Effects of hedgerow management and restoration on biodiversity

Final report

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Executive summary

Hedgerows can provide key semi-natural habitat within intensively farmed landscapes, and can deliver habitat and resources for a range of important wildlife, in addition to supporting ecosystem services. The value of hedgerows in supporting wildlife varies, depending on the management applied. Hedgerow management options have high uptake within agri-environment schemes (AES), both historically in Environmental Stewardship (ES) and in the current Countryside Stewardship (CS) scheme, including the Hedgerow and Boundaries grant. Previous studies on hedgerow management have shown substantial potential effects of hedgerow management regimes on the provision of resources for overwintering wildlife (Sparks and Croxton, 2007), and some indication of benefits for wildlife (Maudsley et *al.* 2000), but have not been quantified or rigorously tested. Here, results from three large-scale manipulative field experiments are presented, to assess different hedgerow management and rejuvenation methods in relation to the provision of resources for wildlife, and the response of invertebrates.

The **aims** of this study were:

1) To examine the effects of simple hedgerow cutting regimes promoted by CS and ES, and the potential for cutting to allow incremental growth, on the quality and quantity of wildlife habitat, and food resources in hedgerows.

2) To identify, develop and test low-cost, practical options for hedgerow restoration and rejuvenation applicable at the large-scale under both CS and ES.

Methods

Two experiments were conducted to assess hedgerow cutting treatments. Experiment 1 consisted of replicated cutting frequency (every year vs. every two years vs. every three years) and timing (autumn vs. late winter) treatments, applied to replicate sections of hawthorn-dominated hedgerow at a single site in Cambridgeshire. Experiment 1 pre-dated this research project, and so it provided initial findings on these cutting regimes early in the project, which informed the revision of ES hedgerow options in 2012. Experiment 2 was run at five sites in lowland England over seven years (2010 – 2016), on hedgerows dominated by hawthorn (two sites), blackthorn (one site) or a mixture of woody species (two sites). In addition to testing the same cutting treatments as Experiment 1 on a wider range of hedgerow types and locations, Experiment 2 was designed to test the effect of cutting intensity, in order to assess a new hedgerow management option that might be included in future AES.

A second multi-site experiment was conducted at five separate lowland sites in England, to compare traditional forms of hedgerow rejuvenation (Midlands style hedge-laying, coppicing) with alternative methods (conservation hedging, wildlife hedging, reshaping with a circular saw). Woody species composition varied between rejuvenation sites, further details below (Section 2.2). Rejuvenation methods were applied to replicate sections of hedgerows, and assessed immediately following implementation in terms of their cost and the time to apply each method. In addition, ongoing management (cut twice in five years as per current ES guidance) was applied to half of each rejuvenated plot, in a split-plot design. The other half was left unmanaged following the rejuvenation. Regrowth, hedgerow structure and berry provision were assessed over three years following the hedgerow rejuvenation.

Key findings

Hedgerow management (frequency, timing and intensity of cutting)

- Cutting once every three years (a current AES hedgerow option) had clear benefits, compared with cutting once every year, which is the current standard practice for hedgerows outside AES schemes. Hedgerow plots cut once every three years had more flowers from two woody hedgerow species (hawthorn and blackthorn), which were shown to be linked to enhanced utilisation of these floral resources by pollinating invertebrates.

- More berries were available for overwintering wildlife from four woody species (hawthorn, blackthorn, bramble and dog-rose) on plots cut once every three years. At some sites the increase in hawthorn and blackthorn berries were limited to plots cut in winter.

- More Lepidoptera (butterfly and moth) caterpillars and pupae were present on plots cut once every three years, and there was a greater species richness on these plots. More eggs of brown hairstreak butterfly, a conservation priority species, were found on plots cut once every three years in autumn.

- There was weaker evidence for the benefits of cutting once every two years. Plots cut once every two years had more hawthorn flowers at some sites and in some years, but flowers were not increased across multiple woody species. More berries were available over winter from four woody species (at some sites) on those plots cut once every two years in winter, but not on plots cut every two years in autumn.

- Cutting to allow incremental growth (retaining around 10 cm recent growth when a hedge is cut, so the height and width gradually increases) forms part of the management advice for the current CS hedgerow option, but is not included as a compulsory management prescription. Results from this project provide strong support for the inclusion of this reduced, incremental trimming intensity in future AES hedgerow management prescriptions.

- Cutting at a reduced intensity to allow incremental growth resulted in substantially more hawthorn and blackthorn flowers and berries, leading to increased utilisation of these plots by pollinating invertebrates. Lepidoptera diversity was also increased under this reduced intensity cutting treatment, as were the number of brown hairstreak butterfly eggs. Regrowth following incremental cutting was reduced for both blackthorn and field maple, compared to standard cutting intensity.

- The benefits of an incremental cutting intensity were not dependant on the timing of cutting, unlike some benefits of the reduced cutting frequency treatments. On land where access for hedge cutting is limited to some times of year (e.g. on land too wet to access with a tractor and flail in late winter), this reduced intensity cutting will provide a range of benefits for wildlife.

- The timing of cutting affected the Lepidoptera community using the hedgerows. Plots cut in winter had a greater overall abundance of larvae and pupae than those cut in early autumn, but fewer brown hairstreak butterfly eggs, a priority species for conservation. Timing of cutting should be tailored to the requirements of species present at particular sites. To achieve this, AES hedgerow option prescriptions should include some flexibility about the timing of cutting. Current hedgerow options within ES and CS do contain this flexibility.

- Visitation rates of pollinating invertebrates to woody hedgerow flowers were strongly linked to floral abundance, within each species. Pollinating invertebrates made relatively more visits to blackthorn and bramble than hawthorn, perhaps because alternative floral resources are scarcer when blackthorn and bramble are flowering.

- There was no evidence to support the assertion that cutting frequency can alter the woody structure of hedgerows, over the six years of this experiment. There was some weak evidence that maximum gap size in the base of hedgerows may be slightly smaller under an incremental trimming intensity, compared with plots cut back to a standard height and width.

- Regrowth of hawthorn was largely unaffected by the timing and intensity of cutting. This suggests that the effort required for cutting hawthorn hedges under regimes that differ in timing and intensity should be about equal. In contrast, regrowth of blackthorn and field maple was reduced under the incremental cutting intensity treatment.

Hedgerow rejuvenation methods

- Of the three layed rejuvenation methods (Midlands hedge-laying, conservation hedging and wildlife hedging; see Section 2.2 for details), wildlife hedging was far quicker to apply than the other two methods (on average less than 1 minute vs. 12 and

33 minutes). However, it cost 62% of the price of conservation hedging and 33% that of Midlands hedge-laying. Wildlife hedging requires three people and heavy machinery, which may be why the time it took was reduced more than price.

- Differences between the three layed rejuvenation methods in regrowth and berry provision were greatest in the two years immediately following rejuvenation. Berry provision was not reduced immediately following rejuvenation for wildlife and conservation hedging, but was for Midlands hedge-laying. However, by the third year there was no difference. Canopy regrowth in the second growth season following rejuvenation was less vigorous following wildlife hedging, though this difference was no longer apparent by the third season.

- Regrowth from basal stools also differed between layed treatments, as wildlife hedging resulted in taller shoots and fewer basal stems with shoots. There were differences in the basal hedge structure between these three methods, as the wildlife hedging plots had a greater woody area and smaller maximum gaps than the other two layed treatments.

- The conservation hedging was twice as quick to apply and about half the cost of Midlands hedge-laying. The conservation hedging plots had slightly lower rates of canopy regrowth in 2012 and a heavier berry weight in 2010-2012, but by 2013 did not differ from plots rejuvenated using Midlands hedge-laying in terms of regrowth, structure or berry provision. Conservation hedging has similar medium-term benefits as more traditional hedge-laying styles, and thus could provide a cost-effective rejuvenation alternative under AES such as Higher Level Stewardship, or the Higher Tier of the current CS scheme.

- Coppicing was the second cheapest rejuvenation method tested if fencing was not required, and showed the most vigorous basal regrowth following rejuvenation. Coppice affected hedges over a longer time-scale than the other methods tested, shown by differences in regrowth, structure and berry provision that were still apparent three to four years later. Coppiced hedgerow sections had the most vigorous basal regrowth following rejuvenation.

- Reshaping with a circular saw was the cheapest rejuvenation method tested, and had longer term effects on canopy regrowth and berry provision than the three layed methods. Circular saw plots continued to produce greater canopy regrowth compared with the unmanaged control plots three years after rejuvenation, and still had reduced berry weights four years later. The structure of circular saw plots was more similar to that of control plots than the other rejuvenation methods, as the density of woody material in the hedge base was not increased.

- Reshaping with a circular saw and coppicing have benefits as cost-effective methods by which to encourage canopy and basal regrowth respectively. Both methods reduced berry provision even four winters following rejuvenation, compared to unmanaged plots. In addition, reshaping with a circular saw did not increase the density of hedge bases, and immediately following rejuvenation coppiced plots also had little basal woody material. Both methods may provide less shelter for mammals and invertebrates than the three layed rejuvenation methods, over the four year timescale tested in this project, and potentially longer.

Summary

The findings of this project provide support for some existing AES hedgerow management options, within both the ES and CS schemes, in terms of the provision of resources for wildlife and the invertebrate communities that utilise hedgerows. New management techniques have been shown by this project to have potentially more substantial and consistent benefits; reduced intensity cutting to allow incremental growth; and conservation hedging as an alternative to traditional hedge-laying. Early results from this project were used to inform the revision of hedgerow AES options in 2012, and through peer-reviewed papers, knowledge transfer events and resources, the findings of this project have been and continue to be widely communicated.

1. Introduction and project aim

1.1 Introduction

1.1.1 Why study hedgerows?

Throughout lowland Britain hedgerows are important landscape and historic features, and they play a key role in wildlife conservation, stock management, shelter and erosion control. The hedgerow network may also play an important future role in climate change adaptation by enabling the movement of species through intensively managed landscapes (Lawton et al., 2010). Recent research has found hedgerows facilitate key ecosystem services, such as pest control and pollination (Morandin & Kremen, 2013; Morandin et al., 2014; Morandin et al., 2016)

Hedges require frequent management in order to maintain their character, condition and ecological function, and to prevent them overgrowing and shading crops. These activities can be classified into: a) maintenance, typically trimming every one to three years, to control competitive species (e.g. elder *Sambucus nigra* L.), sustain bushy growth and maintain condition, shape and size, and b) rejuvenation, such as laying or coppicing, which is carried out every 20+ years to rejuvenate or restore structural integrity, and prevent hedges from becoming gappy at the base or overgrown.

Current agri-environment scheme (AES) policy seeks to influence hedgerow management by encouraging more relaxed cutting regimes, cutting in the winter rather than the autumn under the Entry Level Stewardship (ELS; Natural England, 2013a) and Countryside Stewardship (CS; Natural England 2018) schemes. The conservation of species-rich hedgerows by appropriate management is supported under the Higher Level Scheme (HLS; Natural England, 2013b) and through capital grants under the CS scheme, including the Hedgerows and Boundaries grant (Natural England, 2017). The Hedgerows and Boundaries grant provides capital funding for one-off hedgerow management, which is open to landowners not in the broader CS scheme (Natural England, 2017).

Provision of hedgerow berry resources for overwintering wildlife and nectar resources for pollinating invertebrates are major objectives of the current CS and ELS hedgerow cutting options (BE3, EB 1/2/3). Previous research had indicated that leaving hedges uncut for at least two years resulted in increases in the berry yield of hard-fruited species compared with hedges subjected to annual cutting (Croxton & Sparks, 2002). Early results from the current project have demonstrated that cutting hawthorn-dominated hedges every two years in early autumn does not significantly increase berry resource availability for wildlife over winter compared with annual cutting (Staley et al., 2012b). By contrast, cutting hedgerows in late winter every two years, or once every three years, increases hawthorn (*Crataegus monogyna* Jacq.) berry availability over winter and hedge flower production (Staley et al., 2012a; Staley et al., 2012b).

The current project also tests whether these initial results are more broadly applicable across a range of hedgerow types and species. Cutting hedgerows in winter every two years may be difficult to implement on low ground with heavy soils, as the quality of field margins can be reduced due to soil compaction if they are driven on in wet weather. Vehicle tracks and soil compaction are not permitted on field margins that are managed as part of AES agreements (Natural England 2013a). Incrementally increasing the height of hedge cutting each year may prove to be a means of providing fruit each season, allowing hedges to develop gradually over time in a controlled manner and avoiding the need to cut in the winter. The value of this novel approach was tested in this project.

The invertebrate fauna shows a somewhat mixed response to the effects of timing and frequency of hedge cutting (Marshall et al., 2001a; Marshall et al., 2001b; Maudsley et al., 2000). For example, Psyllidae (plant suckers) were significantly more abundant on uncut hedges, whereas Thysanoptera and Collembola were enhanced by trimming. It has been suggested that regular hedge cutting could result in a greater diversity of invertebrates, due to the stimulation of new woody plant growth. However, late winter cutting may be detrimental due to the removal of insect eggs and Lepidoptera larvae. Finally, hedges are known to provide important resources of pollen and nectar within intensively managed landscapes (Croxton et al., 2002; Jacobs et al., 2009), but prior to this project there was little or no research on the effects of hedge cutting regimes on provision of flowers for pollinating insects (e.g. bees and butterflies).

In addition to rigorous testing of alternative hedgerow cutting regimes, this project addressed the urgent need to develop low-cost and effective means of restoring and rejuvenating hedgerows. This need is driven by several factors, including a growing number of hedges being left entirely unmanaged and developing into lines of trees (Carey et al., 2008), increasing costs of labour, a growing shortage of skilled practitioners, and limited funds under AES for traditional rejuvenation practices such as laying. Traditional hedge-laying techniques improve the structure of hedgerows by encouraging more vertical growth and removing large gaps from the base of the hedge (Brooks & Agate, 1998), but are costly, time-consuming and require skilled practitioners. The benefits of alternative forms of rejuvenation, such as coppicing or reshaping with a circular saw, have not been rigorously compared with hedge-laying in relation to their effects on regrowth, structure and berry provision for wildlife. In addition, a mechanised form of laying (‘wildlife hedging’) has recently been developed (Dodds, 2005) and was tested here.

1.1.2 Uptake of hedgerow management options in agri-environment schemes

ELS options	ELS agreements starting 2009 – 2012			ELS agreements starting 2013 – 2014		
	Option hedgerow cutting regime	Points per 100m*	Length of hedgerow (km)	Option hedgerow cutting regime	Points per 100m*	Length of hedgerow (km)
EB1 / EB8	Cut both sides of each hedgerow not more often than once in two years	22 / 38	60,811.33	Hedgerow management for landscape: Cut both sides of each hedgerow not more often than once in two years	16 / 38	6,505.09
EB3 / EB10	Cut both sides of each hedgerow not more often than once in three years	42 / 56	28,409.58	Hedgerow management for landscape and wildlife: Cut both sides of each hedgerow not more often than once every three years or cut each hedgerow no more than once every two years between 1 January and 28 February.	42 / 56	5,083.14

Table 1.1 Uptake (kms) of hedgerow options in the Entry Level Stewardship (ELS) agri-environment scheme (AES) before and after revision of options in 2012, and the ELS points associated with each option. EB8 and EB10 involve ditch management in addition to hedgerow management. The requirements for hedgerow management under EB8 and EB10 are the same as for EB1 and EB3 respectively. Data obtained from Natural England (2013a) and Emily Ledder (Natural England, personal comm.). * points awarded for hedge only / hedge and ditch management.

CS agreements starting 2016			
Option code	Option management	Payment per 100m	Length of hedgerow (km)
BE3	Cut hedgerows: 1) either no more than one year in three between 1 September and 28 February - leave at least two-thirds of hedges untrimmed each year, or 2) no more than one year in two between 1 January and 28 February - leave at least one-half of hedges untrimmed each year.	16*	4,900.99
BN5**	Hedgerow laying	940	241.31
BN7**	Hedgerow gapping up	950	70.08
BN11**	Planting new hedges	1160	169.73

Table 1.2 Uptake (kms) of hedgerow options in the mid and higher-tier of Countryside Stewardship (CS) AES for agreements starting in 2016. * points where management applied to both sides of a hedge (8 points for 1 side); ** capital options (single payment). Data obtained from Natural England (2016/17). Options BN5 and BN7 are also funded under the Hedgerows and Boundaries grant within CS.

Annual cutting in the autumn (in September post-harvest) is the most common practice for hedgerow management in England outside AES, whereas autumn cutting on a biennial cycle is the prescribed management for hedges in AES ELS options EB1 and EB2. Cutting hedges once every two years in late winter or once every three years in either autumn or winter is prescribed for AES options EB3 (ELS), HB11 and HB12 (HLS) and BE3 (CS).

Cutting hedges every two calendar years (EB1/2) has proved to be one of the most popular ELS options to date (Natural England, 2009). As discussed above, early results from the current project showed no increase on berry provision for overwintering wildlife, on hedges cut every two years in autumn, compared to the standard practice of cutting annually in September (Staley et al. 2012b), though the number of flowers for invertebrates was increased. These results, from a single site, formed part of the evidence for revision of ELS hedgerow cutting options in 2011. These changes were introduced as part of MESME (Making Environmental Stewardship More Effective) in Jan 2013, which included a reduction in the number of points available for two year cutting (Table 1.1 above). Following these changes, there was a shift away from the two year cutting in autumn option (Table 1.1; 56% of hedgerow length going into two year autumn cutting following MESME, 68% previously). These results also informed management prescriptions for the hedgerow cutting option in the new CS scheme (Natural England, 2018). BE3 is the only hedgerow cutting option under the new CS scheme (there are additional capital options within CS for one-off hedgerow rejuvenation and planting). Under BE3 funding is provided for cutting once every three years either in autumn or winter, or once every two years in winter (Natural England, 2018; Table 1.2).

1.1.3 Report structure

The design of each of the three experiments and data collection methods are described in Section 2. Results and discussion of each field experiment are detailed in Sections 3 – 5 (Experiments 1- 3 respectively). The findings from across all three experiments are summarised in Section 6, along with a brief overall discussion (detailed discussions relating to each experiment are in Sections 3-5 with each set of results), and recommendations for hedgerow management and agri-environment options, given the findings of this project. Outputs from the project, including publications in peer-reviewed journals and knowledge transfer events and resources, are listed in Section 7.

1.2 Project aims and hypotheses

1.2.1 Aims

1) To examine the effects of simple hedgerow cutting regimes promoted by ELS, and the potential for cutting to allow incremental growth, on the quality and quantity of wildlife habitat, and food resources in hedgerows.
2) To identify, develop and test low-cost, practical options for hedgerow restoration and rejuvenation applicable at the large-scale under both ELS and HLS.
3) To make recommendations for the development of hedgerow options under existing and new AES.

1.2.2 Hypotheses

i) Cutting hedges every two or three years, and cutting in winter, will improve their provision of resources for pollinators, overwintering wildlife and invertebrate communities compared with cutting annually in autumn.
ii) Cutting hedges to allow incremental growth, rather than cutting them back to a standard height and width, will improve their quality for wildlife to a similar extent as cutting once every two or three years in winter.
iii) Alternatives to hedge-laying that are quicker and cheaper to apply will result in similar rates of regrowth, structure and provision of berries as those achieved with traditional hedge-laying.

