) reported the adverse effects of hedgerow tree loss and that bird-rich hedges were associated with a larger hedge basal area, containing many tree species and some dead timber.

Lakhani (1994) summarised hedgerow survey results from ITE (Parish *et al.* 1994a, 1995), RSPB (Green *et al.* 1994) and Oxford University (MacDonald & Johnson 1995). These surveys reached broadly similar conclusions to those of O'Connor (1987) which suggested that species richness was enhanced in tall broad hedges. The presence of a ditch, woody species richness, base flora, berries and flowering (attracting invertebrates) were all beneficial to bird populations. All three of these surveys were based in lowland Britain, though the RSPB survey achieved greater geographical coverage. Within these studies individual species preferences were identified, some species were attracted to hedgerow trees and adjacent land use had an effect.

Using an alternative approach, Arnold (1983) used landscape blocks as a basic sampling unit. However the importance of hedgerows, woody species richness and ditches was still very apparent in his work.

Lack (1988) reported a much greater density of birds at hedge intersections than in sections. Of 12 examined species, ten were more abundant in intersections, five of these (wren (*Troglodytes troglodytes*), robin (*Erithacus rubecula*), blackbird, blue tit and great tit) significantly so.

The preference of individual bird species

The work carried out by The Game Conservancy Trust and others have identified the habitat needs of native game birds (e.g. Jenkins 1961; Rands 1986; Rands 1987; Sotherton & Rands 1987). These suggested a preference by partridges for short hedgerows with a dense base flora adjacent to arable crops. Conservation Headlands have been shown to benefit these species.

Stoate and Szczur (1994) found that the majority of yellowhammer and whitethroat nests occurred in field margins. These were numerous in the presence of vegetated ditches and the importance of a denser base flora was demonstrated. Both species were much lower nesting than chaffinch, which was also recorded in the study; in fact the yellowhammer often built on the ground. The mean nest height for chaffinches (1.26 m) suggested that short hedges were unlikely to be preferred by this species. Mason and Macdonald (2000) reported contradictory results with both whitethroat and yellowhammer preferring taller hedges. However, further results by The Game Conservancy / Allerton Trust (e.g. Stoate 1999; Stoate *et al.* 2001) confirm preferences for lower nesting. An earlier study by Mason (1976) reported higher survival in warbler nests below 60 cm but identified species height preferences; the lesser whitethroat (*Sylvia curruca*) needed a greater vertical structure than other *Sylvia* warblers.

Sparks *et al.* (1996) summarised the hedgerow preferences (particularly height) for a number of breeding bird species. Very obvious differences existed between species; birds normally associated with woodlands requiring a greater vertical structure.

An unpublished RSPB study of the cirl bunting indicated a preference for large untrimmed hedges of diverse composition. Since the species can nest up to late September the need to delay cutting in order to protect this species is vital.

Adjacent land use

Early papers by Alexander (1932) and Chapman (1939) suggested a greater abundance of birds in pasture fields than in arable crops even after hedgerow density was taken into account. It is interesting to note that both these studies pre-date modern pesticide practices. Williamson (1967), Parish *et al.* (1994a) and others all suggested a lower density of birds in arable situations and this pattern has been confirmed in winter surveys (Wilson *et al.* 1996; Buckingham *et al* 1999; Chamberlain *et al.* 2001). This may only be partly explained by hedgerow management differing between the two types of regime. Conversely, individual species may also show a preference for arable field boundaries over pasture boundaries, for example skylark and corn bunting.

The Boxworth Project (Grieg-Smith *et al.* 1992) compared contrasting pesticide regimes. Some potentially debilitating pesticide effects were observed on skylark and house sparrow (*Passer domesticus*). Within the 'full insurance' category there was a decline in starling density, and a reduction in the size of tree sparrow (*Passer montanus*) nestlings. Otherwise no effect on the breeding of four species of hole-nesting birds was detected.

A comparison of birds in organic and conventional farming systems (Chamberlain *et al.* 1999) suggested higher numbers of hedgerow birds on organic farms, though this may be largely attributed to a more relaxed hedge management. Further work on birds in different farming systems and on set-aside have confirmed a general avoidance of winter sown crops in preference for set-aside or stubbles (e.g. Wilson *et al.* 1996; Buckingham *et al* 1999).

The hedgerow as a food resource

Hedges are a very important resource for fruit and berry production (Snow & Snow 1988). Recent management advice, for example the Countryside Commission's Hedgerow Incentive Scheme (Countryside Commission 1992) and Defra's Countryside Stewardship Scheme (Defra 2003) recommended delaying cutting until early in the new year to maximise the food value of the hedge whilst preventing disturbing nesting birds. They also recommended that the hedge is cut no more than twice every five years and that height be kept to a minimum of 2 m. This advice is supported by the findings of Sparks and Martin (1999) and Croxton and Sparks (2002). Croxton and Sparks (in press) reported the timing of berry availability and stressed the need to avoid autumn cutting to allow birds to feed on berries.

The BTO Winter Farmland Hedgerow survey (Tucker 1989; Chamberlain *et al.* 2001) indicated that berry producing species were important for a number of bird species, including redwing (*Turdus musicus*) and fieldfare (*Turdus pilaris*). In fact, internationally significant numbers of redwings and fieldfares may depend on berry stocks in British hedges (R. J. Fuller, pers. comm.). Birds were more numerous in the early part of the winter, presumably feeding on the berry crop. The feeding preferences of birds have been described in Snow and Snow (1988). Some work on hedge management carried out by FWAG in Wiltshire included berry production studies (Moorhouse 1990). These indicated that the bulk of fruit production occurred above 2 m.

Most studies of hedgerow bird populations have been carried out in summer months. The exceptions to this have been the work of Parish *et al.* (1994a, 1995) and the BTO winter survey (Tucker 1989; Chamberlain *et al.* 2001). The latter survey confirmed that similar hedgerow characteristics to those in summer encourage diversity in winter, i.e. large hedges, few gaps, dense basal cover. However, as in summer, there are exceptions notably red-legged partridge and skylark . O'Connor (1987) believed that the value of hedgerows in winter was undoubtedly underestimated.

THE EFFECTS OF HEDGEROW MANAGEMENT ON BIRD POPULATIONS

General effects

Suggestions of suitable hedgerow management for bird species have usually been based on the findings from correlative studies that have examined the relationship between numbers of birds and attributes of hedges.

Many of these suggestions have been incorporated by Firbank *et al.* (1993) into guidelines on management of set-aside for wildlife. They suggested that taller thicker hedges, especially in meadows, could support more species than short frequently trimmed or gappy hedges and described the benefits of extending hedges by incorporating scrubby margin. They also suggested that saplings should be encouraged to develop into hedgerow trees.

Osborn (1987) reported that overgrazing, agrochemical application and burning have had adverse effects on the hedge base flora. A problem with gappiness caused by elder (*Sambucus nigra*) may require special treatment. She recommended that hedges should be managed individually to achieve their greatest potential. Joyce *et al.* (1988) suggested that continued trimming reduced hedgerow vigour, accelerating ageing and leading to death and gappiness.

The Countryside Commission (1974) suggested that management could be directed to producing a continuous interconnected system of large hedges to serve both aesthetic and wildlife needs and which, where possible, should be widened to include awkward corners, damp areas and other agriculturally unproductive land. In reporting the further deterioration of hedges within their study sites the Countryside Commission (1984) suggested over-management would lead to gradual deterioration. The practice of herbicide spraying of hedgerow bottoms leads to unknown effects on the hedge itself. Gappy hedges are susceptible to various problems, including damage by stock.

The management of the adjacent field edge will inevitably influence the value of the hedge for birds. The base flora merits protection from herbicide application, not only to provide nesting cover and a food source, but also to restrict development of annual weeds. Work on Conservation Headlands has demonstrated clear benefits to game birds, but these benefits have not been demonstrated for other groups of birds (Fuller 1984; Cracknell 1986; Green *et al.* 1994).

The effects of hedge management on food supply, both within and adjacent to the hedge, is likely to have implications on birds and is an area that merits further examination.

Specific effects

Work by The Game Conservancy Trust (e.g. Rands & Sotherton 1987) has suggested methods of managing field margins, including hedgerows, for the benefit of game birds. They recommend biennial trimming and the retention of a perennial flora at the base of hedge. For game birds a short hedgerow of less than two metres tall is recommended. Whilst this contrasts with the recommendations for species diversity generally, it reinforces the view that blanket management will not benefit all species. Indeed tall hedges are good for driving game birds on a shooting day (N. W. Sotherton, pers. comm.). Aebischer *et al.* (1994) stressed the dense cover needed by grey partridges for nesting and that hedgerow density (km/ha) was important.