2 Experimental designs and methodology

2.1 Experiment 1: Long-term effects of timing and frequency of cutting on resource provision for wildlife

2.1.1 Experimental design and field site

A randomised plot experiment was conducted from 2006 to 2014, to test the effects of the timing and cutting of hedgerow management on the number of hawthorn flowers, berry provision for overwintering wildlife, and hedgerow structure. This experiment used four hedgerows that were planted in 1961 at Monks Wood, Cambridgeshire, UK (52.4026 °N, -0.2357 °W) on former arable land (Croxton et al., 2004). The arable land was converted to grassland and subsequently managed by a mixture of hay cutting and topping and occasional extensive livestock grazing in the absence of fertiliser and pesticide inputs. The hedgerows had previously been managed by autumn or winter cutting on a one or two-year cycle to maintain them at a height of 2 – 3 m.

In autumn 2005 three hedgerows were divided into 32 contiguous plots of 15m length. The following management treatments were allocated to plots at random in factorial combinations:

1) cutting frequency treatment (annual vs. cut every two years vs. cut every three years), and
2) cutting timing treatment (autumn vs. winter).

In addition, two unmanaged control plots on an adjacent hedge were monitored that had not been cut for 15+ years, and were never cut during the current experiment. The autumn cut was conducted in September each year, and the winter cut in January or February. Each treatment combination of cutting frequency and timing was replicated either eight (for annually cut plots) or four times (for two and three-year cut plots; Sparks and Croxton, 2007). The cutting cycle in relation to each year of the experiment is summarised in Table 2.1. On each cutting occasion all growth since the last cut was removed, and all cutting was implemented with a tractor mounted flail cutter. The sides of the hedge were cut vertically resulting in a rectangular cross-section.

Year	Timing of cutting	Annual plots	Two-year plots	Three-year plots
2005	Autumn	cut	cut	cut
2006	Winter Autumn	cut cut	cut	cut
2007	Winter Autumn	cut cut	 cut	
2008	Winter Autumn	cut cut	cut	 cut
2009	Winter Autumn	cut cut	 cut	cut
2010	Winter Autumn	cut cut	cut	
2011	Winter Autumn	cut cut	 cut	 cut
2012	Winter Autumn	cut cut	cut	cut
2013	Winter Autumn	cut cut	 cut	
2014	Winter	cut	cut	

Table 2.1: Summary of hedgerow cutting treatments applied each year from 2005 to 2014 to Monks Wood Experiment 1. Winter cutting was applied in January or February of each year, so removed hedgerow growth from the previous year.

2.2 Experiment 2: Timing, intensity and frequency of hedgerow cutting

2.2.1 Experiment 2 design

A randomised block experiment was used to investigate effects of the following hedge management treatments on flower production, berry yield, utilisation of flowers by pollinating insects, invertebrate abundance and structure at five sites:

1) Time of cutting (early autumn *vs.* late winter);
2) Intensity of cutting (standard cut back to old cut line *vs.* incrementally raising the cutter bar by approximately 10 cm each time the hedge is cut. Thus, after the last cut of each experiment regime (6 years), annual incremental cutting has allowed a 1 m hedge to increase to approximately 1.6 m, incremental cutting every two years has resulted in a 1.3 m tall hedge and incremental cutting every three years in a 1.2 m tall hedge);
3) Frequency of cutting (one-, two- and three-year cycles).

These experimental treatments were applied in full factorial combinations (2 × 2 × 3), with three replicates of each treatment applied at each site to contiguous hedgerow sections of between 15 to 20 m in length, from September 2010 to January / February 2016 at each experimental site.

Treat ment	Time of cutting	Intensity of cutting	Frequency of cutting	Cutting dates
1	Autumn	Standard	Annual	Sept 2010, 2011, 2012, 2013, 2014, 2015, 2016
2	Autumn	Standard	Once every two years	Sept 2011, 2013, 2015
3	Autumn	Standard	Once every three years	Sept 2012, 2015
4	Autumn	Incremental	Annual	Sept 2010, 2011, 2012, 2013, 2014, 2015, 2016
5	Autumn	Incremental	Once every two years	Sept 2011, 2013, 2015
6	Autumn	Incremental	Once every three years	Sept 2012, 2015
7	Late winter	Standard	Annual	Jan/Feb 2011, 2012, 2013, 2014, 2015, 2016
8	Late winter	Standard	Once every two years	Jan/Feb 2012, 2014, 2016
9	Late winter	Standard	Once every three years	Jan/Feb 2013, 2016
10	Late winter	Incremental	Annual	Jan/Feb 2011, 2012, 2013, 2014, 2015, 2016
11	Late winter	Incremental	Once every two years	Jan/Feb 2012, 2014, 2016
12	Late winter	Incremental	Once every three years	Jan/Feb 2013, 2016
13	Control – no cutting			

Table 2.2: Summary of hedgerow management treatments applied to Experiment 2 sites from September 2010 – September 2016.

2.2.2 Field sites Experiment 2

The five field sites comprised: two hawthorn (*C. monogyna*) dominated hedgerow sites at Marsh Gibbon, Oxfordshire (MG planted in 1840: 51°53’N, 1°03’W); and Woburn, Buckinghamshire (WO planted between 1793 and 1799: 51°58’N, 0°37’W); one blackthorn (*Prunus spinosa* L.) dominated site at Waddesdon estate, Oxfordshire (Waddesdon blackthorn, WB: 51°50’N, 0°53’W); a mixed species hedgerow site planted under Countryside Stewardship in the mid-1990s at Waddesdon Estate, Oxfordshire (Waddesdon mixed, WM: 51°50’N, 0°56’W) and a traditional mixed species hedge on a bank in Yarcombe, Devon (YC planted 200 – 300 years ago: 50°51’N, 3°03’W). Woody species composition of the different Experiment 2 sites is given in Table 4.1. The winter cutting treatments were not applied at the WB hedge, due to a shortage of suitable hedgerow, but were applied at the other four sites (e.g. Figure 2.1).

Figure 2.1: Block 1 of three experimental hedgerow blocks at Woburn Estate, Bedfordshire. 20m hedgerow sections under varying management treatments are shown, differing in heights and widths. Photo taken March 2014, soon after winter cutting of plots under two and three-year cutting rotations (Table 2.2).

Unfortunately an error was made by a hedgerow contractor at the Marsh Gibbon (MG) site in autumn 2014, and all the experimental sections along two blocks were cut. As a result the treatments could no longer be applied at this one site, and monitoring at the MG site ceased from 2015 onwards.

2.3 Experiment 3: Rejuvenation of hedgerows

2.3.1 Experimental design

Rejuvenation treatments were applied to 24 m long contiguous hedgerow plots in a randomised block experiment in November 2010:

1) Midlands hedge-laying, a traditional form of rejuvenation (Figure 2.2b). Up to 50% of side branches were removed. Stems were partially severed at the base, leaving a small section of living cambium intact, laid over at approximately 35°, and woven into a dense woody linear feature. Remaining branches were then laid to one side of the hedge leaving the other side bare with no branches. Frequent stakes and top binders were used to secure the stems and branches in place.

2) Conservation hedge-laying, a quicker, rougher alternative to traditional hedge-laying (Figure 2.2a). Stems were cut at the base as above and laid over. Remaining stems and branches were laid along the line of the hedge rather than to one side. Fewer branches were removed, stakes were used sparingly, and binders omitted.

3) Wildlife hedging (Figure 2.2d). A chainsaw was used to make rough basal cuts on every stem, and the hedge was pushed over along its length with a 360 digger. No brash was removed, and some stems were entirely severed when the hedge was pushed over.

4) Circular saw (Figure 2.2c). The hedge was reshaped into a tall, box like shape by cutting of the sides and top of the hedge using a tractor mounted circular saw.

5) Coppicing. Hedge stems were cut to approximately 10 cm above ground level with a chain saw. Nearly the entire volume of the hedge was removed.

6) Control. No rejuvenation treatment applied.

Each rejuvenation treatment was replicated either two or three times at each site, in a randomised block design, resulting in 12 replicates of each rejuvenation treatments across five field sites (details below). Contractors who specialised in each form of rejuvenation were employed to apply the treatments, to ensure that they realistically resemble hedgerow rejuvenation in the wider countryside.

Figure 2.2: Rejuvenation treatments applied to experimental hedgerow sections, November 2010: a) conservation hedging, Crowmarsh Battle; b) Midlands hedge-laying, Wimpole Hall; c) circular saw, Wimpole Hall; d) wildlife hedging, Upcoate Grange.

Management treatments were applied in a split-plot design, in the autumn for three years following the rejuvenation treatments (2011– 2013). Management consisted of no further cutting or cutting once every two to three years (equivalent to trimming twice in 5 years as specified in HLS guidance). An additional annual cut treatment was applied just to the Midlands hedge-laying rejuvenation treatment. Combinations of rejuvenation and management treatments were applied to 12 m plot lengths (Table 2.3).

Treatment	Rejuvenation technique	Management: cutting frequency	Sites implemented
1	Midlands laying	Annual	UG, WH, NE, CB
2	Midlands laying	Every two to three years	UG, WH, NE, CB
3	Midlands laying	Uncut	UG, WH, NE, MW, CB
4	Conservation laying	Every two to three years	UG, WH, NE, CB
5	Conservation laying	Uncut	UG, WH, NE, MW, CB
6	Wildlife hedging	Every two to three years	UG, WH, NE
7	Wildlife hedging	Uncut	UG, WH, NE, MW
8	Coppicing	Every two to three years	UG, WH, NE, CB
9	Coppicing	Uncut	UG, WH, NE, MW, CB
10	Circular saw	Every two to three years	UG, WH, NE
11	Circular saw	Uncut	UG, WH, NE, MW
12	Control, no rejuvenation	Every two to three years	UG, WH, NE, CB
13	Control, no rejuvenation	Uncut	UG, WH, NE, MW, CB

Table 2.3: Summary of rejuvenation and subsequent management treatments applied to field sites in Experiment 3. Rejuvenation treatments were applied once in November 2010, and management treatments for the following three years (2011 – 2013). Sites: MW = Monks Wood, NE = Newbottle Estate, UG = Upcoate Grange, WH = Wimpole Hall, CB = Crowmarsh Battle.

2.3.2 Field sites Experiment 3

Five field sites were used for Experiment 3, four of which contained mature hedgerows dominated by hawthorn: Monks Wood, Cambridgeshire (MW, 52°24'N 0°14'W), Newbottle Estate, Northamptonshire (NE, 52°01'N 1°12'W); Upcoate Grange, Buckinghamshire (UG, 51°58'N 0°37'W); Wimpole Hall, Cambridgeshire (WH, 52°08'N 0°01'W); and one mixed species site at Crowmarsh Battle, Oxfordshire (CB, 51°36'N 1°05W). Wildlife hedging and circular saw reshaping could not be applied at CB as the hedge was not mature enough.

Each treatment was replicated three times at each of WH and NE, and twice at the other three sites. The management treatments were not applied at MW due to a shortage of suitable hedgerow, so the experimental hedgerow sections at this site were not cut following the initial rejuvenation.

2.4 Data collection methodology

2.4.1 Vegetation composition

The percentage composition of woody species was assessed in each plot in Experiments 2 and 3 in summer 2010, prior to the application of the first cutting and rejuvenation treatments, and again in summer 2013. The extent to which each species extended through the entire width of each hedge plot was also estimated, in one of five depth classes (<10%, 10–25%, 25-50%, 50-75%, 75-100%). This was to account for differences between woody scrambling species (e.g. dog-rose *Rosa canina* agg. and bramble *Rubus fruticosus* agg.) which grow largely on the surface of hedgerows, and structural woody species (e.g. hawthorn).

2.4.2 Flower counts

Production of flowers by the main woody species (hawthorn, blackthorn and bramble) was assessed annually at peak flowering on all three experiments. Percentage cover of blackthorn and hawthorn flowers was estimated in early and late spring respectively, using five 50 × 50 cm quadrats sub-divided into 25 cells on each plot. Quadrats were approximately equally spaced on the target species along the length of each plot, but excluding 2.5 m at each end to exclude edge effects, and mid-way up the height of each plot. In addition, flowers were counted in one of the five quadrats on each plot, to determine a relationship between average percentage cover and number of flowers. The number of bramble flowers was counted on each plot in mid-summer, together with flowers of any other woody scrambling species present. The height and width of each plot was measured at five evenly spaced positions along the length of each plot, to calculate plot surface area which was used to convert flower numbers per quadrat to flowers per 1m hedge length.

2.4.3 Berry availability over winter

The number and weight of berries were assessed in autumn each year following the September cutting treatments, to assess the provision of berries for overwintering wildlife. Berry assessments were carried out each year on all three experiments. The numbers of berries for all species were counted in five 50 × 50 cm quadrats per plot positioned as above, and berries of hard-fruited species were collected (Figure 2.3). Plot height and width were measured as above for flower counts. Berries were weighed to obtain fresh biomass, dried for 48 hours at 80 °C to constant mass and weighed again. In addition, 50 berries from each quadrat were weighed fresh and dry to determine individual berry mass and % dry matter.

Figure 2.3: Collecting hawthorn berries within a 0.5 × 0.5m vertical quadrat against the face of an experimental hedgerow plot at MW, Experiment 1.

2.4.4 Cost and speed of hedgerow rejuvenation methods

The contractor for each rejuvenation method was asked to estimate the cost of rejuvenating 100 m of that type of hedgerow commercially, at each site for Experiment 2. Where applicable, a separate quote was also supplied for clearing and disposing of the brash created by each rejuvenation method. The time taken to apply the rejuvenation treatment to each experimental plot was recorded.

2.4.5 Pollinator visitation rates

Invertebrate pollinators visiting hawthorn, blackthorn and bramble flowers were assessed at peak flowering times in 2011-2013 for Experiment 2 only. Timed counts were conducted using 2 m × 1 m quadrats for visitation to hawthorn and blackthorn, or 10 m transects for visits to bramble flowers. The numbers of visits by to flowers by pollinator taxa were recorded, with invertebrates assigned to functional groupings (e.g. cuckoo vs. mining solitary bees) or species (Lepidoptera). The abundance of flowers of each dicot species in the hedge base and adjacent margin was recorded using an index of abundance, together with temperature, wind speed and cloud cover. The pollinating invertebrate taxa recorded are summarised in Table 4.5.

2.4.6 Invertebrates

Two sampling methods were used to assess the abundance of invertebrate taxa present within the hedgerow plots in early summer, every year from 2011-2013, for Experiment 2 only.

1) Beating: Prior to beating hedgerows were checked for nesting birds. A length of guttering was inserted through the width of the hedge, and the hedge immediately above the guttering was hit five times with a range pole (Maudsley et al., 2002). Invertebrates were brushed from

the guttering into a ziplock bag (Figure 2.4b). Beating was conducted in three positions at five metre intervals along the length of each plot. Lepidoptera larvae were identified to species in the laboratory, or if necessary were reared on hawthorn foliage until they emerged as adults to determine the species. Other invertebrates were stored in 70% industrial methylated spirits and identified to Order and just for Coleoptera to Family.

2) Guttering pan traps: A length of guttering was half-filled with water, and inserted through the width of the hedge horizontally. Three days later the trap was collected. Invertebrates that had fallen into the water were stored in alcohol and identified as above.

Lepidoptera has been chosen as a focal group due to their role as indicators for terrestrial diversity, and their close relationship with the quality and quantity of their larval host plants. In addition, numbers of brown hairstreak (*Thecla betulae* L.) butterfly eggs found on blackthorn in hedgerow plots at YC were assessed each winter (Figures 2.4c and 2.4d), following the discovery of two brown hairstreak caterpillars during the beating sampling.

Figure 2.4: Invertebrate sampling in May: a) beating a hedgerow section above a section of guttering inserted in an experimental hedgerow plot, b) collecting the invertebrates from the guttering section, c) and d) brown hairstreak butterfly eggs surveyed at YC field site in February each year.

2.4.7 Hedge structure

The effects of management on woody hedge structure were quantified by taking and comparing high resolution digital images in late winter (February), before the leaves were present. This was to test whether hedges cut less frequently have larger gaps at the base, an assertion sometimes made by landowners. A white sheet was placed behind the hedge to maximise contrast. Hedge density and gappiness were determined using ERDAS Imagine (ERDAS Imagine 2013) image processing software (Figure 2.5).

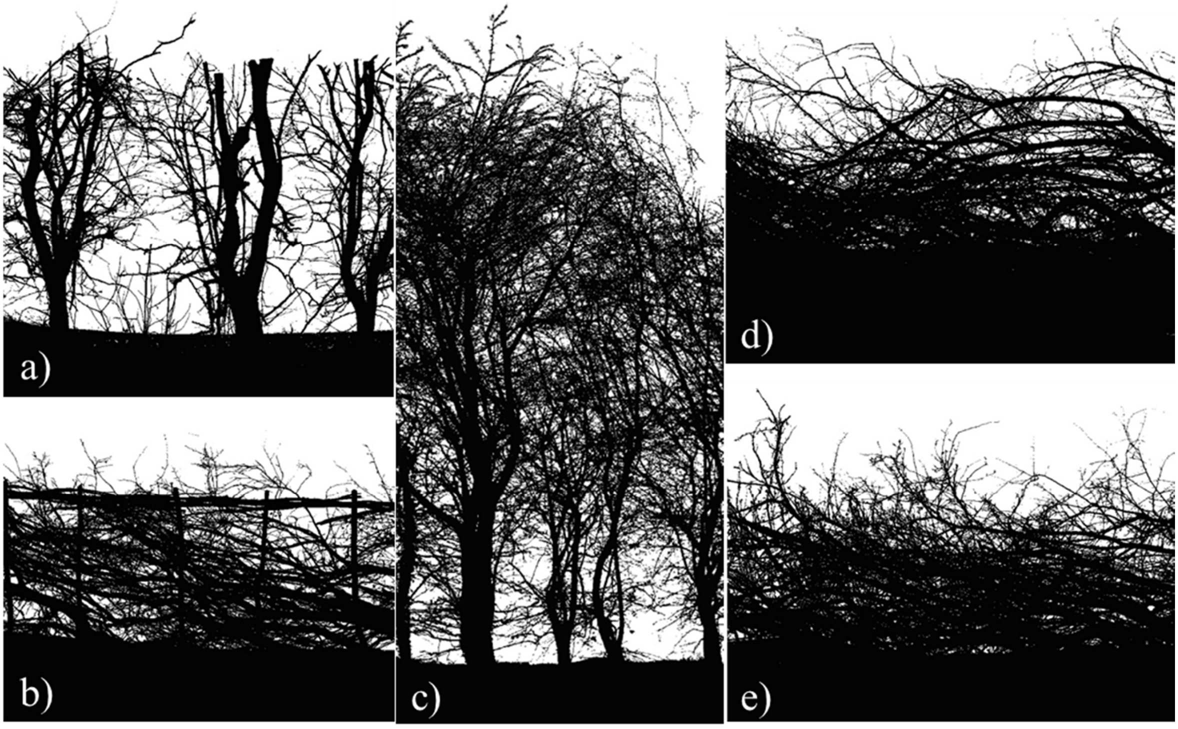

Figure 2.5: Hedgerow structural photographs, simplified to hedge vs. gaps for image analysis. Rejuvenation treatments: a) circular saw, b) Midlands hedge-laying, c) control plots (not rejuvenated), d) wildlife hedging and e) conservation hedge-laying.

The years in which hedge structure was assessed depended on the management cycle for each experiment. For Experiment 1, photographs were taken in February 2012 (6 years after cutting treatments had started). For Experiment 2, hedge structure was assessed in 2011 (after the first year of treatments were applied), 2014 and 2016 (after 6 years of cutting treatments, when all plots had just been cut). For Experiment 3, structural photographs were taken in 2011 just after the rejuvenation treatments had been applied, and at the end of the experiment in 2014.