A preliminary analysis of the BTO winter survey (Tucker 1989) suggested a greater abundance of thrushes, as much as double, in untrimmed hedges and that shape was important to overall abundance. When recent trimming had taken place, there was less difference in the value of the five examined hedge shapes. Neglected hedges or undercut and irregular hedges supported more birds than those subject to long term management. Earlier work by Moore *et al.* (1967) also suggested higher bird numbers in uncut hedges, particularly those of hawthorn (*Crataegus* sp.).

The A-shaped hedge, much favoured in some quarters, was possibly the poorest bird habitat of the five examined types (Tucker 1989). The A-shaped hedge is a bit of an anachronism. In the past it seems to have been promoted as a hedge of conservation value but Moorhouse (1990) suggested it was detrimental to base flora, whilst elsewhere it has been suggested that it promotes a thick shrub base.

O'Connor (1987) supported the idea that tall wide hedges will promote a base flora. Whilst based on limited data, the severe trimming of three hedges in Cambridgeshire resulted in the total loss of breeding birds (Parish *et al.* 1994b). Hedge coppicing in Hertfordshire (Lack 1987) led to a substantial loss of bird territories.

GAPS IN KNOWLEDGE

Estimates of bird density in hedgerows are available, as is the knowledge of how these are affected by adjacent land use and the presence of intersections. Hinsley *et al.* (1995) found higher bird densities in small woodlands with more hedgerow connections. It would be interesting to see how bird density changes in hedges close to woodland and for what distance a woodland exerts an influence over a connected hedgerow system. Suitable raw data already exist from the BTO's Common Bird Census records but would require interrogation.

Several studies suggest that bird species richness is enhanced in hedgerows of diverse shrub composition. The value of planting new hedges of diverse composition could be investigated on an experimental basis: using some hedges of pure hawthorn, and others of mixed composition. Monitoring of the subsequent bird populations must be considered as a long term exercise. Alternatively, results might be more quickly, but less accurately, obtained by taking a relatively diverse hedgerow and gradually reducing the floral diversity of one or more of the layers (base flora, scrub species, climbers etc.) and examining the effects on bird populations.

Most lacking in studies of birds are experimental manipulations of hedgerows. Few of the studies of bird populations have looked at hedge management *per se*. Rather, most have looked at existing hedge composition and dimensions and their relationship with bird populations. Whilst this approach can indicate appropriate management, this was not the primary focus of the research. Some work was carried out by FWAG in Wiltshire (Moorhouse 1990) but involved small samples. More work could be done to investigate the food supply of hedgerows in both summer and winter. The RSPB survey (Green *et al.* 1994) recorded the shape of the hedge cross section but did not include this information in their analysis. In order to supply Defra with hard recommendations on appropriate forms of hedge management an experimental management programme is necessary. It is envisaged that such research would require fairly homogenous hedgerows to provide the experimental material and a properly designed experiment comparing management could be carried out on these. Baseline monitoring would be necessary to ensure, or adjust for any lack of, homogeneity in the bird populations. The disadvantage of experimental management for hedgerow birds is the long plots required (probably 200m).

In recent years there have been admirable examples of the exploitation of existing data sets (e.g. Gillings & Fuller 1998; Chamberlain *et al.* 2001) and much additional information on hedgerow birds has been gleaned. More work on the effects of contrasting hedge shapes is evidently necessary, as is information on the quality of particular hedges (e.g. composition, density, cover, food supply) from a bird's perspective. A study on reproductive performance in farm hedges could help to address concerns about high predation rates in some hedge studies and general declines in farmland populations.

MAMMALS AND HEDGEROWS

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INTRODUCTION

Although comprising only a small proportion of the UK countryside, hedgerows are an important, and often essential habitat for many species of mammal within the agricultural landscape. The majority of Britain's mammals evolved in deciduous woodland (Tew 1992), but many species have now become adapted to existence within the agricultural framework of field margins and border features. Mammals utilise hedgerows in a variety of ways, from shelter (Tapper & Barnes 1986) and feeding (Angelstam *et al.* 1987), to use as corridors for dispersal (Spellerberg & Gaywood 1993).

A loss in hedgerows over the last 20 years (Barr *et al.* 1994) has been associated with a relative decrease in the biodiversity of agricultural habitats (Menneer 1994). This has resulted in changes in government policy, such as the withdrawal of grant aid for hedge removal, the introduction of legislation to protect 'important' hedgerows and the provision of further incentives for hedge management and planting (Dwyer 1994). The rate of hedgerow loss now seems to be reducing (Barr *et al.* 1994; Haines-Young *et al.* 2000).

This section collates research information on most species of mammal that are regularly encountered within the farmland landscape.

THE UTILISATION OF HEDGEROWS BY MAMMALS

Hedgehogs (Insectivora: Erinaceidae)

Hedgehogs (*Erinaceus europaeus*) are most abundant where there is close proximity of grassland to woodland, scrub or hedgerow. The hedgehog is likely to be present in nearly all lowland agricultural habitats where there is sufficient cover for nesting. Hedgehogs utilise hedgerows for nesting in summer, and for hibernation in winter. However, despite the animal's appropriate name, there appears to be only limited information available on the types, or management, of hedgerow preferred (Corbet & Harris 1991; Morris 1993). Hedgerows that have an abundant food supply of ground living invertebrates, and a dense basal layer of vegetation, should probably be encouraged for the benefit of this species.

Shrews (Insectivora: Soricidae)

Common shrews (*Sorex araneus*) and pygmy shrews (*S. minutus*) are widespread wherever there is ground cover, and are frequently live-trapped in hedgerows by researchers (Tew *et al.* 1994). Both common and pygmy shrews are rarely caught away from hedgerows in agricultural habitats. Those that are occasionally found within the field are likely to be nesting in a hedgerow, and only briefly venturing into the field for foraging (Tew *et al.* 1994).

It has been suggested (e.g. Plesner Jensen 1993) that factors other than vegetation cover influence the distribution of shrews. Food availability was found to be particularly important. All shrews are insectivores. Common shrews take a wide variety of invertebrate prey found within hedgerows; especially beetles, earthworms, woodlice, spiders, slugs, snails and insect larvae. The diet of pygmy shrews is similar, except that they do not take earthworms (Corbet & Harris 1991). The abundance and distribution of common shrews is therefore thought likely to be primarily dependent on the distribution of earthworms, while the density of surface-living invertebrates determines pygmy shrew numbers.

Occasionally water shrews (*Neomys fodiens*) can be found in hedgerows up to 3 km from water (Corbet & Harris 1991). It is likely that these animals are dispersing, and that hedgerows are important corridors between suitable habitats, such as streams and ponds (Tew *et al.* 1992).

Bats (Chiroptera)

Until very recently almost nothing was known about the habitat requirements of bats, particularly for foraging (Harris & Woollard 1990). Bats are now known to fly along hedgerows to travel between roosts and feeding sites (Entwistle *et al.* 1996, Jones et al. 1995), to exploit available insect populations (Ransome 1996), and for protection against predators or wind (Limpens & Kapteyn 1991; Verboom & Huitema 1997).

The presence of continuous hedgerows close to maternity roosts is very important for the Pipistrelle (*Pipistrellus pipistrellus*) (Oakeley & Jones 1998). These, and other bats with echo-location calls of limited range, such as the Brown long-eared (*Plecotus auritus*), rely very strongly on continuous landscape features for orientation (Entwhistle *et al.* 1996). Larger bats with a longer range sonar, such as the serotine (*Eptesicus serotinus*), travel further from roost to feeding site, and are less dependent on such features (Verboom & Huitema 1997), but still use trees and hedgerows as corridors (Robinson & Stebbings 1997).

Linear vegetation features have been found to correlate positively with the distribution and foraging habitat of bats in Britain (Walsh & Harris 1996a, 1996b). Continuation of unbroken hedgerow corridors and management to increase insects, particularly moths, will help benefit bat populations. Lamplit roads or hedges, with more insects flying around street lamps, have been found to attract more bats (Blake *et al.* 1994); but some species, particularly the horseshoe bats, avoid lit areas.