2.4.8 Hedgerow regrowth

The amount of regrowth on experimental hedgerow plots was assessed in summer 2015, for Experiment 2 only. This was the sixth year of the experiment, and all experimental plots were cut the following autumn/winter. Two sets of regrowth data were collected for hawthorn, blackthorn, field maple (*Acer campestre* L.) and just for one site (YC) for hazel (*Corylus avellana* L.).

1) The number of shoots protruding from the previous cutting point, across a 0.2 m wide cross-section of the hedgerow face. This was assessed for both sides and the top the hedgerow for each woody species, on two positions spaced out evenly along the side of each hedgerow plot. A mobile boom lift was used to access the top of the hedgerow plots for these assessments (Figure 2.6).

2) The length, maximum diameter and biomass of 12 shoots of each species assessed, from each experimental hedgerow plot. The shoots were cut where the hedgerow had previously been trimmed with a flail, in order to assess regrowth since last cut. Growth in the last year was assessed, as well as total regrowth since the last cut shoots were brought back to the laboratory to be dried, and woody dry biomass was determined.

Figure 2.6: Collecting regrowth sample from top of an experimental hedgerow plot at YC, using a 4 × 4 boom lift.

2.5 Data analysis

Where multiple samples of a response variable had been assessed per plot (e.g. flower cover, berry availability, hedgerow regrowth), means per plot were calculated prior to analysis. Flower cover was converted to number of flowers using linear regression. Flower numbers and berry fresh mass data were converted to values per 1 m hedge length using plot surface area values calculated from hedgerow height and width measurements (Section 2.4.2).

Two types of analyses were conducted for each individual response variable being investigated. Firstly, cumulative values over multiple years were calculated for each plot to determine the effects of cutting or rejuvenation treatment on resource provision over the length of the experiment. Where necessary to meet the assumptions of parametric tests, variables were log(x) transformed prior to analysis. For Experiment 1, GLMs (Generalised Linear Models) were used to test the effects of cumulative cutting frequency and cutting timing on flower abundance, berry provision over winter and hedgerow structure. GLMMs (Generalised Linear Mixed Models) were used to test how the cutting treatments altered with year, for data collected in each of eight years (flower abundance and berry provision). GLMs were used to test the effects of the frequency, timing and intensity of cutting, and of site on cumulative production of flowers; berry availability over winter; pollinator visitation; invertebrate abundance, diversity and species richness; hedgerow structure and regrowth of woody species for Experiment 2. For Experiment 3, ANOVAs were used to test the effects of rejuvenation treatment and site on cumulative regrowth parameters and berry availability. Hedge structure in 2011 and 2014 were analysed separately. Generalised Linear Mixed Models (GLMMs) were used to test the effects of ongoing hedgerow management following rejuvenation for Experiment 3, which had a split-plot design (Faraway, 2005).

Secondly, GLMMs were used to test whether response variables that were measured each year were affected by cutting and rejuvenation treatments for Experiments 2 and 3 respectively, and whether these treatment effects varied with year. Model simplification for both sets of analyses was tested using likelihood-ratio tests (Faraway, 2015).

Multivariate response variables (e.g. pollinator taxa visiting flowers) were analysed using constrained correspondence or redundancy analyses (depending on whether the data had a unimodal or linear distribution respectively (Leps & Smilauer, 2003). Permutation tests were used to test the effects of cutting frequency, timing and intensity on multivariate variables (Oksanen et al., 2013). All statistical analyses were carried out in R version 3.2.5 (R Core Development Team, 2016) using packages lme4 (Bates et al., 2015), lmerTest (Kuznetsova et al., 2014) and Vegan (Oksanen et al., 2013).

3. Experiment 1 Results and Discussion: Long-term effects of timing and frequency of cutting on resource provision for wildlife

3.1 Hawthorn flower abundance

There were 20.2 times more hawthorn flowers on control plots which had not been cut for several years before and during the experiment, compared with plots cut every year ($t_{1,27}$ = 9.39, $P < 0.001$; Figure 3.1). Over the entire course of the experiment, hedgerow plots which were cut once every two or three years had 1.7 and 1.9 times more hawthorn flowers than those cut every year ($t_{1,28}$ = 3.5, $P < 0.01$ and $t_{1,28}$ = 6.71, $P < 0.001$ respectively). Hedgerow plots cut in winter had fewer hawthorn flowers than those cut in early autumn ($t_{1,28}$ = 4.28, $P < 0.001$) for all three cutting frequencies (Figure 3.1).

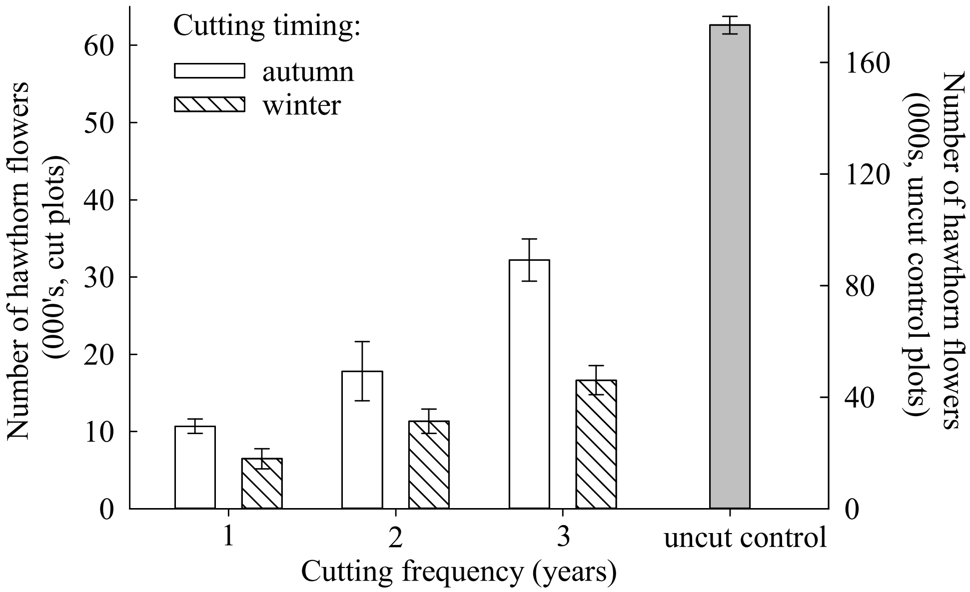

Figure 3.1: Cumulative number of hawthorn flowers (000s, mean ± SE) per 1m hedgerow section, over eight years of cutting frequency and cutting timing experimental treatments at Monks Wood Experiment 1. Uncut control hedgerow plots are on different scale (right y axis) to plots under cutting treatments (left y axis).

There were more hawthorn flowers on plots cut once in three years, compared with those cut every year, in six out of eight years of the experiment (2007: $t_{1,182}$ = 1.58, $P < 0.01$; 2008: $t_{1,182}$ = 2.58, $P < 0.001$; 2009: $t_{1,182}$ = 1.67, $P < 0.01$; 2010: $t_{1,182}$ = 1.20, $P < 0.05$; 2011: $t_{1,182}$ = 2.43, $P < 0.001$; 20013: $t_{1,182}$ = 2.41, $P < 0.011$;). In 2012 only, there were fewer hawthorn flowers on plots cut every three years, compared to those cut every year ($t_{1,182}$ = 2.09, $P < 0.001$). Hedgerow plots cut once every two years had more hawthorn flowers in three out of eight years, compared with those cut every year (2007: $t_{1,182}$ = 1.67, $P < 0.01$; 2009: $t_{1,182}$ = 1.08, $P < 0.05$; 2013: $t_{1,182}$ = 2.20, $P < 0.001$), and fewer flowers in one year (2012: $t_{1,182}$ = 1.58, $P < 0.01$).

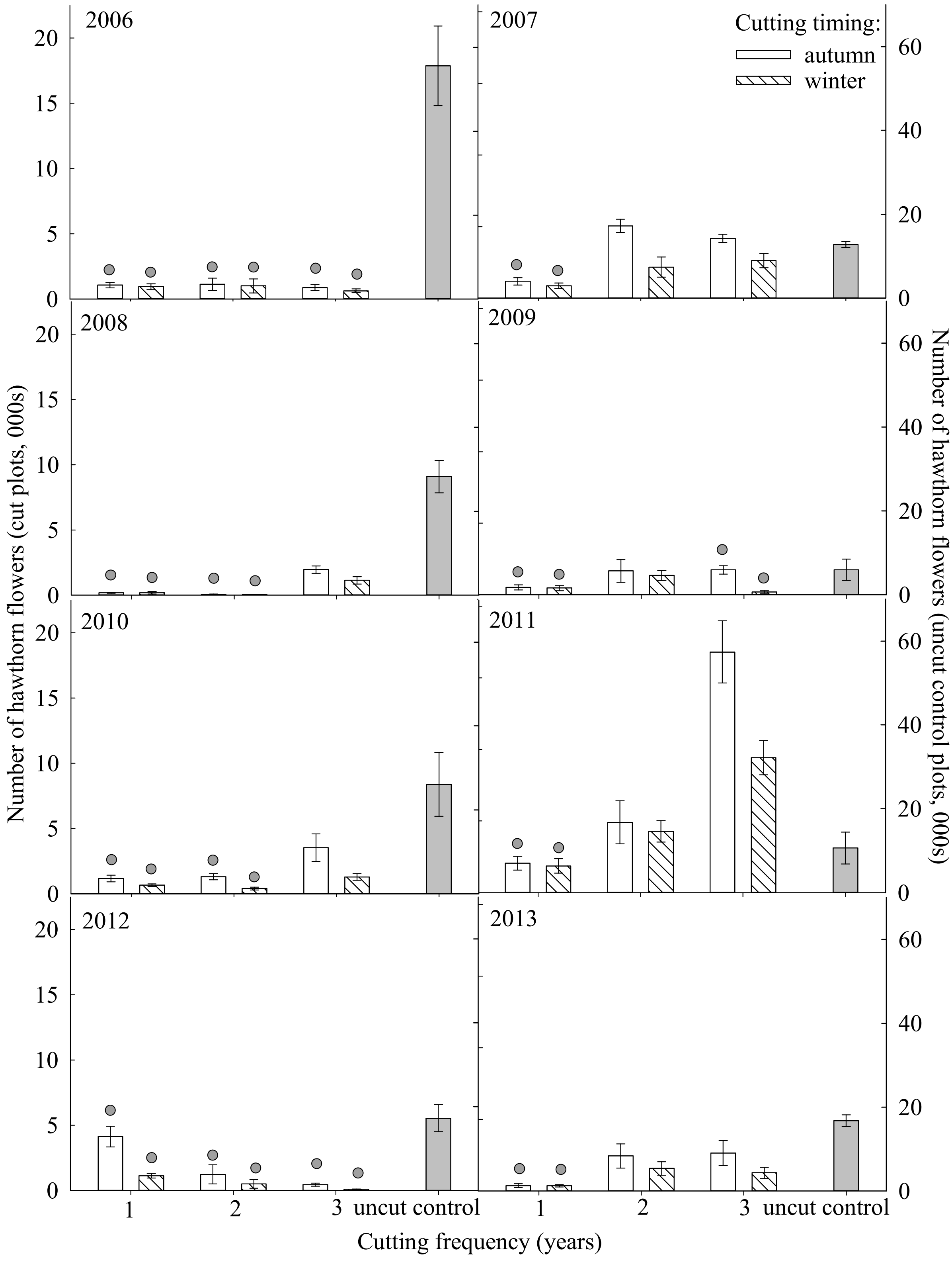

Figure 3.2: Number of hawthorn (*Crataegus monogyna*) flowers (000s, mean ± SE) per 1m hedgerow section for each year of frequency and cutting timing treatments at Experiment 1. Uncut control hedgerow plots are on different scale (right y axes) to plots under cutting treatments (left y axes). ● = plot cut the preceding autumn or late winter.

Timing of cutting also affected hawthorn flower production, but only in two out of the eight years of the experiment. In 2012 there were fewer flowers on plots cut the preceding late winter, compared with those cut the preceding autumn, regardless of the frequency of cutting (2012 × winter interaction: $t_{1,182} = 1.12$, $P < 0.05$), while in 2009 the same reduction in flowers on winter plots was found just for those cut once every three years (2009 × three-year cutting frequency × winter: $t_{1,182} = 2.12$, $P < 0.001$). These occasional reductions in the number of hawthorn flowers following winter cutting may be due to the formation of buds in late winter, which are then cut off during the late winter hedge trimming. These annual effects were driven by the cutting cycle, as all plots were cut in the autumn or winter preceding the 2012 flower count (Figure 3.2).

3.2 Berry availability over winter

The uncut control plots at Monks Wood (Experiment 1) had a cumulative hawthorn berry weight across all eight years that was 30.7 times greater than that of the plots cut every year ($t_{1,27} = 14.4$, $P < 0.001$). The cumulative weight of hawthorn berries over eight years on plots cut once every three years was 3.5 times greater, compared to hawthorn berry weight on plots cut every year ($t_{1,28} = 2.12$, $P < 0.001$). Plots cut once every two years had a 1.7 times heavier cumulative weight of hawthorn berries on average, compared to plots cut every year ($t_{1,28} = 2.53$, $P < 0.05$). Plots cut in late winter had more berries available over-winter, compared to those plots cut in autumn on which berries were removed in September ($t_{1,28} = 2.37$, $P < 0.05$).

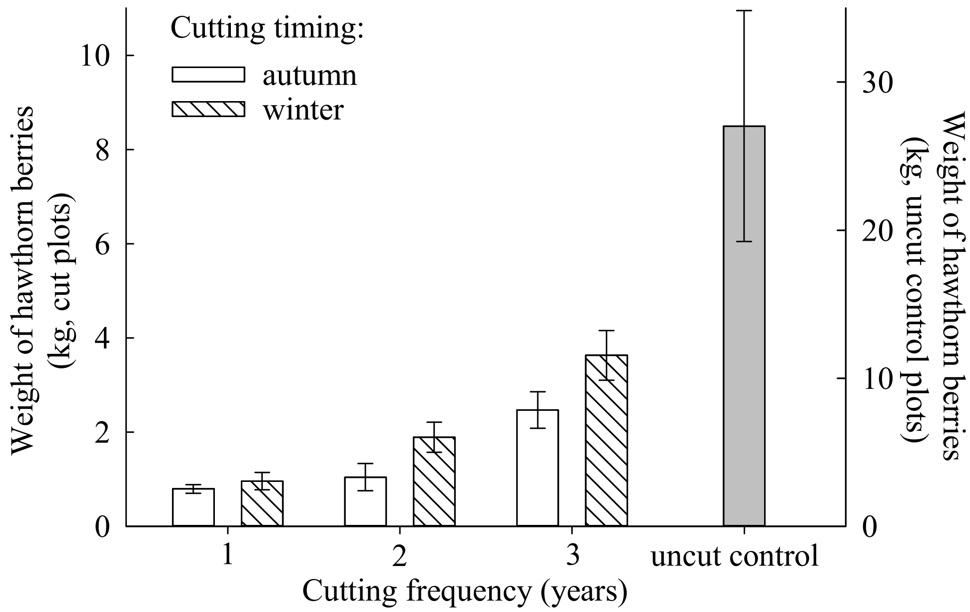

Figure 3.3: Cumulative fresh weight (kg, mean ± SE) of hawthorn berries per 1m hedgerow section available for wildlife over winter after autumn plots had been cut, assessed over eight years for Experiment 1. Uncut control hedgerow plots are on a different scale (right y axis) to plots under cutting treatments (left y axis).

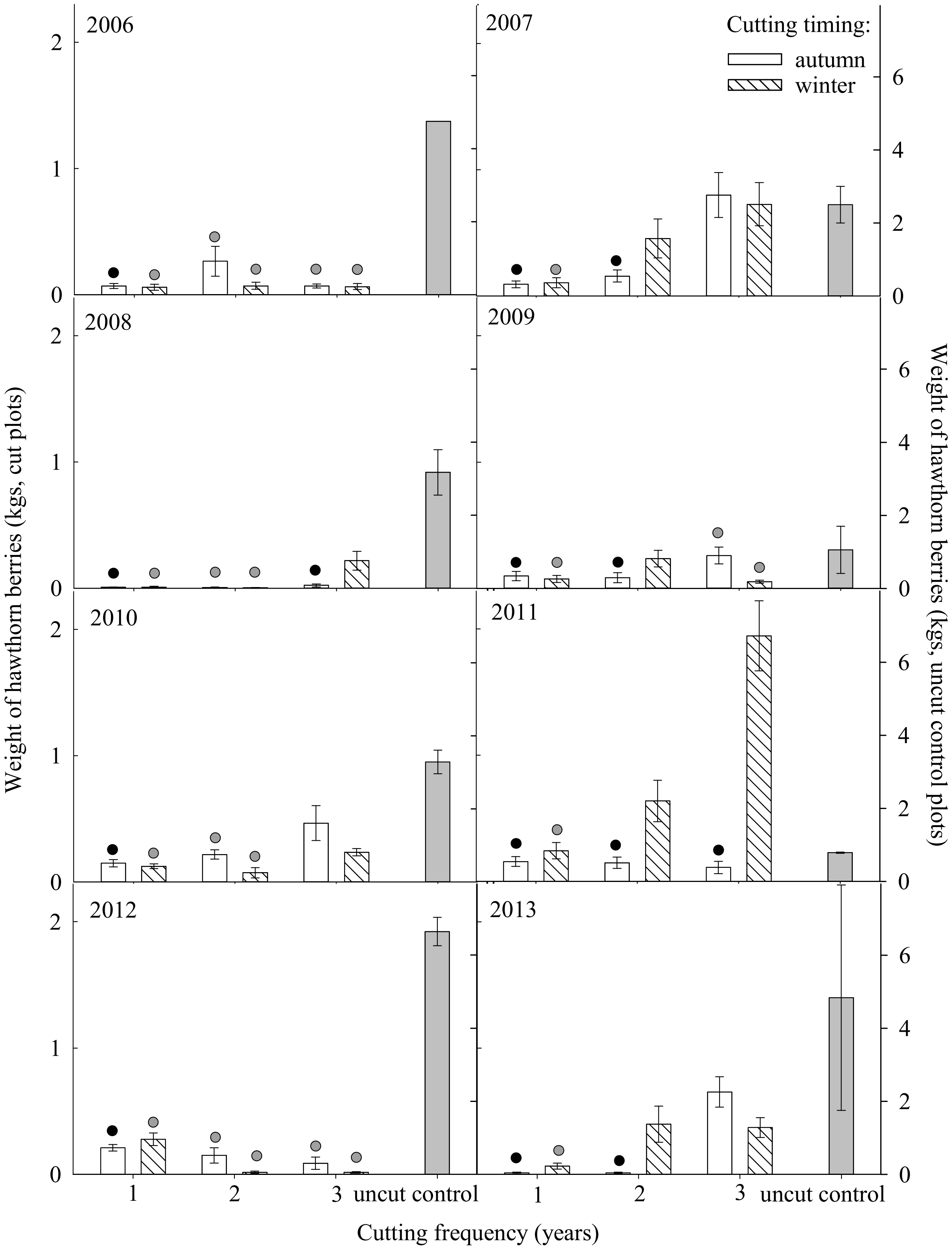

Figure 3.4: Fresh weight of hawthorn berries (kg, mean ± SE) per 1m hedgerow section, for each year of frequency and cutting timing treatments at Experiment 1. Uncut control hedgerow plots are on a different scale (right y axes) to plots under cutting treatments (left y axes). ● = plots that were cut just before the berry assessment, ● = plots cut the preceding autumn / late winter.