The removal of trees and hedgerows, as well as fragmenting habitat connectivity, increases surface wind speeds, making it more difficult for insects to fly on windy nights, and reducing the amount of food available to bats (Harris & Woollard 1990). Loss of hedgerow trees also reduces the availability of potential roost sites, and may affect populations of tree roosting species, such as the noctule (*Nyctalus noctula*).

Rabbits and Brown hares (Lagomorpha: Leporidae)

Many hedgerows contain rabbit (*Oryctolagus cuniculus*) burrows. Management of hedgerows to maximise biodiversity and increase populations of mammals generally may also increase rabbit populations. This is unlikely to be popular with farmers, and may even militate against management for wildlife where rabbits are already a problem (Deane 1989). Actions to control rabbits may, therefore, need to be included as part of a hedgerow management plan. Rabbits can physically damage hedgerows by browsing, bark stripping or excessive burrowing. This could potentially reduce species richness and diversity, and the hedgerow's effectiveness as a stock barrier.

The brown hare (*Lepus europaeus*) is a species which seems to have two main habitat requirements. Brown hares feed in arable areas where cereal growing predominates (Corbet & Harris 1991), but also require a resting area. This may also provide shelter if it is a tall crop, woodland, or hedgerow (Tapper & Barnes 1986). Hedgerows are mainly used during the day for shelter, whereas open fields are used for night-time feeding.

Both rabbits and hares can cause severe damage to newly planted hedges, unless they are well protected by fencing or plant guards.

Voles (Rodentia: Muridae: Arvicolinae)

Two species of vole are commonly found on farmland, the bank vole (*Clethrionomys glareolus*) and the field vole (*Microtus agrestis*).

Bank voles

The bank vole's preferred habitat is deciduous woodland (Corbet & Harris 1991), but they can also be found in hedgerows throughout the year. Indeed, Tattersall *et al.* (2002) found bank voles significantly more abundant in hedgerows than they did in woodland, and they were more common in woodland edges that were bounded by hedgerows. In Britain, the bank voles preferred foods are fleshy fruits and seeds when they are available. At other times leaves are eaten, those of woody plants being preferred to herbs, and dead leaves are eaten during the winter (Corbet & Harris 1991). Bank voles have been found to be very dependent on the presence of hedgerows in agricultural areas, rarely moving far from them (Pollard & Relton 1970). As with shrews, ground cover is an important habitat requirement (Gurnell 1985), as is hedgerow connectivity (Paillat & Butet 1996). FitzGibbon (1997) found that during the autumn bank voles were more abundant in woods connected with hedges, and that herb cover was also important in determining abundance. Additionally, Bellamy *et al.* (2000) found that bank voles were most numerous on road verges with large, and particularly tall, hedges.

The distribution of voles within hedgerows has also been associated with the abundance of seeds and berries (Poulton 1994). Observations by Tew (1992, 1994), suggest that as the cover of the crop increases throughout the summer, bank voles frequently forage up to 25 m from the hedgerow. Food availability may be low in the crop, but it is possible that the invertebrate fauna within the cereal crops represents an alternative when food abundance is relatively low in the pre-fruiting hedgerow (Tew 1994).

Field voles

Field voles are herbivorous, feeding primarily on green leaves and stems of grasses. Their favoured habitat is rough, ungrazed grassland, however lower population densities do occur in marginal habitats such as hedgerows (Corbet & Harris 1991). Both species of voles are known to cause damage to forest trees and other woody species, and may feed on young plants in new hedges. Bank voles have been recorded eating tree bark (Keeler 1961). Field voles can cause considerable damage to grassland, as well as young plantations of fruit trees and woody stemmed agricultural plants (Corbet & Harris 1991).

Mice (Rodentia: Muridae: Murinae)

Wood mice

The association between wood mice (*Apodemus sylvaticus*) and agricultural habitats is well documented (e.g. Green 1979). They are common within hedgerows, but are also able to exist entirely within cultivated areas (Pollard & Relton 1970). Their high population densities in many farmland hedgerows suggests that they adapt easily to change and are great opportunists on arable land (Kotzageorgis & Mason 1997). Angelstam *et al.* (1987) and Poulton (1994) found a very strong association between the abundance of hedgerow berries and wood mice capture rates. Recent diet choice studies have shown that wood mice have a preference for some of the foods available within hedgerows, whilst avoiding other foods completely (Plesner Jensen 1992). Of the naturally available foods, blackberries (common in hedges) are the most favoured. Preferred crop plants include sweetcorn, wheat and oilseed rape. In spring, when fruits and seeds are not available, the hedgerow may still provide shelter and bolt-holes for mice foraging on open margins and fields (Montgomery & Dowie 1993). Weisel & Brandl (1993) found a higher density of small mammals on the southern rim of a hedge; this may have been due to better food resources than in the centre or on the northern rim of the hedge. Woods *et al.* (1996) have briefly considered the potential of new hedgerows as harbourage for wood mice and bank voles and their implications as agricultural pests. Wood mice are only known to cause problems very occasionally, when sugar beet is drilled (Flowerdew 1997). Apart from this occasional seasonal problem, their benefit as prey for a wide range of carnivorous mammals and birds should outweigh their status as a pest.

Yellow-necked mice

Yellow-necked mice (*Apodemus flavicollis*) mainly occur within mature deciduous woodlands. Hedgerows are marginal habitats for this species (Corbet & Harris 1991), however populations can be found in old, well-established hedgerows. Some hedgerow management, such as coppicing has lead to the complete abandonment of it by yellow-necked mice (Kotzageorgis & Mason 1997).

In a study of hedgerows in Germany, Sohler (1996) found that, perhaps surprisingly, yellow-necked mice preferred areas with little or no foliage, whilst wood mice preferred areas with dense foliage.

Harvest mice

The harvest mouse (*Micromys minutus)* is a species of which little is known about its general ecology. Harvest mice favour areas of tall, dense vegetation, in which their breeding nests are found (Corbet & Harris 1991). In a Mammal Society survey (Harris 1979) hedgerows were the habitat in which the largest percentage of nests were found (13.4%). This may, however, be a biased figure, affected by the choice of habitat types searched by recorders. Despite this, hedgerows must feature as a very important resource for harvest mice, probably for both food supply and nest building.

Dormice (Rodentia: Gliridae)

Common Dormouse

The common dormouse (*Muscardinus avellanarius*) is a species traditionally associated with deciduous woodland with plenty of secondary growth and scrub. Hazel (*Corylus avellana*) was thought to be an almost essential species that provided the principle source of food, in the form of nuts, for fattening prior to hibernation (Bright *et al.* 1996), although recent studies have regularly found dormice in hedgerows far from any hazel (Eden & Eden 1999). In a Mammal Society survey (Hurrell & McIntosh 1984) hedgerows were found to be their second most important habitat, although Bright and MacPherson (2002) found that densities of dormice within hedgerows were comparable to those within woodlands, so hedgerows can certainly provide a high quality habitat. They found that population density was primarily related to hedgerow height and secondly to shrub diversity. Hedgerows that supported densities of dormice comparable to woodlands needed to be at least 4m high. Intensively managed, low diversity hedgerows lacked dormice. Also important was the association within habitats between scrub, hedgerow and bramble. For example, a dense woodland with no secondary layer and no surrounding hedgerow might not provide the necessary food or cover. Bright *et al.* (1994) and Bright (1998) emphasised the importance of hedgerows for the survival of dormice, relating the use of hedges as corridors for dispersal. This was confirmed by Bright and MacPherson (2002) who found that densities of juvenile dormice were inversely related to the proximity of ancient woodland, implying that hedgerows do indeed act as dispersal corridors. During this study, radio-tracking found that dormice fed on bramble, dog-rose and hazel and avoided hawthorn, and their ranges covered a smaller area than those in woodlands. They state that *"hedgerows therefore need to be diverse and productive to supply them with sufficient food"*. That dormice *need* diverse, ancient hedgerows, as Bright and MacPherson (2002) suggested, is different to the view of Chanin and Woods (2003) who also found dormice at lower densities in heavily flailed and low diversity hedges. They also found dormice nests within hedgerows and dormice present for more than one month in 50% of hedgerow sites. This suggests that dormice are resident in, at least, the better quality hedgerows.