The fresh weight of berries available to wildlife over winter varied from year to year, as a result of the cutting treatments. On plots cut once every two years, there was a greater weight of berries produced on those cut in winter compared with plots cut annually, in four out of eight years of the experiment (2007 × two-year cutting frequency × winter cutting: $t_{1,224}$ = 3.58, $P < 0.001$; 2009 × two-year cutting frequency × winter cutting: $t_{1,224}$ = 3.47, $P < 0.001$; 2011 × two-year cutting frequency × winter cutting: $t_{1,224}$ = 4.14, $P < 0.001$; 2013 × two-year cutting frequency × winter cutting: $t_{1,224}$ = 4.46, $P < 0.001$). These were the four years in which plots on a two-year cutting frequency had not been cut the previous autumn/winter, so the winter plots had two years growth on them (Figure 3.4). In contrast, the autumn two-year plots had just been cut in each of these four years, removing berries in September so they were not available over-winter. In two of the remaining four years, there was a lower weight of berries on plots cut once every two years in winter (2008 × two-year cutting frequency: $t_{1,224}$ = 2.63, $P < 0.001$; 2012 × two-year cutting frequency: $t_{1,224}$ = 3.69, $P < 0.001$), probably as a result of the reduced number of flowers immediately following trimming (see Section 3.1). However, the cumulative berry weight results show that across all eight years of the experiment, cutting in late winter did result in a greater weight of berries (Figure 3.3).

Berry availability from plots cut once every three years also followed the cycle of cutting treatments. In both 2008 and 2011, there was a greater weight of berries on plots cut once every three years in winter compared to those cut annually (2008 × three-year cutting frequency × winter: $t_{1,224}$ = 2.34, $P < 0.05$; 2011 × three-year cutting frequency: $t_{1,224}$ = 7.48, $P < 0.001$). In 2007, there was a greater weight of berries on plots cut once every three years, irrespective of the timing of cutting (2007 × three-year cutting frequency: $t_{1,224}$ = 6.33, $P < 0.001$). The weight of berries was lower on plots cut once every three years in winter in 2009 and 2012, probably due to the reduction in the number of flowers in years immediately after winter cutting, as for the two-year cutting frequency (2009 × three-year cutting frequency × winter: $t_{1,224}$ = 2.06, $P < 0.05$; 2012 × three-year cutting frequency: $t_{1,224}$ = 2.27, $P < 0.05$). For both two and three-year cutting frequencies, the heaviest cumulative berry weight was found on plots cut in late winter.

3.3 Hedgerow structure

There was no effect of the frequency or the timing of cutting on the percentage of woody material in the bottom 90 cm of the hedgerow plots, in 2012 when all plots had just been cut that autumn/winter after six years of experimental treatments (Figure 3.5). There was a slight trend towards less woody material in uncut control plots compared to plots cut every year, but this was not statistically significant ($t_{1,27}$ = 1.73, $P = 0.095$).

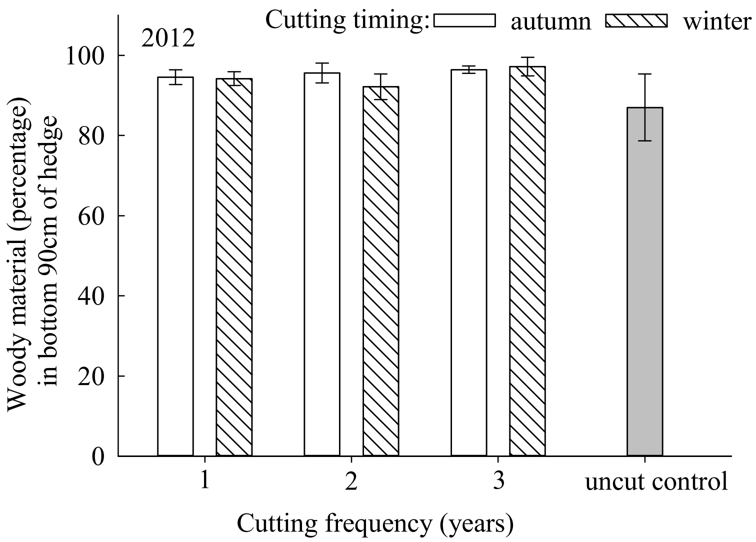

Figure 3.5: Woody material (percentage, mean ± SE) in the basal 90 cm of plots calculated from digital images taken in 2012, measured in terms of permeability (Section 2.4.7). In 2012 all Experiment 1 (Monks Wood) plots had just been cut that autumn/winter, after six years of experimental treatments.

Maximum gap size was not significantly affected by the frequency or timing of cutting in 2012 (Figure 3.6). In 2012, there was a trend towards smaller gaps on plots cut once every three years, but this was not statistically significant ($t_{1,27} = 1.75$, $P = 0.091$).

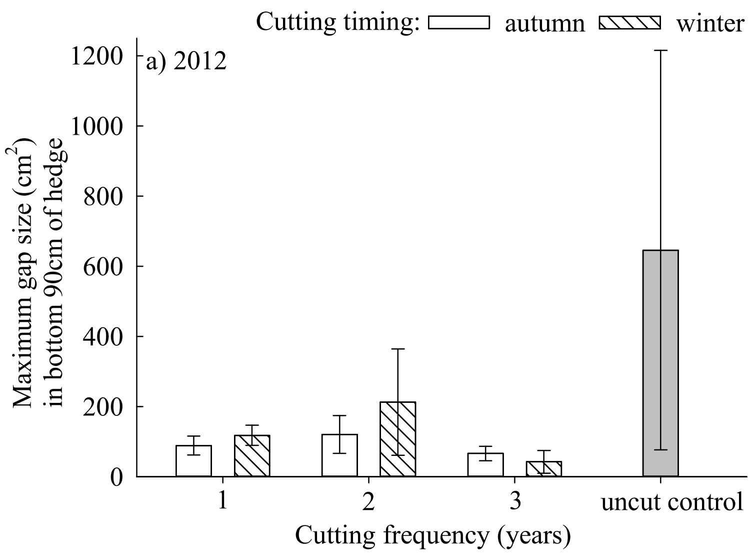

Figure 3.6: Maximum gap size (cm^2; mean ± SE) in the basal 90 cm of plots calculated from digital images taken in 2012. In 2012 all Experiment 1 (Monks Wood) plots had just been cut that autumn/winter, after six years of experimental treatments.

3.4 Discussion of Experiment 1 results

Cut hedges produced fewer flowers and a lower fresh weight of berries in all years than the monitored uncut hedges at the Monks Wood experiment. The magnitude of these differences confirms that uncut hedgerows provide far greater resources for wildlife than cut hedgerows, even those cut under a reduced cutting frequency. It is unlikely that the majority of hedgerow length could be left unmanaged, given the practical demands of farm management and the need to prevent unmanaged hedgerows from turning into lines of trees over the longer term.

Hawthorn flowers and fruits on young wood in the second year of growth, in common with many woody species. Annual cutting does not allow flowers and berries to form on the majority of young growth that protrudes from the hedge face, as shown from the results here. Cutting hedges once every two years in autumn was shown not to increase berry provision over-winter at the Monks Wood experiment, as these are removed with the autumn flail cutting, though it does result in more hawthorn flowers being produced in the second year of growth than cutting annually. There was a reduction in the number of flowers produced on winter cut plots in the year immediately following cutting, which resulted in a corresponding reduction in berry weight that autumn for plots cut once every two or three years. This may have been due to buds forming in late winter being removed during the winter cutting treatment, and not being replaced by the hawthorn. However, despite this temporary reduction in flowers, the cumulative data show that the winter cut plots had a greater mass of berries more often than the plots cut in autumn, due to the removal of berries during autumn cutting. Provision of both hedgerow flowers for pollinating invertebrates and berries for overwintering wildlife was maximised on managed hedgerows plots cut once every three years, on this experiment at Monks Wood. There was no evidence that any of the cutting frequency and timing treatments resulted in significant changes to hedgerow structure over the nine years of the experiment (2006 – 2015), compared to hedgerow plots cut annually.

4. Experiment 2 Results and Discussion: Testing the frequency, timing and intensity of hedgerow cutting using a multi-site experiment

4.1 Cutting treatment application – difficulties with cutting in late winter

All hedgerow cutting treatments were applied as specified. However, the winter cutting had to be delayed beyond the 28th February deadline for hedge trimming on several occasions due to adjacent field margins (managed under HLS/ELS options) being too wet to drive on. Of the six years when hedgerows were cut in winter during this research project, a derogation was obtained to delay the hedge cutting until March on all four sites in three years (2010, 2014 and 2016), on one site in 2011 and at two sites in two years (2013 and 2015). Even with a delayed cutting date in March, all or some of the winter plots had to be cut by hand at the Waddesdon mixed species hedge in 2013, 2014 and 2016, as margins were still too wet for access with a tractor. Implementing hedgerow cutting in late winter may therefore not be feasible prior to 28th February for many landowners. Cutting after 28th February necessitates an ES/SPS derogation, and may pose a risk to birds nesting in hedgerows. This does call into question the feasibility of late winter cutting as a widespread option for hedgerows managed under AES.

4.2 Vegetation composition

The frequency, timing and intensity of cutting had no effect on the change in hedgerow content of woody scramblers between 2010 and 2013 for any of the species tested (dog-rose, bramble, honeysuckle (*Lonicera periclymenum* L.), white bryony (*Bryonia dioca* Jacq.), ivy (*Hedera helix* L.)). Bramble cover increased slightly at Yarcombe during the course of the experiment, but not at any other site (Table 4.1).

	MG	WB	WM	WO	YC
Crataegus monogyna	85.1	12.4	56.4	73.4	11.2
Prunus spinosa	0.4	75.6	15.7	8.0	25.9
Acer campestre	0	0.9	12.7	0.3	31.7
Corylus avellana	0	0	9.8	1.2	11.2
Rubus fruticosus agg.	11.1	5.5	0.1	4.8	4.9
Rosa canina agg.	3.6	1.0	0	4.6	3.3
Ulmus procera Salisb.(elm)	0	0	0	0	5.8
Sambucus nigra	0	1.7	0	6.2	1.0
Cornus sanguinea L. (dogwood)	0	0	0	0	4.2
Euonymus europaeus L. (spindle)	0	0	4.3	0	0.4

Table 4.1: Average percentage cover of the ten most abundant woody hedgerow species at each field site for Experiment 2. Sites: MG = Marsh Gibbon, WB = Waddesdon blackthorn hedge, WM = Waddesdon mixed species hedge, WO = Woburn, YC = Yarcombe.

4.3 Flower abundance

4.3.1 Hawthorn

The frequency of hedge cutting had a significant effect on cumulative hawthorn flower production over six years. Hedgerow plots cut once in three years had 1.5 times more hawthorn flowers than those cut annually ($t_{1,128} = 2.38$, $P < 0.005$), in total across six years, while those cut every two years did not differ significantly from the annual plots (Figure 4.1). Cutting to allow incremental growth produced 1.9 times more hawthorn flowers on average than cutting back to a standard height and width ($t_{1,128} = 5.23$, $P < 0.001$). In addition, there was a trend towards an interaction between cutting frequency and intensity ($t_{2,128} = 1.80$, $P = 0.077$), whereby the frequency of cutting did not affect flower abundance for hawthorn hedges under incremental management, but plots under standard cutting intensity had a greater abundance of hawthorn flowers if cut once every three years. Hedgerow plots that were not cut (control plots) had 5 times more hawthorn flowers than those cut annually in autumn ($t_{1,140} = 8.22$, $P < 0.001$).

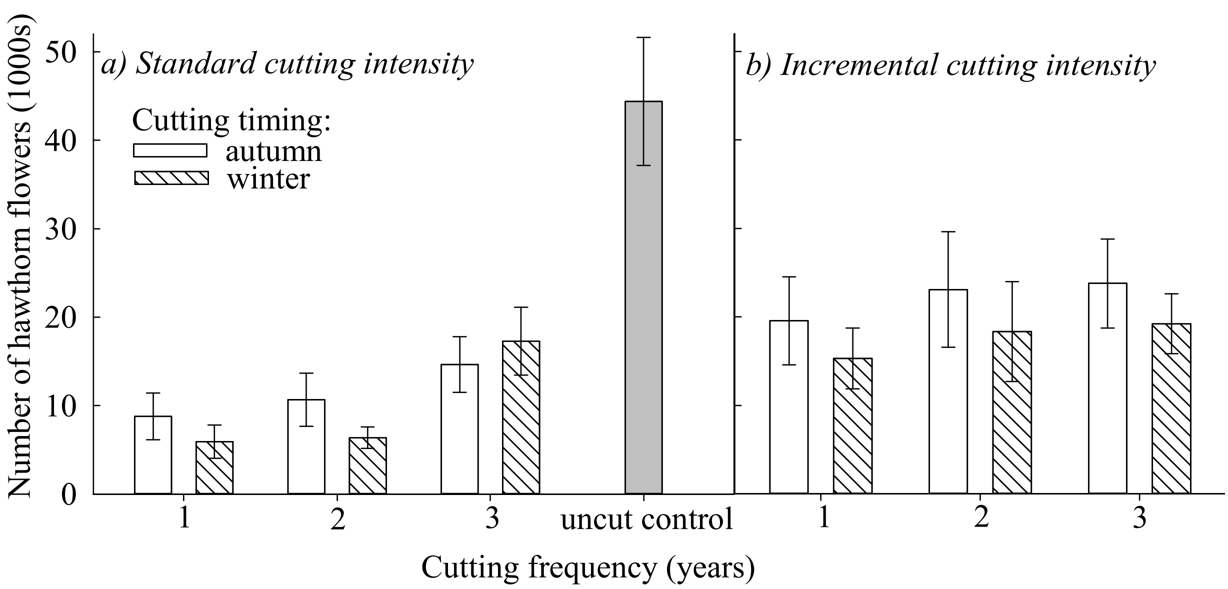

Figure 4.1: Cumulative number (1000s, mean ± SE) of hawthorn flowers per 1 m hedgerow length under cutting frequency, timing and intensity treatments, produced over six years (2011 – 2016). Average across all experimental hedges with hawthorn present.

The timing of hedgerow cutting did not affect the number of hawthorn flowers consistently across all sites, though at Marsh Gibbon only, there were fewer flowers on plots cut in winter compared with those cut in autumn (Marsh Gibbon site × timing of cutting: $t_{1,128} = 2.20$, $P < 0.05$). Only three years of flower data were collected at Marsh Gibbon, due to the cutting error (Section 2.2.2), so results from this site cannot be interpreted in the context of a six year response to cutting treatments. At the other three sites, where cutting treatments were applied and flowers assessed for six years, there was no significant effect of the timing of cutting on cumulative hawthorn flower abundance.

Cutting frequency interacted with year to significantly affect the abundance of hawthorn flowers (Likelihood-ratio test (LRT): $\chi^2_{10} = 124.5$, $P < 0.001$). In 2011, 2012 and 2015, there were more flowers on plots cut once every three years. 2012 and 2015 were the third year of the cutting cycles, in which there were three years of woody growth present on the hedgerow plots. Plots cut once every two years had more flowers than those cut annually in 2011 and 2015. The effects of cutting intensity increased over the six years of the experiment (LRT: $\chi^2_5 = 14.26$, $P < 0.05$), with significantly more flowers on plots cut for incremental growth in 2014 and 2016, compared to a standard cutting intensity.

4.3.2 Blackthorn

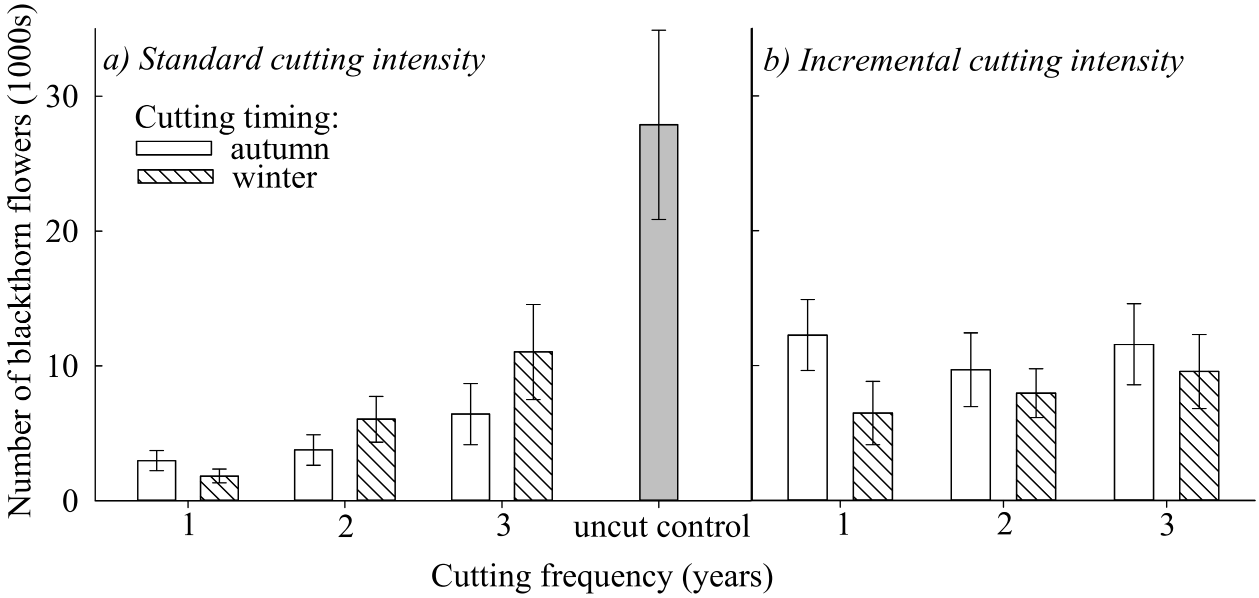

Figure 4.2: Cumulative number (1000s, mean ± SE) of blackthorn flowers per 1 m hedgerow length under cutting frequency, timing and intensity treatments, produced over six years (2011 – 2016).

The cumulative number of blackthorn flowers over six years was similarly affected by the frequency of cutting. The number of blackthorn flowers was on average 1.6 times greater on plots cut every three years than those cut annually ($t_{1,81} = 2.03$, $P < 0.05$), while those cut every two years did not differ significantly from the annual plots (Figure 4.2). The strongest effect was due to cutting intensity, as there were 1.8 times more blackthorn flowers on average on plots cut for incremental growth, compared to those cut back to a standard height and width ($t_{1,81} = 4.63$, $P < 0.001$).

The timing of cutting had a smaller effect on the abundance of blackthorn flowers ($t_{1,81} = 2.06$, $P < 0.05$), and there was a trend towards an interaction between timing and intensity of cutting, whereby the number of flowers was reduced on winter plots compared with autumn plots, when cut to an incremental intensity ($t_{1,81} = 1.89$, $P = 0.063$). The uncut control plots had 9.3 times more flowers than those cut annually ($t_{1,66} = 3.1$, $P < 0.01$).

The effects of cutting frequency on the number of blackthorn flowers significantly varied with year (LRT: $\chi^2_{10} = 80.71$, $P < 0.001$). Plots cut once every two years had more flowers than those cut annually in 2011 and 2015, while those cut once every three years had more flowers in 2011, 2012 and 2015. These yearly differences are largely due to the stage of each cutting cycle, with the exception of 2013 when more flowers might be expected on the two-year plots, but flower production was very low in general due to a cold spring. There was also an interaction between cutting intensity and year (LRT: $\chi^2_5 = 35.83$, $P < 0.001$), whereby there was a stronger effect of cutting for incremental growth on increased abundance of flowers in 2012, 2014, 2015 and 2016 than either 2011 or 2013.

4.3.3 Bramble

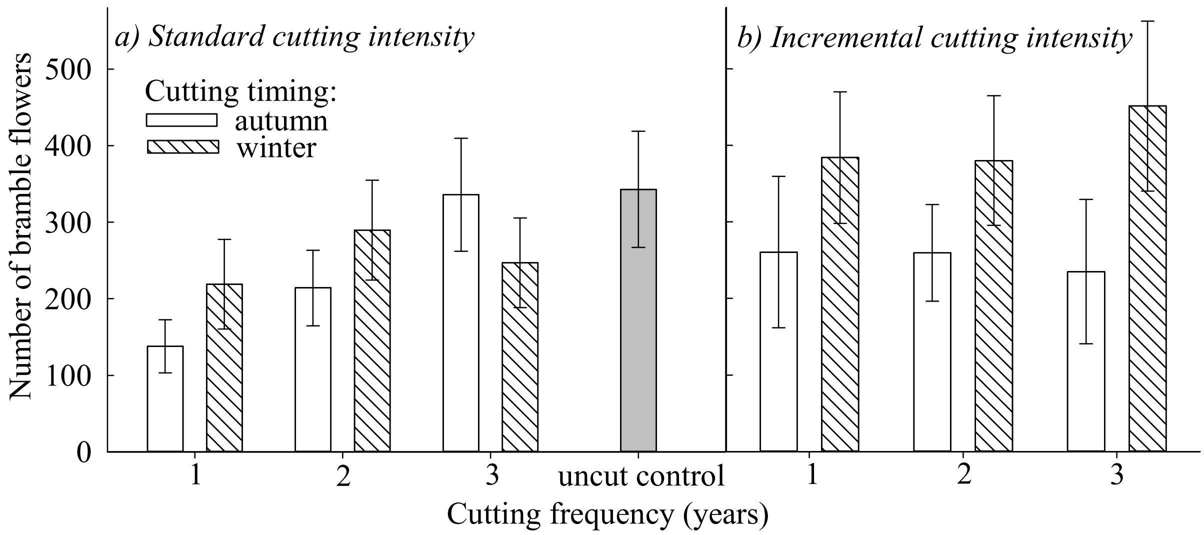

Figure 4.3: Cumulative number (mean ± SE) of bramble flowers per 1 m hedgerow length under cutting frequency, timing and intensity treatments, produced over six years (2011 – 2016).

The cumulative number of bramble flowers produced over six years was strongly affected by the percentage cover of bramble in each plot at the start of the experiment ($t_{1,119} = 5.22$, $P < 0.001$). Plots cut in winter had 1.4 times more flowers than those cut in autumn, on average ($t_{1,119} = 2.19$, $P < 0.05$).

The response of bramble flowers to the cutting treatments varied between years. In 2015 only, there was a greater number of bramble flowers on plots cut every two years compared with those cut annually ($t_{1,93} = 2.08$, $P < 0.05$). In 2016 there was a trend towards fewer bramble flowers on plots cut once every three years ($t_{1,93} = 1.83$, P =0,068), just after the three-year plots had been cut. Bramble flowers were more abundant on plots cut in winter than those cut in autumn in two of the six years (2015: $t_{1,93} = 3.35$, $P < 0.001$, 2016: $t_{1,93} = 4.59$, $P < 0.001$). There were more flowers on plots cut for incremental growth in 2014 ($t_{1,93} = 1.97$, $P < 0.05$) and 2016 ($t_{1,93} = 2.47$, $P < 0.05$), compared with those cut back to a standard height and width.

4.3.4 Discussion of flower results

These results for the production of flowers in response to cutting frequency and timing treatments at Experiment 2 are broadly supportive of those for hawthorn from the single-site Experiment 1 at Monks Wood (Staley et al., 2012b), though there are some differences. After six years of cutting treatments, there were 2.6 times more hawthorn flowers on plots cut every three years compared with those cut annually at Monks Wood. A slightly smaller increase was found at the multi-site Experiment 2 after six years (1.5 times), but the findings are similar. There were greater cumulative numbers of hawthorn flowers on both the two and three-year cutting frequencies compared with plots cut annually at Monks Wood, whereas at Experiment 2 the cumulative hawthorn flower production did not differ between plots cut every one and every two years. However, when the hawthorn flower data were analysed by year, rather than summed across all six years, in two out of the six years there were significantly more flowers on the plots under the two-year cutting frequency, indicating some benefit of the two-year cutting regime. Plots cut in winter at Monks Wood (Experiment 1) had fewer hawthorn flowers the following spring than those cut in autumn, but Experiment 2 does not show a consistent effect of timing of cutting on hawthorn flower production, though one site (Marsh Gibbon) responded in a similar way to Monks Wood.

Experiment 2 has a broader remit than the Monks Wood experiment, as it tests the response of more than one hedgerow species to cutting frequency and timing, and also includes cutting intensity. Production of flowers by blackthorn in response to cutting frequency and timing broadly follows the response of hawthorn for Experiment 2, in that substantially more flowers were produced under a three-year cutting cycle compared with an annual cycle, but no significant difference was found between plots cut every one or two years in relation to the cumulative number of blackthorn flowers. In some years, there were more blackthorn flowers on plots cut once every two years. Both woody species produced substantially more flowers on plots cut to allow incremental growth of the hedgerow compared with those cut back to a standard height and width, and the benefits of a reduced cutting intensity increased over the six years of the experiment. Bramble showed a slightly different response to the cutting treatments, as cutting timing had the strongest influence, with fewer bramble flowers on plots cut in autumn.

All three species provide some support for the current CS BE3 and ELS EB3 hedgerow options in relation to increased cumulative flower production under a three-year cutting cycle. However, the value of cutting every two years for increased flower production has only been demonstrated in two or three out of the six years of this experiment. The low flower numbers on Experiment 2 in 2013 made detecting effects of a two-year cutting cycle less likely. The strong effect of cutting intensity on the number of flowers for both hawthorn and blackthorn lend support to the inclusion of this form of management in future AES hedgerow options.

4.4 Berry availability over winter

4.4.1 Hawthorn

The cumulative weight of hawthorn berries over seven years, available over winter to wildlife, was affected by the frequency, timing and intensity with which plots were cut (Figure 4.4). No significant differences were found between sites in their response to the cutting treatments in relation to hawthorn berry weight, though overall there was a lighter weight of hawthorn berries at the Waddesdon mixed species hedge and Yarcombe mixed species hedge than at the hawthorn-dominated sites (Marsh Gibbon and Woburn).

Overall, the intensity of cutting had the greatest effect on the weight of hawthorn berries available over winter. On average, there was a 1.7 times heavier weight of berries on plots cut to allow incremental growth, compared with those cut back to a standard height and width ($t_{1,123} = 4.57$, $P < 0.001$). There was a significant interaction between the frequency and timing of cutting ($t_{1,123} = 2.75$, $P < 0.01$). Plots cut once every three years had a 3.1 times heavier weight of hawthorn berries on average compared with plots cut every year, but only if cut in winter rather than in autumn. There was a similar difference between the uncut control plots, and plots cut every year ($t_{1,129} = 5.21$, $P < 0.001$).

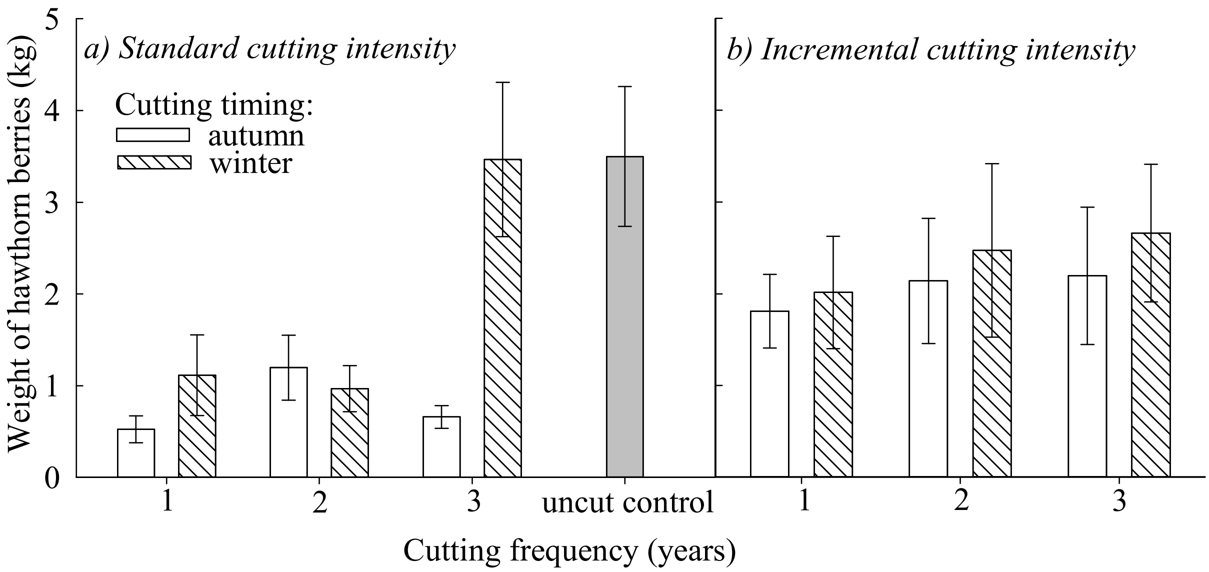

Figure 4.4: Fresh weight of hawthorn berries (mean ± SE) available over winter, under cutting frequency, timing and intensity treatments, along 1m of hedge. Cumulative weights over seven years (2010 – 2016).

The effects of the frequency and timing of cutting on the weight of hawthorn berries varied with year (Likelihood ratio test: $\chi^2_{1,12} = 47.48$, $P < 0.001$). In 2012 and 2015, plots cut every three years in winter had a greater weight of berries ($t = 4.13$, $P < 0.001$ and $t = 2.59$, $P < 0.01$ respectively), compared with plots cut annually. These yearly trends reflect the stage of the cutting cycle, as when berries were assessed in 2012 and 2015, there was three years' growth on the plots cut once every three years. Similarly, plots cut once every two years in winter had a heavier weight of hawthorn berries than those cut annually in 2011 ($t = 2.01$, $P < 0.05$) and a trend towards a heavier weight in 2015 ($t = 1.04$, $P = 0.096$), in both years there were two years' growth present.

Year had a large effect on overall berry production regardless of cutting treatment; for example the uncut control plots had 4.6 times more berries in 2014 than in 2013. There was a heavier weight of hawthorn berries on plots cut for incremental growth in four years (2011, 2012, 2014, 2016). In the two years in which hawthorn berry weight did not differ between the two cutting intensities (2013 and 2015) there were few berries produced overall (lightest berry weights on the uncut control plots), so the chances of demonstrating an effect of cutting intensity were smaller.

4.4.2 Blackthorn

The cumulative weight of available blackthorn berries over seven years was affected by the frequency, timing and intensity with which hedges were cut (Figure 4.5). On average, there was a 2.6 times greater weight of blackthorn berries on plots cut to allow incremental growth compared with those cut back to a standard height and width ($t_{1,47} = 3.26$, $P < 0.05$).

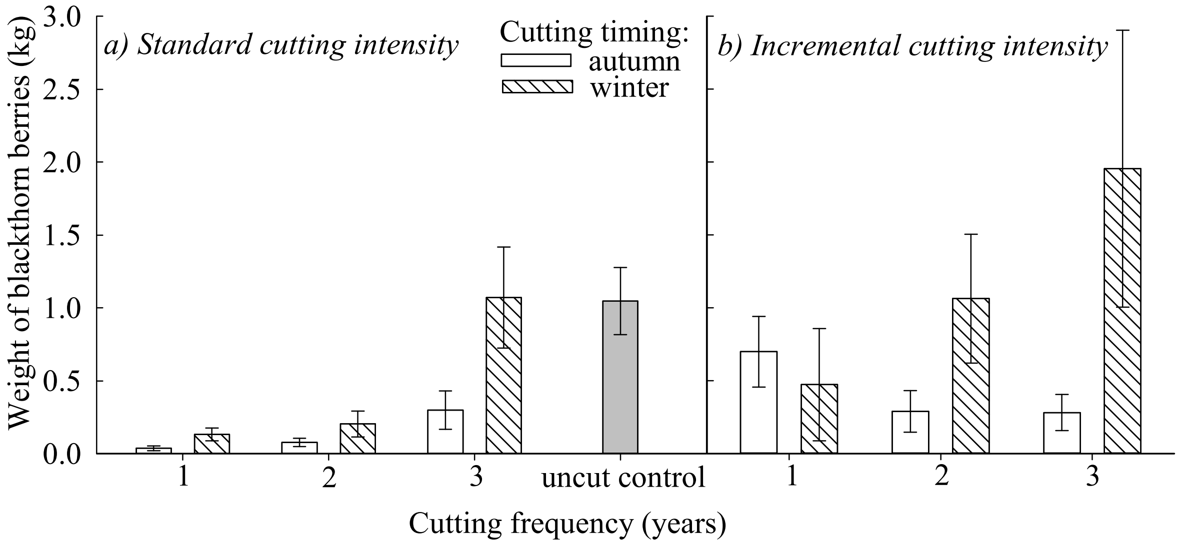

Figure 4.5: Fresh weight of blackthorn berries (mean ± SE) available over winter, under cutting frequency, timing and intensity treatments, along 1m of hedge. Cumulative weights over seven years (2010 – 2016).

The effect of timing of cutting on cumulative weight of blackthorn berries depended on the cutting frequency (cutting frequency two years × timing: $t_{1,47} = 3.88$, $P < 0.05$; cutting frequency three years × timing: $t_{1,47} = 4.22$, $P < 0.05$). Timing did not affect berry weight on annually cut plots, but those cut every two or three years had a greater weight of blackthorn berries if cut in winter compared to autumn. Blackthorn berry weight was 2.1 times greater on plots cut every two years in winter compared with those cut annually in winter, and 5.0 times greater on those cut in winter every three years compared with annually cut plots.

Weight of blackthorn berries was 28 times greater on uncut control plots, compared with those cut to a standard intensity every year in autumn ($t_{1,62} = 3.92$, $P < 0.001$).

4.4.3 Bramble

The total number of blackberries available over four years was 2.5 times greater on plots cut in winter compared with those cut in autumn ($t_{1,119} = 4.11$, $P < 0.001$, Figure 4.6). Plots cut every three years had 1.44 times more blackberries than those cut annually ($t_{1,119} = 3.56$, $P < 0.001$), and plots cut once every two years had 1.38 times more blackberries ($t_{1,119} = 2.73$, $P = 0.001$), in both cases compared with those cut annually. Trimming intensity did not affect the cumulative number of blackberries.

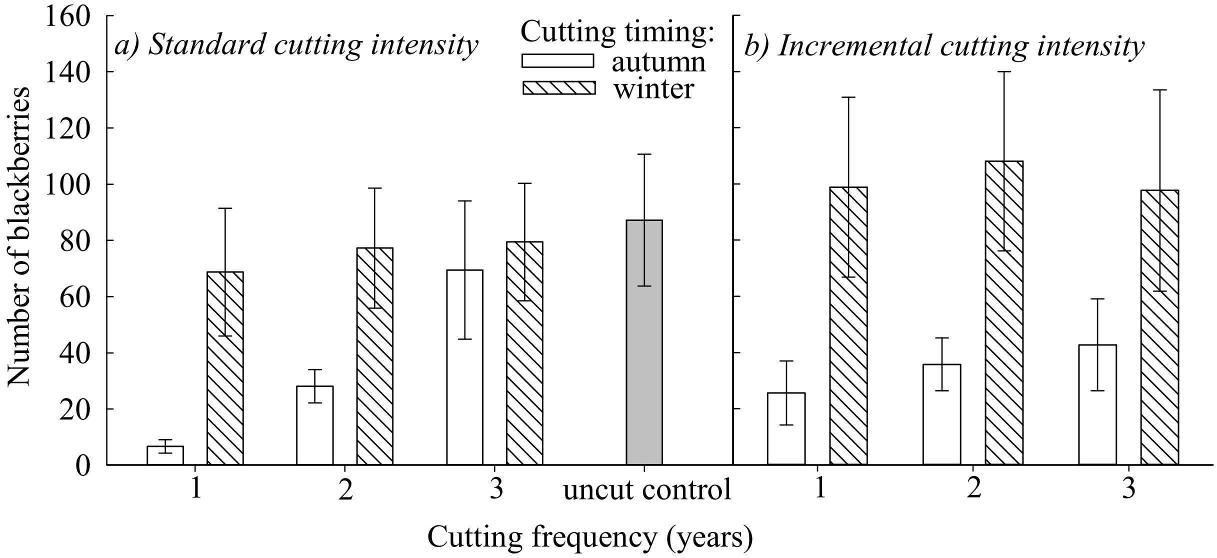

Figure 4.6: Number of blackberries available over winter (mean ± SE), under cutting frequency, timing and intensity treatments, along 1m of hedge. Cumulative weights over seven years (2010 – 2016).

4.4.4 Dog-rose

The effects of cutting timing depended on cutting frequency (cutting frequency two years × timing: $t_{1,83} = 2.33$, $P < 0.05$). Dog-rose berry weight did not differ between autumn and winter cutting for plots cut annually, but did for those cut every two or three years. There was a trend towards a lower weight of dog-rose berries on plots cut back to a standard height and width, compared with those cut to allow incremental growth, but this result was not statistically significant at $P < 0.05$ ($t_{1,83} = 1.70$, $P < 0.1$).

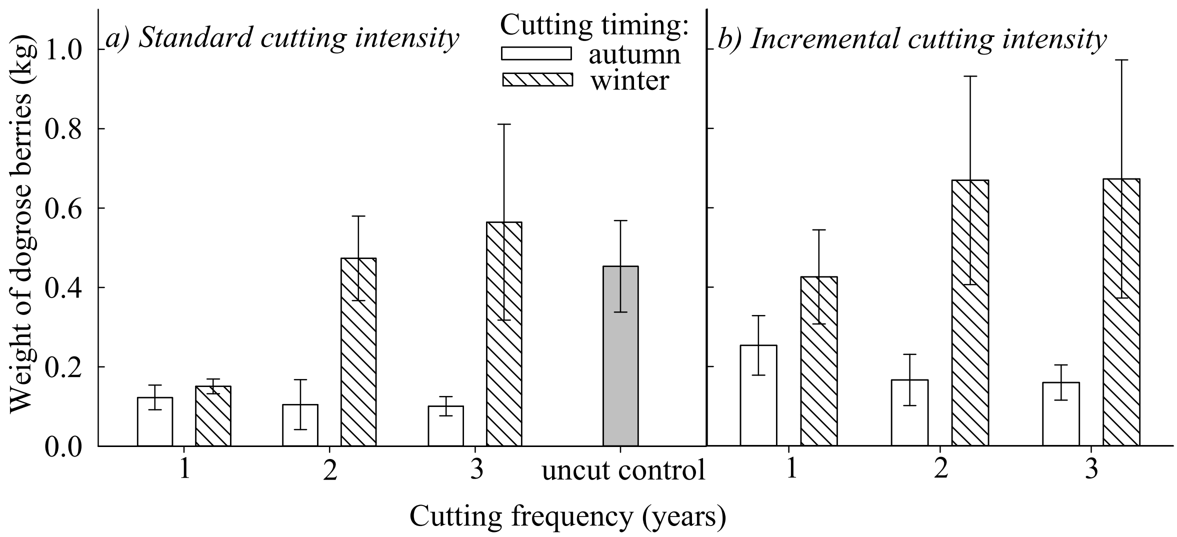

Figure 4.7: Fresh weight of dog-rose berries (mean ± SE) available over winter, under cutting frequency, timing and intensity treatments, along 1m hedge. Cumulative weights over seven years (2010 – 2016).