Foxes (Carnivora: Canidae)
The fox (*Vulpes vulpes*) is a highly adaptable, unspecialised species. Its lack of specific habitat requirement is one reason for its success in Britain (Corbet & Harris 1991). Fox earths are often found in hedge-bottoms. They undoubtedly utilise hedgerow habitats as a major source of food. However, even with removal of hedgerows, foxes may still be able to adapt to a change in habitat, such as they have done in the urban environment (Harris 1986).

Martens (Carnivora: Mustelidae)
Stoats and Weasels
In agricultural areas stoats (*Mustela erminea*) and weasels (*Mustela nivalis*) hunt mainly along field boundaries where prey is most abundant (Tapper 1979). Hedgerows which support large populations of small mammals (mice, voles and shrews) and rabbits will encourage these predators. Weasels tend to hunt exclusively in hedgerows throughout the winter and spring, but forage in arable fields during the summer (Tew 1992).

Polecats
Results from a radio-tracking study carried out on polecats (*Mustela putorius*) indicated that hedgerows are the third most important habitat type for this species, after woodland edges and farmyards (Birks, 1998). In areas devoid of woodland, therefore, hedgerows could be a very beneficial habitat for this species - as it expands its range eastward across England.

Rabbits in hedgerows are the polecat's major food source and their burrows provide resting sites. Hedgerows also function as corridors for the dispersal of the species (J. Birks, pers. comm.).

Badgers
Badger (*Meles meles*) numbers are highest in south-west England, where they are mainly associated with deciduous woodlands and pasture. Populations are at a much lower level in the predominantly arable landscapes of East Anglia where changes in habitat, including the removal of hedgerows, have caused significant reductions (Harris & Woollard 1990). Skinner *et al.* (1991) found similarly low badger populations in Essex, thought to be a result of farming intensification.

Hedgerows often contain the entrances to badger setts. Neal and Cheeseman (1996) found that in areas where woods and copses were scarce, hedgerows and scrub were the most commonly used alternatives for sett locations. In Somerset and Devon, they found that there were almost always badger setts in hedgerows where they were traditionally set on banks, or if there were disused farm tracks bounded by banks with overgrown hedges.

Deer (Artiodactyla: Cervidae)
Agricultural crops tend to be fast growing and of high nutritional value - making them a desirable food source for deer. Hence, fallow (*Dama dama*), red (*Cervus elephus*), roe (*Capreolus capreolus*) and muntjac deer (*Muntiacus reevesi*) are frequently found in lowland agricultural habitats, and are frequently associated with damage to crops (Putman and Moore 1998).

Muntjac deer in Britain have been shown to select arable land classes and avoid upland marginal ones (Chapman *et al.* 1994). However, an analysis of landscape features associated with the distribution and abundance of muntjac, roe, fallow and red deer in lowland England has shown few clear associations between deer presence on farms and landscape or linear features (Palmer 1998). This suggests that hedgerows are of an uncertain value to deer within the agricultural landscape, and it might be that deer could exist without them provided alternative harbourage was available.

Deer can be responsible for direct damage to hedges. Newly planted hedges are vulnerable to grazing damage from deer, and damage to mature hedges is usually the result of larger species of deer attempting to push their way through small gaps.

EFFECTS OF HEDGEROW MANAGEMENT ON MAMMAL POPULATIONS

Hedgerow variables that are important in determining the diversity of mammals

Three basic factors affect a hedgerow's capability to support a diverse and species-rich mammal community:

1. The type and amount of food available within the hedgerow. Favourable conditions being a large invertebrate population or prolific annual seed and berry crop.

2. The vegetation structure and composition of the hedgerow. For instance, a dense, herb-rich basal layer or a continuous line of hedgerow trees is preferred by several species.

3. The continuity and connectivity of the hedge within the landscape. For instance, a hedgerow that connects patches of small farm woodlands will have greater value as a corridor for the dispersal of mammals.

Consideration of the whole hedgerow ecosystem as a complex web, with many interacting populations of different species, is vital in creating and maintaining optimal hedgerow biodiversity. The enhancement of hedgerows for mammals should be considered alongside recommendations in other sections of this publication.

How to improve a hedgerow for mammals

Generally, the larger the hedge, the better it is likely to be for many species of mammal. Sohler (1996) found that, in very young hedgerows (2-13 years old), densities of trapped small mammals increased with the age of the hedgerow; but this finding was probably also related to hedge size. Where the margins of a hedgerow are left to grow out onto adjoining land, there will be an increase in species richness and diversity. Also, a wider hedgerow is likely to be more effective in acting as a wildlife corridor (Tischendorf & Wissel 1997). This will probably be reflected in higher numbers of mammals which feed and shelter in hedgerows (Deane 1989). Where hedgerows are managed in this way they have been known as 'expanded hedgerows'.

Plesner Jensen (1993) has considered the effects of the presence of various boundary features and management regimes on farmland rodents. It was found that the presence of boundary features such as hedges and ditches were more important than field margin management regimes. Boundaries with hedgerows had relatively high numbers of wood mice, bank voles and common shrews. Bank voles were more numerous in margins with ditches than in those without.

Boone and Tinklin (1988) have suggested that the vegetation structure of the hedgerow is critical in determining both the presence and densities of wood mice and bank voles. Sites with more cover and food had higher density populations of mice and voles. Both species are important prey for other mammal species, such as fox, weasel and stoat. In an arable landscape, the hedgerow populations of predator species form a large proportion of the overall predator community. It seems, from the Boone and Tinklin study, that the interconnecting structure of the hedgerows, together with adequate basal vegetation, is important in maintaining both predator and prey populations.

The best management approach to maintain small mammal populations is to encourage minimum interference. A regime which does not involve the annual cutting of autumn fruits would be obviously advantageous. Trimming in late winter is therefore beneficial. To allow for the retention of yellow-necked mice in farmed landscapes, careful consideration of the location and timing of hedgerow management is essential. Coppicing of a hedge, for example, has led to the complete abandonment of it by yellow-necked mice (Kotzageorgis & Mason 1997). Allowing a dense understorey of herbs and grasses to develop under the hedge will maintain greater cover and enhance food resources. This can be achieved by preventing livestock from grazing the hedge bottom, and discontinuing herbicide use there (Boone & Tinklin 1988).

Some studies on the development of conservation headlands have shown an active selection of wood mice for these reduced herbicide areas (Tew *et al.* 1992). The use of other pesticides that might affect mammal populations should be carefully controlled. For example, the use of molluscicide pellets is known to reduce wood mice populations (Shore *et al.* 1997), therefore when applied to a field they should be left as far away from the boundary as possible.

For a hedge to act as an efficient corridor for dispersal, particularly for species with strict habitat requirements, it must ideally fulfil certain prerequisites. For example, hedges which are to be used by dormice should be taller than 4m and have a high species diversity. This is because dormice require a sequence of arboreal foods, and certain tree species are important throughout the year. Hazel (*Corylus avellana*), oak (*Quercus* spp.), honeysuckle (*Lonicera periclymenum*), and bramble (*Rubus fruticosus* agg.) are particularly valuable food sources, but dormice can survive without at least one of them if suitable alternatives are available (Bright *et al.* 1996). Bright and MacPherson (2002) specifically recommend some hedgerow management practices, which would benefit dormice and these are repeated below:

- Hedgerows should be trimmed at three yearly intervals at most and, maintained at a height of three and preferably four metres.
- A proportion of hedges (at least 30%) should be left to grow for at least seven to ten years.
- Not all hedgerows should be cut in any one year, so some heavy fruiting hedges are always present.
- Flails should not be used, if possible, to manage hedgerows
- Coppicing or laying should be used to manage gappy or sparse hedges
- If hedgerow size needs to be reduced, avoid cutting the top and cut one side
- Plant at least five to seven different species in new hedges

Dormice are an almost entirely arboreal species, only very rarely coming down to the ground. Gaps in hedges should be minimised, but where they are required, such as in gateways, they should be bridged for dormice with horizontal poles or branches (Bright & Morris 1989).

Hedges will be most suitable as an aid to dispersal if they physically connect suitable patches of semi-natural habitat. These larger habitat patches will probably contain a more optimal habitat, such as deciduous woodland. Planting a hedgerow, or filling in gaps, may complete a previously interrupted wildlife corridor. Isolated hedgerows may act as a useful 'woodland edge' type habitat, containing discrete populations of mammals, but the value of such hedgerows will be less because they are not acting as effective corridors (e.g. Hobbs 1992, Paillat & Butet 1996).

CONCLUSIONS

There are certain species of mammal, such as harvest mice and dormice, for which the presence of hedgerows within an agricultural environment has a significant effect on maintaining the species. Without hedgerows, harvest mice may lose a very important resource and the effect on this species is likely to be large. Dormice also utilise hedgerows, especially within agricultural habitats where woodlands are small and fragmented. These two species are perhaps the mammals most dependent upon hedgerows. Management of existing hedges can be undertaken in order to maximise benefit to these species. As a consequence, the hedgerow will be of better ecological quality and support larger populations of other small mammals and the predators that they support.

Management guidelines which are generally beneficial for mammals in hedgerows include:

1. Let the hedge grow as tall and wide as is practically possible.

2. Encourage retention/development of a dense hedge-bottom, and allow a dense ground flora of herbs and grasses to develop e.g. by restricting livestock grazing.

3. Maximise the production of autumn fruits by trimming in late winter and/or reducing the frequency of trimming.

4. Minimise herbicide and other pesticide use in the vicinity of hedgerows.

5. Maintain and encourage species diversity within the hedgerow. Additional planting may be necessary.

Gaps in hedges should be filled by planting, or bridged where possible (especially for dormice, if present).

OVERALL CONCLUSIONS ON THE EFFECTS OF MANAGEMENT ON WILDLIFE AND PRIORITIES FOR FURTHER RESEARCH

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INTRODUCTION

MAFF's original Research Specification Document for this review in 1995 set five scientific objectives. These were:

1. *To assess the impact of different forms of management on hedgerow biodiversity, e.g. closely cut, cut into an A-shape or square-topped, laid or coppiced. The impact on wildlife value of non-management (i.e. development into relict hedge) also needs to be taken into account, as does the timing of any management activities.*

2. *To assess the impact of immediately adjacent land use on hedgerow biodiversity, e.g. intensive arable, arable with uncropped strips alongside the hedge, permanent grass, woodland or water-course.*

3. *To assess the relative importance of hedgerows for wildlife in different farming contexts, e.g. arable versus grassland, lowland versus upland. This will need to take account of varying local practices, e.g. Devon pastoral compared with West Midlands/Marches pastoral.*

4. *To identify methods of enhancing biodiversity in hedgerows taking into account costs and practicability, and considering both individual hedges and combinations of hedges which might, for example, form a wildlife corridor.*

5. *To identify gaps in knowledge by an analysis of research needs against published and current research and to provide a prioritised list of future research requirements.*

Although each of these objectives has been addressed already in this report, it is important to note that, despite an extensive literature search and consultation exercise, insufficient information was uncovered to ensure that detailed and definitive answers can be given to all of the questions that these objectives raise. Many publications give unequivocal recommendations for the management of hedgerows to benefit wildlife. The findings of this review suggest that there is, however, only limited (if any) scientific research data to support many of those recommendations. This research information, much of it published within the last ten years, is supplemented by some national survey data, most notably that collected as part of the Countryside Surveys. Many recommendations, which may be perfectly sound, appear to be based primarily on very limited local surveys or the 'observational' evidence of a single naturalist.

In the original version of this review, published in 1995, it was stated that there was *"an obvious shortage of data from long-term, replicated, field experiments, specifically designed to study the effects of different management regimes on hedgerow flora and fauna populations."* This issue has been addressed by some significant UK research projects undertaken since the publication of that 1995 report, but the above statement is still largely accurate. We now know more that we did in 1995, but further research to support Government agri-environment schemes and other hedgerow management initiatives is still necessary. Many fundamental questions remain to be answered.

The Countryside Surveys have clearly illustrated how hedgerow removal has become a much less significant problem in the past 20 years. The *Hedgerows Regulations 1997* should give statutory protection to most of the hedgerows in England and Wales, that comprise the ancient and species-rich hedgerows BAP priority habitat.

The recent survey of farmers and contractors provided the data to underpin the evidence of our own eyes – confirming that the general standard of hedgerow management is poor, in that it is not compatible with sustained biological productivity and plant and animal biodiversity. If, perhaps, it might be argued that the battle against hedgerow removal has been won, there is still much to do before our remaining hedgerow networks are fulfilling their potential as valuable habitats for wildlife.

THE IMPACT OF DIFFERENT FORMS OF MANAGEMENT ON HEDGE BIODIVERSITY

The desirability of a high diversity of species in a hedgerow is dependent on the use of the hedge and on the viewpoint of the user. It has been a generally accepted ecological principle that high species diversity is a 'good thing', in order to maintain a larger gene pool and allow natural processes to be buffered against man-made threats. From a wildlife conservation viewpoint, however, the desirability of a diverse flora and fauna may depend on the 'quality' of the constituent species.

Hedge management

The role of hedge management in determining diversity of hedgerow woody species is still not clear. Some studies have found strong links between a variety of management factors and species diversity, whilst others have found no relationship.

Hedge shape, dimensions and density

Work in Northern Ireland, in particular, has shown that hedge management and height had most influence on tree and shrub species diversity. In one study, complete hedges had significantly more species in the tree and shrub plots and boundary strip plots, than gappy hedges. However, in another study, woody species diversity was greatest in gappy hedges. Taller and wider unmanaged hedges were associated with greater tree and shrub diversity and woodland species were positively correlated with hedge height.

Early recommendations that hedges "*should be kept reasonably short (about 2 m), in order to avoid impoverishing the ground flora by shading it out*," are contradicted by some research which has shown that species-rich ground flora groups were significantly associated with the tallest and widest hedges and that the greater the structural diversity of a hedge, the more likely it was to be associated with a species-rich flora.

An analysis of Countryside Survey 1990 data found that management of the hedge had no significant effect on plant species diversity, either within or beneath the hedge; but a survey in Northern Ireland found that the species diversity of ground flora plots was most strongly influenced by hedge width.

Larger hedges, with greater total areas of foliage, will generally support larger populations of phytophagous insects (although not necessarily more species). This should, consequently, have benefits for species higher in the food chain (e.g. entomophagous insects and insectivorous birds).

Tall hedges (>2 m) have been shown to be beneficial to butterfly species diversity.

A-shaped hedges have been frequently recommended for wildlife conservation purposes. The value of such hedges to invertebrates is, however, disputed - with arguments for and against presented in the literature.

Dense, well connected, hedges are preferred by small mammals (and are probably essential to arboreal species such as the common dormouse, *Muscardinus avellanarius*). Consequently, such hedgerows are also preferred by their predators (e.g. foxes (*Vulpes vulpes*), stoats (*Mustela erminea*) and weasels (*Mustela nivalis*). Butterflies also prefer the shelter of dense, continuous hedges.

The presence of hedgerow trees is thought to be important for bats, providing potential hibernacula for species such as the noctule (*Nyctalus noctula*).

Method of trimming

The use of flails has been shown to be associated with greater numbers of tree and shrub species in Northern Ireland, but with a reduction in species diversity in Cornwall. A reduction of species with finger-bar trimming has also been observed.

There is also evidence that the use of flail mowers has reduced the number of hedgerow trees, or at least prevents the development of new hedgerow trees to replace the many trees lost through Dutch Elm disease, etc.

Overall, it appears that any active management treatment will increase the numbers of plant species (initially) compared with unmanaged hedges, with coppiced hedgerows being associated with the highest species numbers (probably due to increased levels of light). However, not all studies support this contention.

Timing and frequency of management activities

There are numerous references to the need to avoid any active hedge management at the times of bird nesting (spring to early summer), fruit setting (autumn) and fruit eating by birds and small mammals (winter). This leaves a short window in late winter when cutting might best be done. However, it has also been noted that some hedge species (including hawthorn, *Crataegus* sp.) only fruit on the previous year's growth, i.e. that which is usually trimmed off annually. This suggests that cutting should not be carried out more frequently than in every other year.

Avoidance of annual trimming is reported to be important to many invertebrate species, as well as to berry-feeding birds and mammals - hedges that are managed to allow maximum flowering being important food sources for nectar feeding insects. However, more recent research has shown that invertebrate groups show mixed responses to different timings and frequencies of hedge trimming. For example, whilst psyllids are more abundant on untrimmed hedges, springtails and thrips respond positively to regular cutting. Increased trimming frequencies probably stimulate shoot and leaf production and increase leaf area per square metre of hedge face – benefiting herbivorous invertebrate species.