4.4.5 Discussion of berry provision for overwintering wildlife

The weight of hawthorn berries available to overwintering wildlife in response to cutting frequency and timing on Experiment 2 is broadly comparable to results from the Monks Wood experiment (Section 3.2; Staley et al., 2012b), though there are some differences. At Monks Wood there were significant differences in hawthorn berry weight between all three of the cutting frequencies (as there were for flower production), whereas results from Experiment 2 show a greater weight of hawthorn berries from plots cut every three years compared with those cut annually, but no significant difference between two and one-year plots. In addition, at Experiment 2 the increased hawthorn berry weight under a three year cutting cycle is limited to those plots that are cut in winter. Blackthorn and dog-rose followed a similar pattern to hawthorn, but there was an increase in berry weight for these species on plots cut every two years in winter, compared with those trimmed annually. There were also more blackberries (bramble) on plots cut once every two or three years, and more blackberries on plots cut in winter.

Both hawthorn and blackthorn have increased berry availability for overwintering wildlife on hedge plots cut in late winter compared with autumn, though this is limited to plots cut every three years for hawthorn at Experiment 2 sites, and to plots cut every two or three years for blackthorn. At Monks Wood, available hawthorn berry weight was also greater on plots cut in winter.

The intensity of hedgerow trimming strongly affected the availability of berries for overwintering wildlife from hawthorn and blackthorn across Experiment 2. Berry availability was increased by 1.7 – 2.6 times on plots cut to allow incremental growth for these two hedgerow species, compared with plots cut back to a standard height and width. Blackthorn berry provision benefitted to a greater extent from cutting back to allow incremental growth, suggesting that it is particularly vulnerable to a severe trimming intensity.

The increased provision of berries for overwintering wildlife under a three-year cutting cycle provides some support for CS option BE3 and ELS hedgerow option EB3, though results from Experiment 2 show hedges on a three-year cutting cycle need to be cut in winter for hawthorn berry provision to increase. The contrast with results for hawthorn from Monks Wood may be due to the age and type of hedgerows. The hawthorn berry responses from Experiment 2 were driven by the responses at hawthorn-dominated sites (Marsh Gibbon and Woburn), both of which are over 150 years old (Section 2.3.2), in contrast to the hedges at Monks Wood which were planted in the 1960s.

The benefits of a two-year cutting cycle in winter for hawthorn berry availability were demonstrated by the results from Experiment 1, but not shown from Experiment 2 across a wider range of hedgerow types than those tested at Monks Wood, so the two-year winter cutting element of BE3 and EB3 is not supported in terms of berry provision by the dominant hedgerow woody species. The other woody species assessed (blackthorn, dog-rose and bramble) did have increased berry provision under a two-year cutting cycle across Experiment 2, which for blackthorn and dog-rose was limited to plots cut every two years in winter. For these three species, the two-year winter cutting element of option BE3 and EB3 would lead to increased berry availability.

4.5 Pollinator visits to hedgerow flowers

The largest numbers of pollinator visits per plot were to bramble flowers, followed by blackthorn and then hawthorn flowers (Table 4.2), despite hawthorn providing the greatest potential floral resource. The low pollinator visitation rates to hawthorn may have been due to a greater number of alternative floral resources (e.g. flowering field margins) at the time that hawthorn is in flower, compared to relatively few resources in early spring when blackthorn flowers. There were far fewer visits by pollinators to hedgerow flowers in 2013 compared to previous years (Table 4.2), as flowering was later in 2013 and fewer flowers were produced than in earlier years, especially on blackthorn and hawthorn. This reflects a national trend in late flowering, which was 19 days later in 2013 compared with 2011 across the UK (Sparks *et al*. 2014).

Flowering species	Blackthorn			Hawthorn			Bramble		
Number of plots assessed each year	99			156			138		
Year	2011	2012	2013	2011	2012	2013	2011	2012	2013
Total pollinators	738	1373	151	832	1715	72	2865	3134	1474
Total pollinators per plot (mean)	7.45	13.87	1.53	5.33	10.99	0.46	20.76	22.71	10.68
Number of flowers per pollinator quadrat (mean)	298.3	329.2	123.9	556.7	581.7	345.9	154.3	263.7	137.3
Bombus spp. - bumblebees	0	28	0	19	2	1	413	198	208
Solitary bees	32	21	2	210	476	15	82	27	16
Apis mellifera - honeybees	41	18	7	134	244	0	890	914	92
Parasitica - parasitoid wasps	25	16	0	32	104	5	7	10	33
Total Hymenoptera	100	85	9	417	851	24	1403	1153	355
Syrphidae - hoverflies	22	144	6	28	32	6	758	1654	302
Scathophagidae - dung flies	159	644	75	4	56	0	0	15	25
Empididae & Dolichopodidae - predatory	6	1	0	0	131	2	24	28	89
Bombyliidae - bee fly (bee mimic)	40	48	0	0	0	0	0	0	0
Total Diptera	540	1138	120	338	690	25	808	1837	469
Total Lepidoptera	1	3	1	16	10	7	27	102	66
Nitidulidae - pollen beetles	53	139	20	16	97	1	540	37	450
Total Coleoptera	95	166	21	56	161	16	601	56	571

Table 4.2: The number of visits by key groups of pollinators to hedgerow flowers, by year and flowering species. Not all pollinator taxa assessed are included in this table.

4.5.1 Blackthorn pollinators

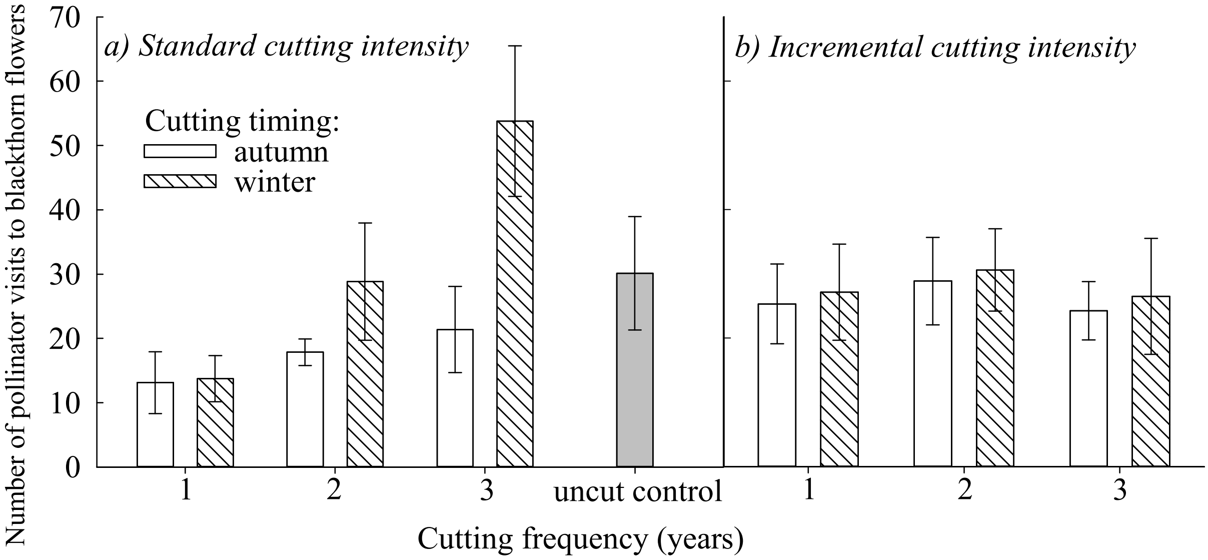

Figure 4.8: Number of pollinator visits (mean ± SE) to blackthorn flowers, under cutting frequency, timing and intensity treatments. Cumulative number of visits over three years (2011 – 2013).

The numbers of pollinator visits to blackthorn flowers in early spring were strongly affected by the number of flowers present on the hedge plot ($t_{1,69}$=5.75 $P < 0.001$) and air temperature ($t_{1,69}$=2.46, $P < 0.05$). There were 1.8 times more visits on average to plots cut in winter at a standard cutting intensity compared with those cut in autumn to a standard intensity ($t_{1,69}$=2.69, $P < 0.01$, Figure 4.8). The frequency, timing and intensity of hedgerow cutting did not significantly affect the number of pollinator visits to blackthorn flowers once the effect of number of flowers was taken into account, and nor did hedge cutting treatment affect the composition of the blackthorn pollinator assemblage.

4.5.2 Hawthorn pollinators

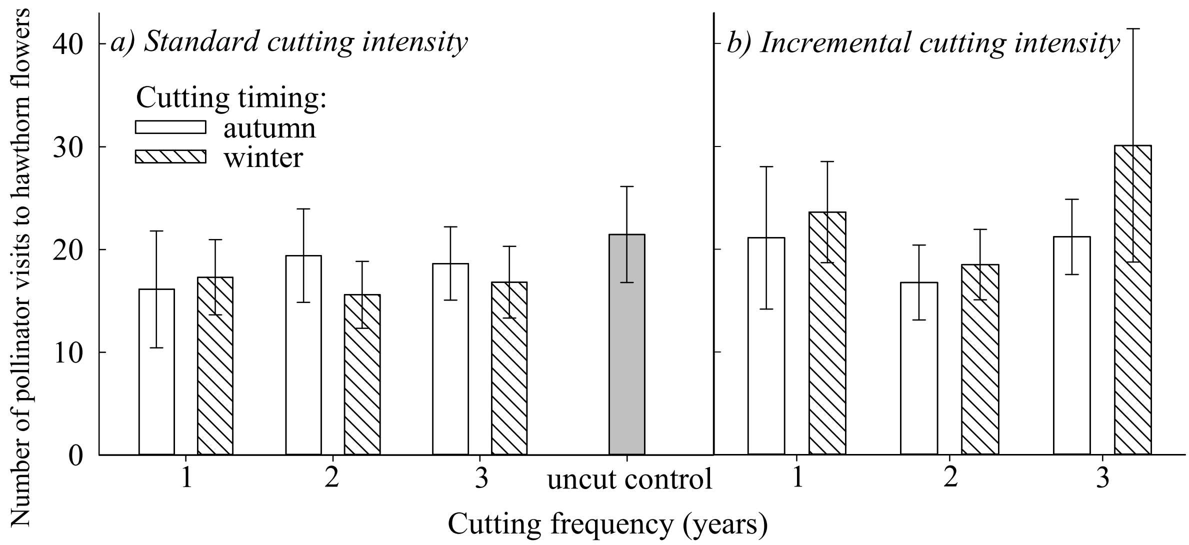

Figure 4.9: Number of pollinator visits (mean ± SE) to hawthorn flowers, under cutting frequency, timing and intensity treatments. Cumulative number of visits over three years (2011 – 2013).

The numbers of pollinator visits to hawthorn flowers were most strongly affected by the number of flowers present on the hedge plot ($t_{1,115}$=4.29 P < 0.001) and also by cloud cover ($t_{1,115}$=2.22, P < 0.05). If number of flowers was excluded from the analysis of pollinator visits, there was a significant effect of incremental growth on the number of pollinator visits compared with those cut to a standard intensity ($t_{1,115}$=2.50 P < 0.05, Figure 4.9), and a trend towards more pollinator visits to plots cut every three years compared with those cut every year ($t_{1,115}$=1.73 P =0.087). However, if the number of hawthorn flowers was included in the analysis the cutting treatments had no effect on the number of pollinator visits, indicating that the effects of incremental cutting intensity and cutting frequency were due to an increase in the number of hawthorn flowers produced on these plots.

There were 1.6 times more pollinator taxa visiting hawthorn flowers over three years on uncut control plots compared with standard plots cut every year in the autumn ($t_{1,115}$=3.11 P < 0.01). There were no consistent effects of cutting frequency, timing or intensity on the number of pollinator taxa, and nor did hedge cutting treatment affect the pollinator assemblage visiting hawthorn flowers.

4.5.3 Bramble pollinators

The number of bramble flowers had the strongest effect on the number of visits by pollinators ($t_{1,91}$=9.36 P < 0.001), and wind speed was also important ($t_{1,98}$=2.65 P < 0.01). If the number of bramble flowers was excluded from the analysis of pollinator visits, the hedgerow cutting treatments had significant effects on the number of pollinator visits (Figure 4.10). There were 1.4 more pollinator visits on plots cut in winter than autumn ($t_{1,98}$=2.17 P < 0.05), and 1.2 times more visits to plots cut to allow incremental growth compared to those cut back to a standard height and width ($t_{1,98}$=2.46 P < 0.05). There was an interaction between the frequency and intensity of hedge cutting; on standard cut plots there were more pollinator visits to those cut every two ($t_{1,98}$=2.11 $P < 0.05$) or three years ($t_{1,98}$=2.51 $P < 0.05$) compared with the annual plots, while cutting frequency did not affect the number of pollinator visits on plots cut to allow incremental growth. However, if the number of bramble flowers was included in the analysis then cutting treatments had no consistent effect on the number of pollinator visits, indicating that the cutting treatment effects were due to an increase in the number of bramble flowers produced on these plots. There were no consistent effects of cutting frequency, timing or intensity on the number of pollinator taxa, or on the pollinator assemblage visiting bramble flowers.

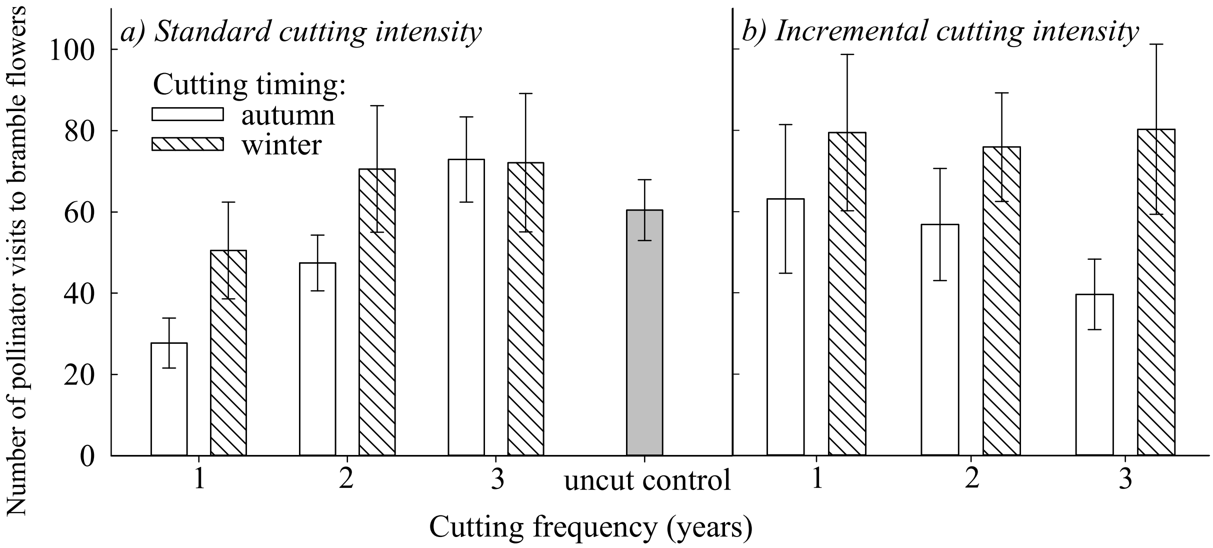

Figure 4.10: Number of pollinator visits (mean ± SE) to bramble flowers, under cutting frequency, timing and intensity treatments. Cumulative number of visits over three years (2011 – 2013).

4.5.4 Discussion of pollinators visiting hedgerow flowers

The numbers of pollinator visits to flowers of all three woody hedgerow species were most strongly influenced by the number of flowers available. The response of pollinators to the cutting treatments was thus driven by the response of flower abundance to the frequency, timing and intensity of hedgerow cutting. Results from Experiment 2 provide strong support for AES hedgerow options that increase flower abundance, as they clearly demonstrate that these increased resources will be utilised more by insect pollinators.

The numbers of pollinator taxa, and the response of the pollinator community measured as a whole, were not affected by the frequency, timing or intensity of hedgerow trimming. This shows that the same community of pollinators were utilising plots under the different cutting treatments, so the cutting treatments altered the extent to which the hedgerows were utilised by pollinators, but not which pollinators visited hedgerow flowers.

Blackthorn and bramble flowers may be more important resources for pollinators than hawthorn flowers, as they both had higher visitation rates per hedgerow plot, despite having a lower abundance of flowers per plot than hawthorn. This may reflect availability in alternative floral resources at the time of flowering. Blackthorn peak flowering occurred between late March and early May in 2011 – 2013 at Experiment 2, a time when few other plant species are flowering in agricultural habitats. In contrast, hawthorn flowered between late April and mid-June, when many other species are also flowering in field margins and hedge bases. The number of pollinator visits to early and late flowering species supports the planting of mixed species hedges, as opposed to single species hedges.

4.6 Invertebrates within hedgerows

4.6.1 Lepidoptera – abundance, species richness and diversity

One thousand one hundred individual Lepidoptera were collected over three years, of which 789 were identified to 62 different species. There were significantly more (16%) larvae and pupae on hedges cut in winter compared with those cut in autumn ($t_{152} = 2.02$, $P < 0.05$; Figure 4.11). Hedgerow plots cut every three years also had a significantly higher abundance (4%) than those cut annually ($t_{152} = 2.7$, $P < 0.01$), while plots cut once every two years did not differ from those cut annually. There was a nearly significant interaction between the timing and frequency of hedgerow trimming (LRT $\chi^2 = 5.9$, P = 0.052), which indicated that the increased abundance due to winter trimming may be limited to hedgerow plots cut once every one or two years. There was no significant effect of trimming intensity, or any interaction involving trimming intensity and the other cutting treatments, on Lepidoptera abundance.

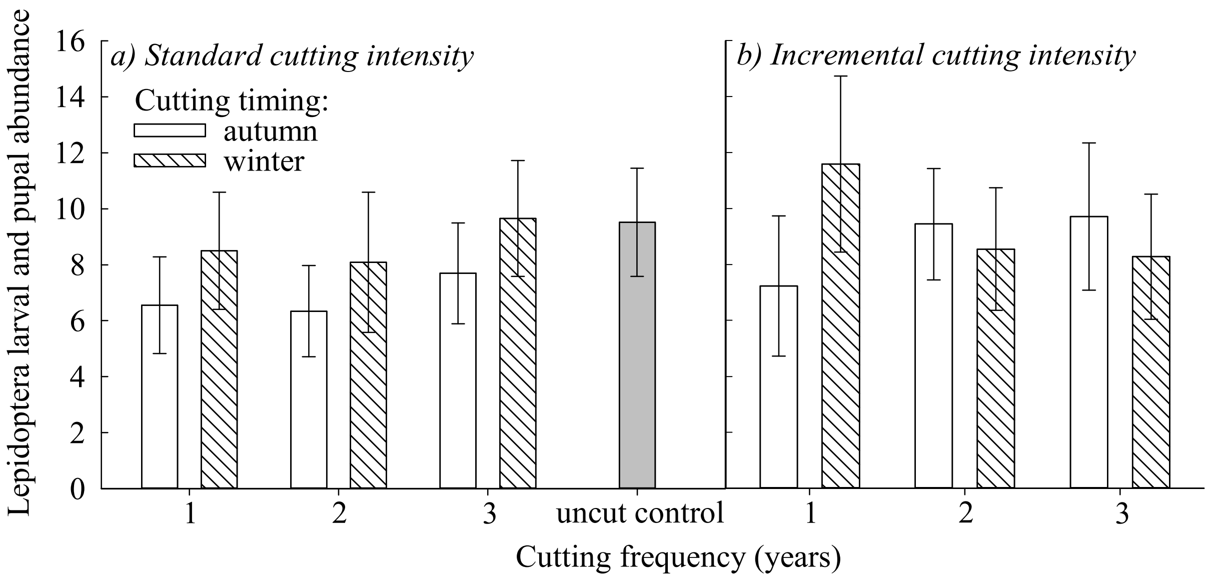

Figure 4.11: The abundance of Lepidoptera larvae and pupae (mean ± SE) on hedges under cutting frequency, timing and intensity treatments. Cumulative data collected over three years (2012 – 2014).