The negative effects of annual hedge trimming on the brown hairstreak (*Thecla betulae*) butterfly (now rare in much of southern Britain) are also well documented.

Relatively infrequent trimming of alternate sides of a hedge is recommend for common dormice.

Work at Wye College has shown that summer cutting of hawthorn leads to a squat, bushy hedge and winter cutting results in a taller hedge. A vertical cut produces a taller hedge and horizontal cutting encourages lateral growth. In more detail, a vertical cut in summer produced a thornier hedge than a vertical cut in winter. Thus, the timing of the cut will determine whether emphasis is given to a thornier hedge, possibly desirable for stock-keeping (although very few hedges are truly stock-proof at modern, high stocking rates), or to one with longer bud-tipped shoots with the potential for more flower and fruit production.

In a survey of hedgerows in Cornwall, there was a 70% reduction in floral species diversity following use of a flail, twice a year - May/June and July/August. After flailing was reduced to a single annual cut, taking place later in the year, plant species started to return. Persistent summer flailing was also shown to greatly reduce the diversity of butterfly and moth species. There has been no work on the optimal timing of hedge bottom management.

Although late winter cutting has clear benefits for berry-feeding birds and small mammals, it may be generally detrimental to invertebrates (e.g. species of Lepidoptera and Diptera), if compared with September trimming. This may be due to the removal of insect eggs laid during the autumn and destruction of overwintering larvae and adults.

These results suggest that diversity of hedgerow management regimes is probably important, if hedgerow biodiversity is to be maximised. However, the optimum scale at which any 'matrix of hedge management' should be operated is not known.

In the absence of further, and more detailed, research information on this subject, and in the light of the fact that current hedgerow management is strongly biased towards annual trimming and August/September timings, it is recommended that ongoing initiatives to persuade more farmers and landowners to trim hedges every 2-3 years in late winter should continue and will bring net benefits to farmland biodiversity.

The impact on wildlife value of non-management of a hedge

There has been no research directed solely at this issue.

The impact of non-management is time related. From the literature, it is reasonable to suppose that if a managed hedge is 'let go' and left unmanaged then, initially, it will gain in woody species, especially good colonisers. The ground flora will similarly diversify and allow shade-loving species to colonise (if niches become available).

However, after some time, as vigorous woody species grow up and become dominant, the number of woody species may decline. Similarly, if there is no 'wildlife management' of the hedge bottom and immediately adjacent land, then the ground flora may become dominated by a limited number of shade-loving species and may become more subject to the effects of adjacent land use, perhaps leading to vigorous, aggressive (e.g. nitropholous) species becoming dominant.

High plant species diversity is likely to be associated with high structural diversity and with change.

Evidence of the effects of non-management on the invertebrate fauna of hedges is again conflicting. One study has shown there to be more phytophagous insect species on unmanaged hedges in comparison with trimmed hedges, but no overall increase in saprophagous or entomophagous species (although flower bugs and harvestmen increased). Another study, however, found a greater number of insect taxa on cut hedges, in comparison to either hedges uncut for five years or 'remnant' bushes and trees. Early results from an experiment in Northern Ireland support this latter conclusion - indicating that any form of hedge management may be better for invertebrates than no management.

The greatest diversity of bird species is likely to be found in large, unmanaged hedges; although species number will probably fall again as a 'relict' hedge further degenerates into a line of trees.

Large hedges (particularly 'expanded hedgerows' which have grown outwards into neighbouring fields) are also believed to be particularly favoured by several species of mammal.

Hooper suggested that the ideal hedge for wildlife was probably unmanaged, around 4 metres in both height and width, and had brambles along the bottom (on both sides). Recognising the impracticality of such a hedge, he recommended a compromise that was again 4 metres tall, but was 2 metres wide with only the sides subjected to trimming.

Hedge-bottom management

Direct application of herbicides into hedge bottoms will, of course, directly affect the flora (as this is the aim of such sprays); it will also damage the invertebrate fauna. Two studies have demonstrated the negative effects of 'total' (i.e. non-selective) herbicide applications on, firstly, ground beetles and spiders and, secondly, predatory invertebrates in general. This might, consequently have significance for pest populations in a neighbouring arable crop (i.e. numbers might increase as natural enemies in the hedgerow are reduced).

Direct spraying to kill patches of nettles (*Urtica dioica*) in hedgerows is a common practice, particularly in grassland areas. This has been directly linked to an observed contraction in the range of two butterfly species - the peacock (*Inachis io*) and small tortoiseshell (*Aglais urticae*).

Maintenance of a dense ground flora will benefit small mammal species - including shrews, bank voles (*Clethrionomys glareolus*) and harvest mice (*Micromys minutus*) - providing additional food sources and essential cover from predators.

THE IMPACT OF IMMEDIATELY ADJACENT LAND USE ON HEDGEROW BIODIVERSITY

Various studies have shown that the diversity of the hedgerow, and especially of the hedge-bottom flora, is strongly affected by the nature of the surrounding land use. Both very intensive land management, and no management at all, are deleterious to the number of herbaceous plant species in hedge-bottoms.

It has been shown repeatedly that herbicides, insecticides and fertilisers frequently 'drift' into the hedgerow (as well as sometimes being deliberately applied). These chemicals kill some plants and may favour others (e.g. nitrophilous plants). Pesticide drift will be much more of a problem from intensively farmed arable fields. Fertiliser drift may be a serious problem in hedgerows adjacent to arable fields or improved grassland.

Pesticide drift into hedgerows, as well as larger field sizes and a greater frequency of management operations, has been suggested as one possible reason that lower numbers of birds are commonly recorded in hedgerows adjacent to arable crops.

Other disturbance factors, such as close cultivation, grazing and manuring may affect the flora and fauna. Close cultivations may also affect shrub root growth.

Having shown that the spraying of field margins, in an attempt to control weeds, has proved largely unsuccessful, several research groups have examined the effects of introducing field margin management into normal agricultural practice. This approach forms a buffer between the hedgerow habitat and its surrounding land and can be managed to favour wildlife, e.g. by sowing wildflower seed mixes.

'Conservation headlands' (with reduced pesticide inputs) or 'extended field margins' (wider grassy strips between the hedgerow and the crop) may bring numerous wildlife benefits. These are considered further in the following section.

Hedgerows associated with other features such as banks, walls or ditches have been found to be favoured by many invertebrates. Bank voles apparently have a particular preference for hedgerows with adjacent ditches.

Work in France has demonstrated that hedgerows in close proximity to ancient forest have a greater number of 'forest' ground beetles.

Amphibians and reptiles are most likely to occur in hedgerows near ponds or woodland, but can live adjacent to arable fields - where these are within a mosaic of land uses, with adequate vegetative cover to facilitate movement.

THE RELATIVE IMPORTANCE OF HEDGEROWS IN DIFFERENT FARMING CONTEXTS

Hedgerows undoubtedly provide an important habitat for many plant and animal species in agricultural areas. They are likely to have particular significance in areas where semi-natural woodlands are scarce.

There have been no studies which have set out to compare hedgerows in different farming contexts. However, analysis of Countryside Survey data, collected from all over Great Britain, shows that while hedges are particularly important as refuges of plant biodiversity in lowland arable landscapes, there has been a significant decline in the diversity of hedgerow ground flora species in pasture-dominated areas between 1978 and 1990. This decline has continued to 1998.

Within Northern Ireland, work has shown that low floral species diversity in hedgerows is associated with lowland, well managed farms with fertile soils, and that high species diversity is associated with the opposite situation.

Hedgerows are known to provide important refuges for flying insects in very exposed areas, such as Cornwall and upland Wales, where little shelter otherwise exists.

All other contextual information (whether by geographic region or farming type) occur as a result of studies being carried out at a particular locality and do not allow comparisons to be made.

For example, a steady deterioration in the quality of the herbaceous vegetation in many arable field boundaries, from a mixture of tussocky grasses and perennial herbs, to flora composed largely of aggressive weedy species, has been documented.

Hedgerows are said to provide a particularly important habitat for invertebrates (and probably for other groups) in 'ancient' landscapes (predominantly pastoral), such as those found in Cornwall, Devon and south-west Wales. These are often pre-Enclosure hedges on hedge-banks.

It has been suggested that 'Hooper's rule' (stating that diversity increases with age of hedge) may hold true in much of eastern and middle England, dominated by planted hedges in arable landscapes; but there are clear, often regional, exceptions.

Hedgerows may provide an important source of dispersing invertebrates for colonisation of suitable new habitats on farms, e.g. set-aside land.

Reptiles and amphibians are thought to be more dependent upon hedgerows in areas that have very few semi-natural habitats. Hedgerows may, therefore, have particular significance for these groups in predominantly arable areas in eastern England.

Woodland bird species may depend very heavily on hedgerows within landscapes with very little woodland. In other areas there may be little semi-natural grassland - important to several species - other than that beside hedgerows.

METHODS OF ENHANCING BIODIVERSITY IN HEDGEROWS

There are three broad methods for enhancing biodiversity in hedgerows:

1. Protect valuable hedgerows

It has been demonstrated that the diversity of woody species is positively correlated with age of the hedgerow. On this basis, older hedgerows should be protected. Similarly, hedgerows originally assarted (cut out) from ancient woodland tend to be the most botanically diverse, and benefit to wildlife will come from allowing such hedgerows to expand (although this may have a cost, in terms of lost production, to the farmer). Old, assarted hedgerows are also frequently the richest in invertebrate species, e.g. snails and ground beetles.

Several studies have shown that there is a positive correlation between the species diversity of shrubs in the hedgerow itself and diversity in the hedge-bottom flora. Therefore, by protecting hedgerows rich in woody species, the ground flora may also benefit.

Other hedgerows that should be protected, from a wildlife point of view, are those that have diverse structure, a greater diversity of habitats and those that are likely to be one of the remaining refuges of plant diversity in a particular landscape.

2. Manage to make existing hedgerows more valuable

Hedgerows need to be managed occasionally to stop them becoming dominated by single species or becoming 'gappy' - which leads to open bases and few ground flora species.

More work needs to be carried out into preferred hedgerow management, but there is evidence that larger, less well-managed hedges may have greater species diversity (although the reverse may be true for several invertebrate groups). A relationship has been established between the presence of woodland ground flora species and overall species diversity. Woodland species perform best in large, shade-giving hedges.

Annual (or more frequent) trimming would seem to be unsympathetic to plant species diversity. Cutting every other year, or less frequently, is probably more appropriate.

Associated with the type of management, the relationship between geographical scale and hedge diversity (i.e. whether all the hedges on one farm, or in one parish, are managed in the same way) needs further research.

Increased floral diversity should benefit invertebrates, as will the presence of hedgerow trees and dead wood. Hedgerow trees may be valuable to bats.

There is a need to buffer hedgerow bottoms against adjacent land use activities. This can be achieved by encouraging the establishment of wide field margins and headlands. Such margins can be enhanced by sowing wild flower seed mixes and by occasional cutting to discourage scrub development. Provision of a gradual transition of different habitats between a hedge and an intensively farmed field (e.g. shrub-tall herb-shorter grass-arable) will increase invertebrate species diversity. A strip of undisturbed herbaceous vegetation adjacent to a hedge will benefit bumble-bees (*Bombus* spp.).

A well-developed ground vegetation will be likely to enhance amphibian and reptile species diversity, as well as benefiting ground-nesting birds and several small mammal species.

Reduced use of pesticides in field margins ('conservation headlands') has been shown to benefit butterfly populations. It is also likely to benefit many other animal groups. Similarly, benefits for some butterfly species may be achieved by establishment of extended grassy field margin strips.

Clear benefits to game birds have been demonstrated where 'conservation headlands' have been adopted.

Fencing hedges to exclude grazing livestock, particularly in intensively stocked areas, can substantially help to prevent further degradation of hedgerows, and is likely to be an essential first step in the restoration of badly stock-damaged hedges.

3. Create new hedgerows, and 'bring back' relict hedges

In planting new hedgerows, the use of more than one species is recommended. Similarly, in 'gapping up' old, relict hedgerows, the use of different species should be considered.

Species planted should be native and appropriate to the locality, and should ideally be of local provenance.

Landscape design and management should aim to achieve a high degree of 'connectedness' within the network, as well as providing connections with sources of forest species - which may be a major influence on species colonisation of available habitats.

Re-establishment of links between important habitats may also facilitate movement of snakes, birds and several mammal species (e.g. water shrews, *Neomys fodiens*, or common dormice). Common dormice will utilise hedgerows for dispersal between woodlands, but hedges must have a high diversity of woody species (especially of fruiting shrubs) and be continuous, as dormice rarely descend to ground level.

PRIORITIES FOR FURTHER RESEARCH

In the course of reviewing the literature, and abstracting relevant material, the authors have noted where further research is needed, either as a result of clear gaps in knowledge or where conflicting evidence surrounding a particular issue indicates that more work is needed.

Having established where more research effort would be useful, the authors have then prioritised their recommendations, based on the following criteria:

- contribution to basic knowledge
- policy relevance
- timeliness.

The authors have not attributed likely costs to each of the recommendations, which are summarised in the following section.

Taking regard of the authors' recommendations, and using the same criteria for prioritisation, the editors have then defined overall priorities for further research. In some cases, this has involved recommending work that cuts across the themes presented in each of the Sections of this report, resulting in some more 'multidisciplinary' proposals. These overall recommendations are given in the final section.

Summary of recommendations for further research, by Section

There are no specific recommendations for further research in the first three sections.

Hedgerow management options and costs

1. Trimming regimes: the effects of various trimming regimes on the growth and structure of new and established hawthorn or mixed hedges over a longer time period (10 years plus) and the effects of trimming only every two or three years, as recommended for berry/fruit production, on the structure of established hedges in the long term.

2. Herbicide use: the use of herbicides for weed control in establishing/re-establishing hedges; with the aim of producing a 'guidance note' for farmers.

3. Environment-friendly weed control: the conflict between the need for weed control and the need to preserve any semi-natural vegetation, when gapping-up a hedge, need more work.

4. Traveller's-joy (or old man's beard): this is reported to be a major problem within hedgerows in southern England. The extent of this problem, and similar problems caused by other competitive climbers, should be further investigated, and if appropriate further research undertaken to identify suitable and safe control measures.

5. Gapping-up: more information is needed about the optimal methods of gapping-up hedgerows. For example, the minimum amount of 'gap' worth planting up when restoring a hedge by coppicing should be determined.

Plants and hedgerows

1. Further, targeted analysis of existing botanical data (e.g. Countryside Surveys): during the course of this review, several observations have been noted about the causes of floral diversity in hedgerows which are based on local observations or the results of regional studies. In the Countryside Survey data sets, there are vegetation data from some 950 quadrats placed alongside hedgerows, in all parts of Great Britain. Associated with these quadrats are spatial data (e.g. proximity to woodlands, boundary nodes), environmental parameters (soil, exposure, aspect) and management factors (both of the hedge and the surrounding land). These data should be analysed to examine the relationships that exist and, especially, in an attempt to confirm results from local or regional studies. There is also scope for a more detailed examination of the data in relation to individual species and biogeographical zones.

2. The 'quality' of hedgerow flora: the review has shown that although several conclusions have been drawn about overall species diversity, there has been only passing reference to the 'quality' of the species assemblages. What species are desirable (i.e. of wildlife interest) in the hedgerow and how can these be encouraged?

3. Hedgerows as corridors for the movement of plants: there is disagreement in the literature about whether plants 'move' along hedgerows. Much of the debate is based on correlative, rather than experimental, studies. There is a need for both long-term monitoring studies, spatial analysis and perturbation experiments, to establish whether plants do move along hedgerows, and over what time-scales.

4. Planting in the uplands: Following up on the work of Hayes *et al* in Wales, further work should seek to

a) identify optimal species choice and planting arrangements in new upland hedgerows, to enhance wildlife diversity in the longer-term
b) identify management(s) of associated field-margin herb-layers (including hedge-bank sides) for general and specific wildlife benefit, the latter particularly in relation to declining or rare flora and fauna;
c) quantify potential benefits of extensively managed field-margins within intensively managed grassland areas, to act as wildlife corridors in linking other upland semi-natural habitats, and
d) identify optimal managements for mature mixed-species hedgerows.

Further research at a greater spatial scale should also investigate the value of linear habitats in replacing declining upland habitats, such as heather moor or oak woodland, and halting their fragmentation, providing ecological alternatives to the traditional hedgerow.