Lepidoptera species richness was greater (18%) on plots cut for incremental growth compared with standard cutting, though the difference between incremental growth and standard plots was not quite statistically significant (LRT $\chi^2_1 = 3.7$, $P = 0.054$). Shannon-Wiener diversity of the whole community was significantly greater (15%) on hedgerow plots cut for incremental growth compared with those cut to a standard height and width (LRT $\chi^2_1 = 3.9$, $P < 0.05$; Figure 4.12).

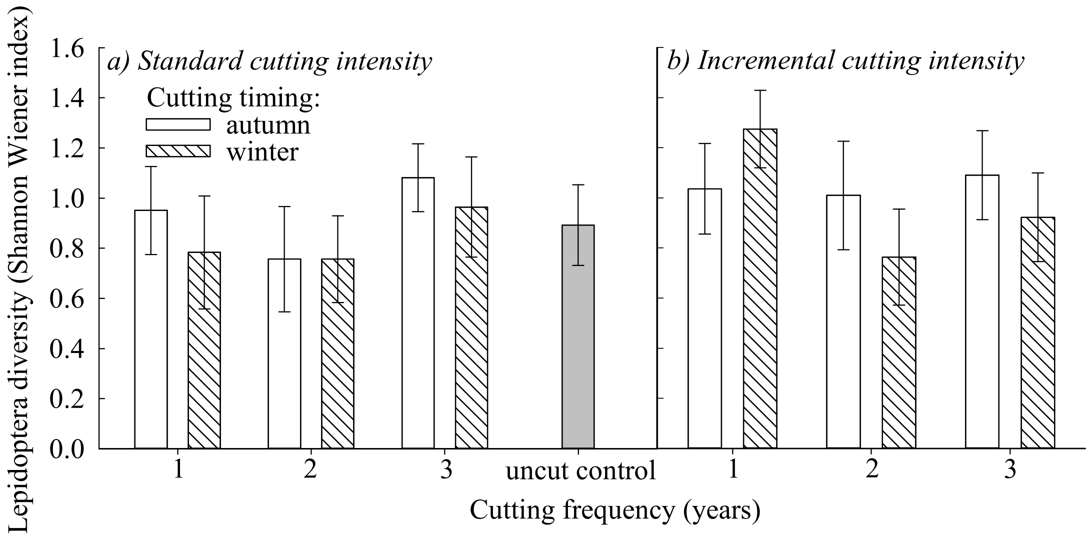

Figure 4.12: Diversity of Lepidoptera (Shannon diversity index, mean ± SE) on hedges under cutting frequency, timing and intensity treatments. Cumulative data collected over three years (2012 – 2014).

The Lepidoptera community was divided into species that are likely to be present on hedgerow plants in September (as larvae or pupae within or on leaves, or as eggs) and therefore vulnerable to autumn hedge trimming, and those that are elsewhere in September (egg, larvae or pupae in moss, soil or detritus, or adults). The species richness of Lepidoptera that are present on hedgerow plants in September was significantly affected by an interaction between the frequency and timing of cutting (LRT $\chi^2_2 = 6.9$, $P < 0.05$), as plots cut in autumn had a greater species richness (54%) if they were cut once in three years compared with every year ($z_{151} = 2.6$, $P < 0.05$). Species richness of the group that are not present on the hedgerow plants in September was not affected by the cutting treatments.

Shannon-Wiener diversity of this second species group was significantly greater (15%) on hedgerow plots cut for incremental growth compared with standard plots ($t_{117} = 2.3$, $P < 0.05$) as was found for the whole Lepidoptera community. In addition, there was a nearly significant interaction between the intensity and timing of cutting, indicating that for this 'robust' species group, the effect of cutting intensity was stronger for plots cut in autumn (LRT $\chi^2_1 = 3.83$, $P = 0.0504$). Shannon-Wiener diversity of the group of species present on hedgerow plants in September was not significantly affected by any of the cutting treatments.

4.6.2 Lepidoptera - brown hairstreak butterfly egg abundance at Yarcombe, Devon

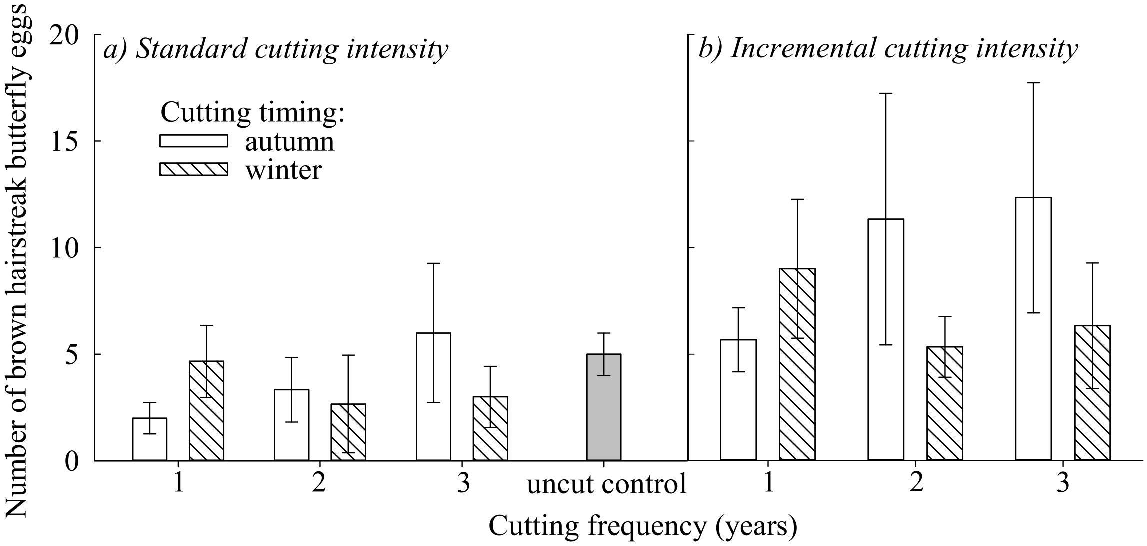

Figure 4.13: Number of brown hairstreak butterfly eggs (mean ± SE) on blackthorn under cutting frequency, timing and intensity treatments at Yarcombe, Devon. Cumulative number of eggs over three years (2012 – 2014).

Assessing cumulative egg abundance per plot over all four years of the survey, hedges cut to allow incremental growth had on average 2.3 times more brown hairstreak eggs than those cut back to a standard height and width (LRT $\chi^2_2 = 35.0$, $P < 0.001$; Figure 4.13). There was an interaction between the frequency and timing of hedgerow cutting on cumulative brown hairstreak egg abundance (LRT $\chi^2_2 = 16.7$, $P < 0.05$); on hedgerow plots cut in autumn, there were on average 1.3 times more brown hairstreak eggs if plots were cut once every three years compared to those cut every year. Hedges cut in autumn also had nearly twice as many eggs as those cut in winter, for those plots cut less frequently than every year (1.96 times more eggs when cut in autumn vs. winter for plots cut once every three years; 1.83 times if cut once every two years).

4.6.3 Invertebrate abundance

Total invertebrate abundance was not affected by the frequency, timing or intensity of hedgerow trimming.

4.6.4 Discussion of invertebrates other than pollinators within hedgerows

Lepidoptera form a substantial component of invertebrate diversity, with over 2,900 species in the UK (Bradley, 2000), and are often used as indicators for terrestrial biodiversity (Merckx & Berwaerts, 2010). Significant declines have been documented for many Lepidoptera species with a range of possible drivers including agricultural intensification (Fox, 2013). The brown hairstreak butterfly is one example of a rapidly declining Lepidoptera species, and has been allocated priority status in the UK Biodiversity Action Plan (Merckx & Berwaerts, 2010).

The abundance of Lepidoptera larvae and pupae in Experiment 2 was increased by cutting once every three years compared with annual trimming. In addition, on plots cut once every one or two years, Lepidoptera larval and pupal abundance was increased by cutting in winter rather than autumn. Species richness of Lepidoptera that are present on hedgerow plants in September was increased on plots cut once in three years, and those cut in winter. This increase in Lepidoptera abundance, and the species richness of part of the Lepidoptera community, provides support for CS option BE3 and ELS option EB3. A single year of Lepidoptera sampling at the Monks Wood experiment showed an increase in abundance of those moth species with concealed larval stages (leaf miners, tentiform and case-bearing larvae) on plots cut every two or three years compared with those cut annually, and on those cut in winter compared with autumn cutting (Facey et al., 2014). However, unlike Experiment 2, there was no effect of cutting frequency at Monks Wood on abundance of free-living Lepidoptera larvae (Facey et al., 2014). Results from Experiment 2 are likely to be more robust as sampling took place over three years, and from five sites rather than one.

In contrast to the general Lepidoptera community, cutting in September resulted in nearly twice the number of brown hairstreak butterfly eggs compared with cutting hedgerows in February. Brown hairstreak adults often persist until late September and in some years early October, and therefore may have laid eggs after the autumn plots were cut in September. Over the four years of this study, autumn plots were cut between 17th and 29th September. Cutting dates were compared with the last date on which brown hairstreak adults were recorded in the three counties surrounding the Yarcombe experimental site (Devon, Dorset and Somerset) for each of the four years, using data from the UK Butterfly Monitoring Scheme (http://www.ukbms.org/). Brown hairstreak adults were recorded on the wing at nearby UKBMS sites on or after the autumn cutting date in three of the four years of the egg monitoring. There is a need to balance the benefits of earlier cutting in relation to brown hairstreak against the conservation of other taxa which are likely to do better under late winter cutting regimes, including the broader Lepidoptera community in hedgerows.

The diversity of Lepidoptera was increased on plots cut to allow incremental growth compared with a standard cutting intensity at Experiment 2, and species richness showed a trend towards the same pattern. Brown hairstreak egg abundance was also greater on plots cut to allow incremental growth. This provides strong support for the inclusion of trimming for incremental growth in future AES.

Total invertebrate abundance was not affected by the frequency, timing and intensity of trimming. The majority of invertebrates sampled (e.g. Hemipera, Diptera) are likely to have been more mobile than Lepidoptera larvae, and may have moved between the contiguous hedgerow plots and used the hedges for short periods rather than as their main habitat.

4.7 Hedgerow structure

There was a trend towards an interaction between the timing and intensity of cutting on the percentage of woody material in the bottom 90 cm of the hedgerow plots in 2016 (Figure 13; $t_{1,84} = 1.94$, $P = 0.055$). This suggests a trend towards percentage of woody material being reduced for plots cut in winter when cut under a standard cutting intensity compared with those cut in autumn, but not on those plots cut for incremental growth. There was no effect of cutting frequency on the percentage of woody material.

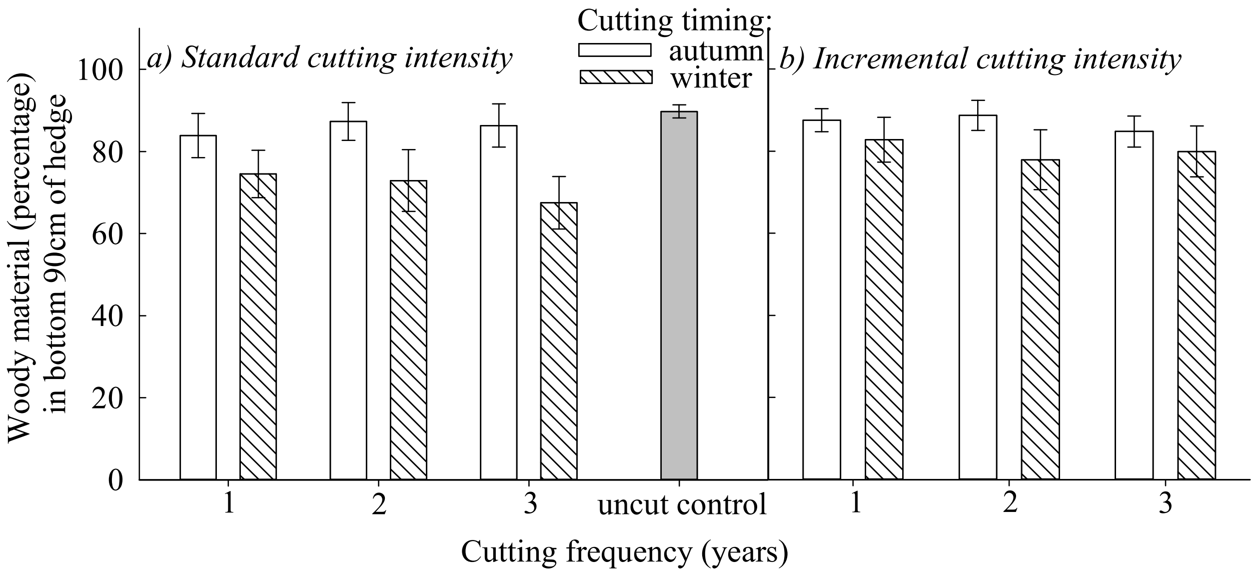

Figure 4.13: Woody material (percentage, mean ± SE) in the basal 90 cm of plots calculated from digital images taken in March 2016, when all plots had just been cut that autumn/winter after six years of experimental treatments.

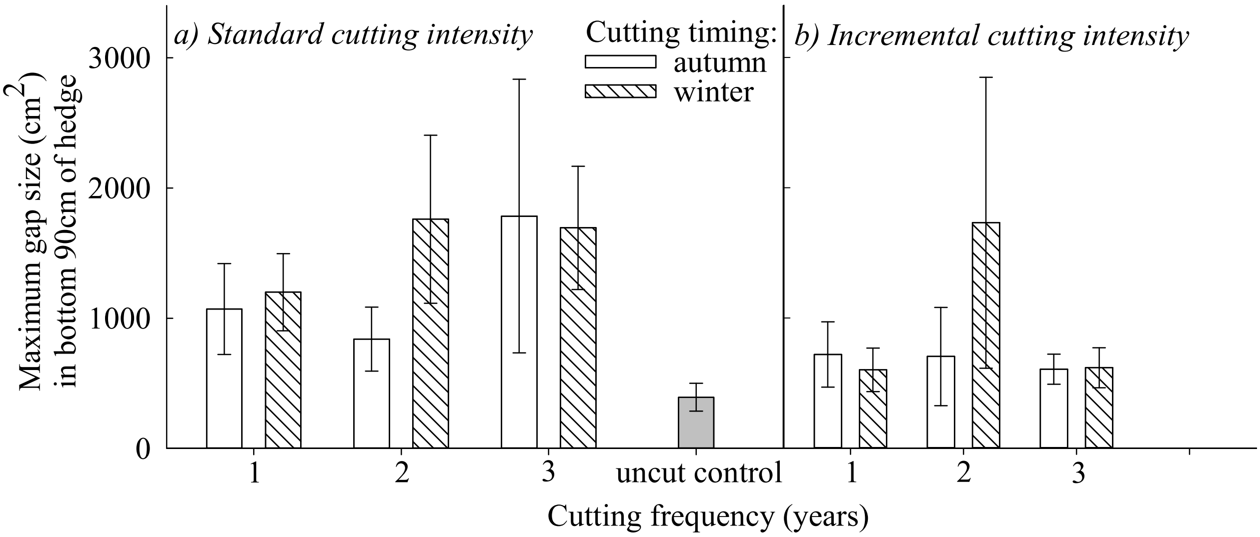

Figure 4.14: Maximum gap size (cm^2; mean ± SE) in the basal 90 cm of plots calculated from digital images taken in March 2016, when all plots had just been cut that autumn/winter after six years of experimental treatments.

Maximum gap size was slightly larger for plots cut back to the same height and width each time (standard cutting intensity), compared to plots cut to allow incremental growth (Figure 4.14; $t_{1,86} = 2.99$, $P < 0.01$). Maximum gap size was not affected by the frequency or timing of cutting regime.

The number of gaps > 20cm diameter (chosen to represent gaps through which small livestock such as lambs could potentially pass) was not consistently affected by the frequency, timing or intensity of cutting. There were fewer of these large gaps in plots cut once every two years in winter when cut to allow incremental growth (Figure 4.15; $t_{1,47} =$ 3.84, $P < 0.001$).

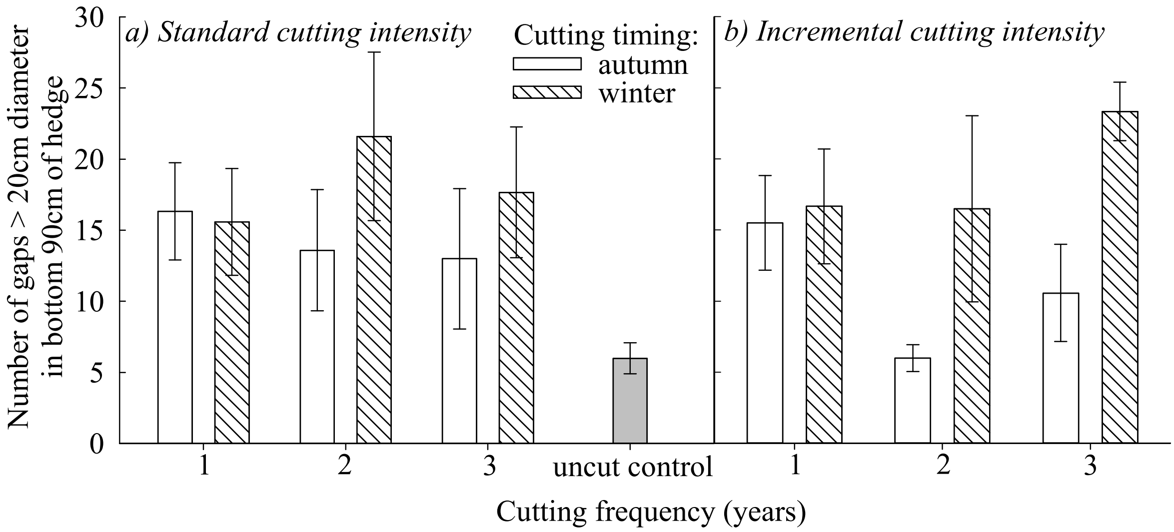

Figure 4.15: Number of gaps > 20cm diameter (mean ± SE) in the basal 90 cm of plots calculated from digital images taken in March 2016, when all plots had just been cut that autumn/winter after six years of experimental treatments.