Invertebrates and hedgerows

1. Current invertebrate population estimates: there is an urgent need to establish baseline data on the invertebrate populations of hedgerows as they exist at the present time. Most of the literature studied during the compilation of this Review has quoted observations or studies carried out in the 1960's and 1970's (e.g. Elton 1966; Pollard 1974). Changes in farming practice and hedgerow maintenance since this time are likely to have resulted in changes in the number and type of invertebrates using hedgerows. There is a need for comparative data on the invertebrate fauna of the major British hedge types. Specific forms of hedgerows, such as 'green lanes', have been noted as being particularly valuable for invertebrates and this should be confirmed.

2. Hedge dependent species: among the best-documented species are those which are considered as either pests or 'beneficials' in agriculture and those which are highly visible and/or mobile such as butterflies. Many of these species are, however, partially dependent upon non-hedgerow habitats. Such a bias in available information may lead to misleading conclusions about hedgerow management. Further research should include a proportion of studies on populations of invertebrates, such as Psocoptera (e.g. book-lice), which are almost entirely dependent on the woody species within the hedge. Psocoptera live on microepiphytes (fungi, algae and lichens) which grow on the bark, leaves and leaf litter and they form an important food source for many other invertebrates (Thornton 1985). Change in the population dynamics of this type of invertebrate may be less subject to uncontrolled factors outside of the hedge habitat than groups such as butterflies.

3. Set-aside: research is required on the effects of the various set-aside options, and their management, on invertebrates in hedgerows. The effects of 'headland set-aside' may be of particular importance, as this would appear to provide an opportunity to fulfil some of the requirements of invertebrate groups such as butterflies, allow desirable hedgerow management practices and, perhaps, be popular with farmers.

4. Landscape ecology: the linkage between individual hedgerows and other landscape elements (network connectivity), and how this affects the diversity of invertebrates, requires investigation. Little work of this sort has been reported in the UK, but the results of a number of studies indicate more precise methods of increasing invertebrate diversity in hedgerows than those currently available.

Amphibians, reptiles and hedgerows

1. Further examination of British Herpetological Society surveys: there is some outstanding work under the JAEP project still to be published and both the Amphibian and Reptile surveys might be further examined to provide additional recommendations on habitat management.

2. Targeted fieldwork: further work is necessary to identify to what extent the hedgerow is used as a habitat, as a corridor and for hibernation by this group of species and little is yet known on the direct effect of hedge management. Because of observational difficulty, and perhaps a lack of perceived aesthetic charm and economic value, this group of species seems to have been overlooked in many studies of the agricultural environment.

Birds and hedgerows

1. Experimental studies of cutting/trimming regimes: most lacking in studies of birds are experimental manipulations of hedgerows. Few of the studies of bird populations have looked at hedge management *per se*. Rather, most have looked at existing hedge composition and dimensions and their relationship with bird populations. Whilst this approach can indicate appropriate management, this was not the primary focus of the research. Some work was carried out by FWAG in Wiltshire (Moorhouse 1990) but involved small samples. In order to provide hard recommendations on appropriate forms of hedge management, an experimental management programme is necessary. It is envisaged that such research would require fairly homogenous hedgerows, to provide the experimental plots, and a properly designed experiment comparing management could be carried out on these. Baseline monitoring would be necessary to ensure, or adjust for any lack of, homogeneity in the bird populations.

2. Species composition of new hedgerows: several studies suggest that bird species richness is enhanced in hedgerows of diverse shrub composition. The value of planting new hedges of diverse composition could be investigated on an experimental basis: using some hedges of pure hawthorn (*Crataegus monogyna*), and others of mixed composition. Monitoring of the subsequent bird populations must be considered as a long-term exercise. Alternatively, results might be more quickly, but less accurately, obtained by taking a relatively diverse hedgerow and gradually reducing the floral diversity of one or more of the layers (base

flora, scrub species, climbers, etc.) and examining the effects on bird populations.

3. Influence of neighbouring woodlands and other spatial analysis: estimates of bird density in hedgerows are available, as is the knowledge of how these are affected by adjacent land use and the presence of intersections. It would be interesting to see how bird density changes in hedgerows close to woodland and for what distance a woodland exerts an influence over a connected hedgerow system. Suitable raw data already exist from the BTO's Common Birds Census results, but would require interrogation.

4. Hedge shape and quality: More work on the effects of contrasting hedge shapes is needed, as is information on the quality of particular hedges (e.g. composition, density, cover, food supply) from a bird's perspective.

5. Reproductive performance and predation: A study on reproductive performance in farm hedges could help to address concerns about high predation rates in some hedgerow studies and general declines in farmland populations.

Mammals and hedgerows

1. Population studies: changes in mammalian populations and biodiversity resulting from different hedge management techniques should be fully quantified. This can be achieved by simple population studies, within hedgerows managed under different regimes.

2. Critical species: more data should be gathered on the significance of hedgerows for 'critical' species, notably harvest mice (*Micromys minutus*) and common dormice (*Muscardinus avellanarius*).

3. Bats: relationships between bats and hedgerows should be studied. The importance of hedgerows as both a food source and navigational aid, and of hedgerow trees as roosting sites, should be investigated.

Overall research priorities

Several authors have pointed out that research on the management of hedgerows and associated wildlife needs to be integrated; no single theme can be researched in isolation because many factors are interdependent. It is recommended, therefore, that specific research proposals recommended below are linked through a 'research umbrella' project which ensures, where possible, uniformity of approach (e.g. scales, sampling unit, definitions). There should be a formal mechanism to ensure that any research which is to be funded is reported to a 'Steering Group' or similar, thus ensuring effective communication among researchers, and to Departments and agencies.

It is possible to group the recommendations given above into larger, more multidisciplinary projects. This is seen as appropriate in some cases (where there is clearly benefit in adopting a standard approach to answer several, related research questions), but not in others (where the recommendation relates to very specific areas of concern or interest). For easy reference, these two different types of research recommendation are listed below as 'multidisciplinary' and 'specific'.

'Multidisciplinary' projects

1. Surveys and populations studies: because much of our current knowledge of hedgerow fauna and flora is based on work that is now several years old, and because there have been demonstrable changes in the countryside over the last few years, and in farm management methods, there is clearly a need to update baseline information on the range of species that is present in hedgerows and on the population ecology of these, especially 'critical' species. We need to know whether these populations are increasing or decreasing and whether changes in agricultural management are likely to reverse any undesirable trends.

2. Examination and further analysis of existing data sets: data collected as part of some large, national surveys (e.g. Countryside Surveys, the UK Environmental Change Network, Farm Business Surveys) and others which are more thematic or regional (e.g. British Herpetological Society survey, Hooper's survey of some ITE Land Classes), need to be re-examined and analysed with hedgerows (and immediately adjacent land use) in mind. It is important to make full use of information of this kind, before new data are collected.

Specific research areas

1. Adjacent land use, headlands and set-aside: although there has been research on the movement of agriculturally important species out of hedgerows into crops, there have been few studies looking at the influence of adjacent land use, especially novel crops, headlands and set-aside on hedgerow species (especially invertebrates); nor of the 'value-added' benefits of having multiple element field edges (i.e. including both a field margin and a field boundary).

2. Landscape ecology: several authors have referred to the need to study hedgerows as part of the wider landscape (holistically). The type of adjacent land use, the presence of surrounding landscape features, linkages to these and movement potential around the landscape network are all likely to influence the species complement of a hedge. The work of Baudry and Burel in France, and Forman in the USA, needs to be developed in the UK.

3. Management matrix: from recent research, it can be assumed that a diversity of management regimes will maximise benefits to biodiversity. However, what is not known is the scale at which any 'management matrix' is best designed and implemented (e.g. field, farm, parish or larger), or the optimal proportions of the different management systems within any given area.

4. 'Quality' and desirable composition of hedgerow flora: agreement needs to be reached on when and where high species diversity is appropriate and on what species are considered to be desirable. Wildflower sowing and the re-establishment of herbaceous vegetation in degraded hedge bottoms, especially in arable areas, needs more research. This might be linked to problems of residual nutrients (which favour fast-growing and vigorous species, at the expense of meadow species) and methods for their removal.

5. Planting methods and choice of species for new hedgerows: certain aspects of hedge establishment need further work, including choice of provenance, protection of young plants, sizes of gap to be planted and desirable species composition.

6. Herbicide use and environmentally friendly weed control: although 'ecological' forms of weed control are being studied (field margin management), the use of herbicides for weed control in establishing/re-establishing hedges needs to be undertaken. Further research on this topic is required.

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