4.8 Rates of woody hedgerow species regrowth

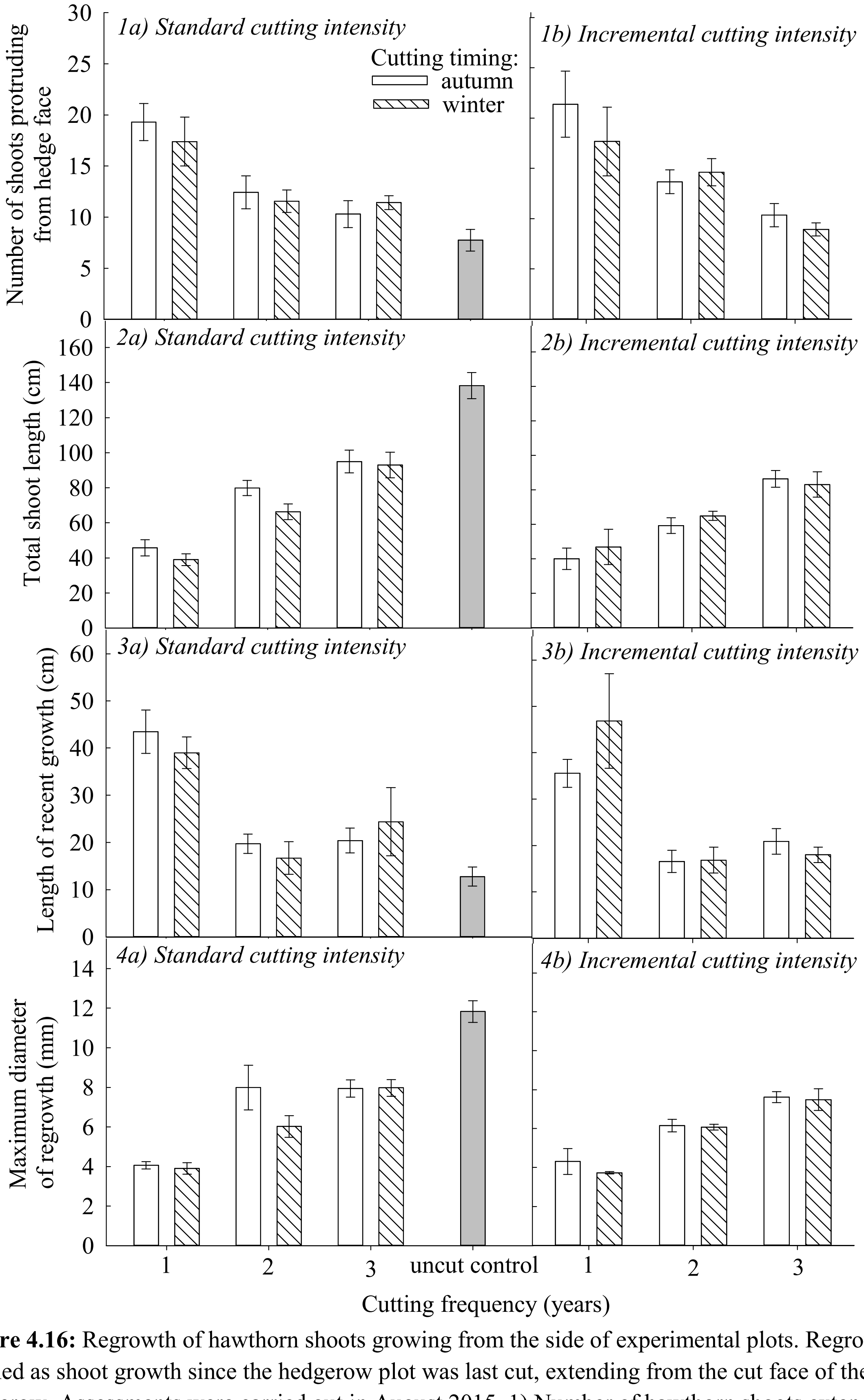

Figure 4.16: Regrowth of hawthorn shoots growing from the side of experimental plots. Regrowth defined as shoot growth since the hedgerow plot was last cut, extending from the cut face of the hedgerow. Assessments were carried out in August 2015. 1) Number of hawthorn shoots extending from 20 cm section; 2) Total length of shoots (cm); 3) Length of growth in spring/summer 2015 (most recent growth), cm; 4) Maximum diameter of shoots (mm).

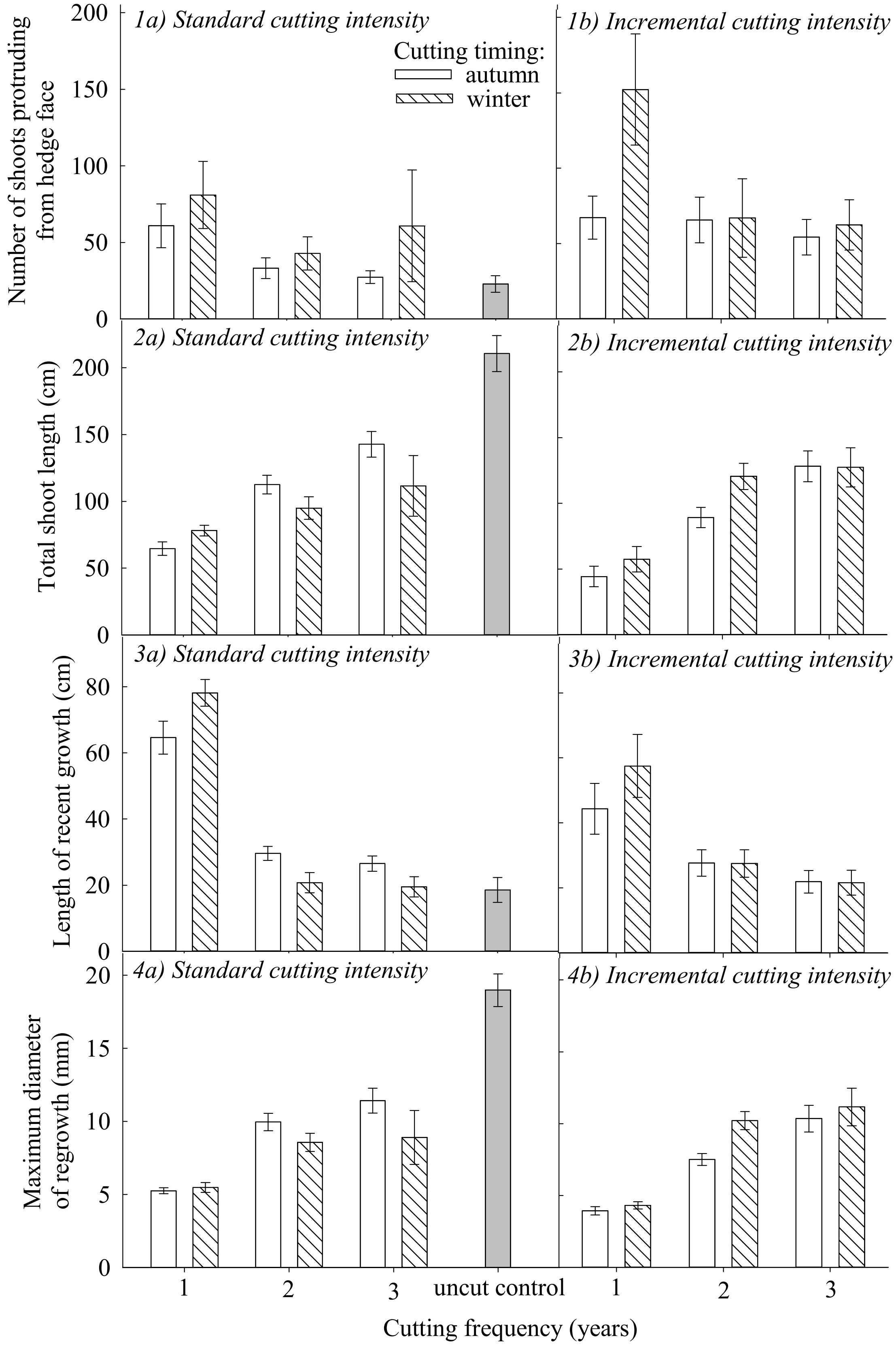

Figure 4.17: Regrowth of blackthorn shoots growing from the top of experimental plots. Regrowth defined as shoot growth since the hedgerow plot was last cut, extending from the cut face of the top of the hedgerow. Assessments were carried out in August 2015. 1) Number of blackthorn shoots extending from 20 cm section; 2) Total length of shoots (cm); 3) Length of growth in spring/summer 2015 (most recent growth), cm; 4) Maximum diameter of shoots (mm).

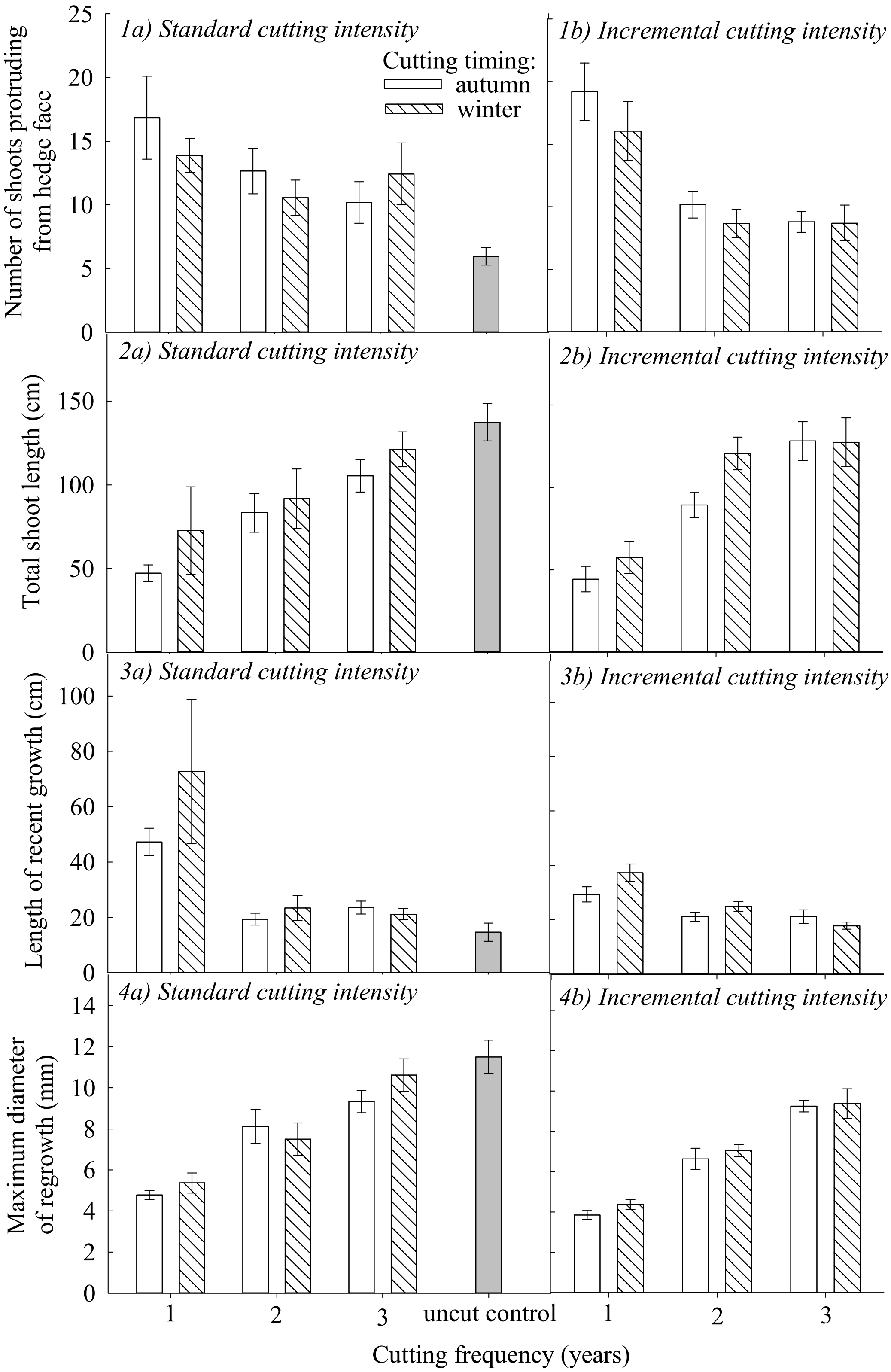

Figure 4.18: Regrowth of field maple shoots growing from the side of experimental plots. Regrowth defined as shoot growth since the hedgerow plot was last cut, extending from the cut face of the hedgerow. Assessments were carried out in August 2015. 1) Number of field maple shoots extending from 20 cm section; 2) Total length of shoots (cm); 3) Length of growth in spring/summer 2015 (most recent growth), cm; 4) Maximum diameter of shoots (mm).

Whether shoots were growing on the top or side of a managed hedge had little effect on the response of regrowth variables to the hedgerow cutting treatments. The few instances where the effects of cutting treatment differed between regrowth from the side or top of a hedgerow plot are listed in Tables 4.3 to 4.5.

4.8.1 Number of shoots

For all three woody species assessed, the number of shoots protruding from the cut face of the hedgerow plots was greater on plots cut every year at a standard cutting intensity, compared with those cut every two or three years (at a standard cutting intensity) and also compared with uncut control plots (Tables 4.3 – 4.5). For all three species, there were also slightly more regrowth shoots on plots cut to allow incremental growth, compared with those cut back at a standard cutting intensity, though the differences in number of shoots were quite small (Figures 4.16 – 4.18).

4.8.2 Length of regrowth shoots

As expected, regrowth shoots were longer in total on plots that were last cut two or three years ago, compared to those cut annually, for all three woody species assessed. In addition, total regrowth was slightly shorter for plots cut to allow incremental growth, compared to those cut back to a standard cutting intensity, for blackthorn and field maple. There was no statistically significant effect of cutting intensity on total length of regrowth from hawthorn (Table 4.3).

Recent shoot growth (in the spring/summer prior to assessments in late August 2015) was longer on plots cut annually than on those cut every two or three years, for all three woody species. For blackthorn and field maple only, there was also an effect of cutting intensity on lengths of recent shoot growth. In addition, for blackthorn and field maple, the effects of cutting frequency were much stronger for those plots cut back to a standard intensity, compared with those cut to allow incremental growth (Tables 4.4 and 4.5).

4.8.3 Diameter of regrowth shoots

The maximum diameter of shoots growing from the cut face of the hedge was greater for plots cut once every two or three years, compared to those cut every year, for hawthorn, blackthorn and field maple (Tables 4.3 to 4.5). For hawthorn, there was no effect of the timing or intensity of cutting on maximum diameter of regrowth. For blackthorn, regrowth growing from the top of plots had a smaller maximum diameter on plots cut in autumn to allow incremental growth, compared with those cut back to a standard height and width in autumn (Table 4.4). For field maple, maximum diameter of regrowth was smaller on plots cut to allow incremental growth than those cut to a standard intensity, both for regrowth on the side and top of the hedgerow plots (Table 4.5).

The diameter of recent regrowth was smaller on uncut plots, and those cut every two or three years, compared with those cut annually, for all three woody plant species. In addition, for both blackthorn and field maple, diameter of recent regrowth was smaller on plots cut to allow incremental growth, and the effects of cutting frequency were also weaker on plots cut using an incremental intensity, compared with those cut back to a standard height and width (Tables 4.4 and 4.5).

4.8.4 Woody biomass of regrowth shoots

Woody biomass of regrowth shoots was closely correlated to the total length of regrowth. Biomass was greater for regrowth shoots on plots cut every two or three years, and on uncut control plots, compared with those cut every year, for all three woody species (Figures 4.16 to 4.18). In addition, for blackthorn and regrowth from the side of hawthorn plots, shoot biomass was lighter from plots cut to allow incremental growth (Table 4.3 and 4.4). For blackthorn, the effect of cutting frequency on biomass was weaker for plots cut in winter, compared with those cut in autumn. For blackthorn and field maple, biomass of regrowth shoots was slightly heavier from the top of plots cut in winter (compared with those cut in autumn), but there was no effect of timing for field maple regrowth from the side of plots.

4.8.5 Discussion of regrowth results

The effects of cutting frequency on regrowth shoots from the cut face of hedgerow plots was largely expected – plots cut every year had more, shorter shoots with smaller maximum diameters and lighter biomass than those last cut two or three years ago (on reduced cutting frequency treatments), for all three species (Bannister & Watt, 1995). Recent regrowth (growth that took place in the summer just before the assessment) was longer and had larger diameters for plots cut every year compared with those cut less frequently, reflecting initially more growth immediately following cutting, with less new regrowth each year in successive years, and very little recent regrowth on the uncut control plots.

The regrowth assessment was designed to test whether cutting timing and intensity might affect rates of regrowth, since the effects of cutting frequency were largely predicable. The results show that for hawthorn, cutting intensity and timing have little effect on the rate of regrowth, apart from slightly more regrowth shoots on plots cut for incremental growth, and slightly lighter biomass (though the latter result was only found for regrowth from the sides of plots).

The responses of blackthorn regrowth to the timing and intensity of cutting were more complex than the response of hawthorn. On the top of plots, there were more shoots of blackthorn regrowth, and the shoots were heavier, when cut in winter rather than autumn. It is possible that late winter cutting, close to the start of spring, stimulates more blackthorn regrowth as flower buds may be cut off, which would not yet have formed in September when autumn plots are cut (Section 4.3 above). Blackthorn flowers earlier than hawthorn, so might have formed buds earlier, making it more susceptible to loss of flower buds when cut in February (or early March when derogations were required for winter cutting; see Section 4.1 above).

Cutting to allow incremental growth affected both blackthorn and field maple regrowth, particularly from the top of hedgerow plots for blackthorn. As for hawthorn, there were more blackthorn and field maple regrowth shoots under incremental trimming, compared with standard intensity cutting. In addition, blackthorn and field maple regrowth shoots were shorter, had smaller diameters and were lighter on plots cut to allow incremental growth. The timing of cutting had little effect on regrowth of field maple, with the exception of slightly heavier field maple regrowth shoots from the top of hedgerow plots cut in winter (but not for regrowth from the side of plots).

The dominant hedgerow woody species in England, hawthorn (French & Cummins, 2001), had regrowth that was largely unaffected by the timing and intensity of cutting. This suggests that the effort required for cutting hawthorn hedges under regimes that differ in timing and intensity should be about equal. In contrast, regrowth of blackthorn and field maple was reduced under the incremental cutting intensity treatment, suggesting that cutting effort (the number of times a flail has to be used repeatedly to cut a hedge) might be reduced on these incremental plots. In addition, if landowners do not wish their hedges to grow beyond a maximum height and width, the reduced regrowth on blackthorn and field maple hedges under an incremental cutting regime may partially compensate for the additional hedge height and width left on the hedge each time it is cut.

	Hawthorn					
	Number of shoots	Length total regrowth	Recent shoot growth	Maximum diameter	Maximum diameter recent shoot growth	Biomass total woody regrowth
Uncut controls [1]	Fewer***	Longer***	Shorter***	Larger***	Smaller for plot sides***, non-significant trend for tops	Heavier***
Frequency: every two years [2]	Fewer***	Longer***	Shorter***	Larger***	Smaller***	Heavier***
Frequency: every three years [2]	Fewer***	Longer***	Shorter***	Larger***	Smaller***	Heavier***
Timing: winter [3]	No effect	No effect	No effect	No effect	No effect	No effect
Intensity: incremental [4]	More***	No effect	No effect	No effect	No effect	Lighter for plot sides*, no effect for top
Interactions between treatments	None	None	None	None	None	None

[1] Comparison is with plots cut every year in autumn at standard cutting intensity.
[2] Comparison is with plots cut every year.
[3] Comparison is with plots cut in autumn.
[4] Comparison is with plots cut to standard intensity.

Table 4.3: Results of statistical analyses of woody regrowth variables for hawthorn. Regrowth assessments were carried out in August 2015, when plots had three, two or one years of regrowth present for assessment, depending on frequency of cutting. All plots were cut the following autumn (September 2015) or winter (Jan / Feb 2016). *** = statistically significant difference at $P < 0.001$; ** = statistically significant difference at $P < 0.01$; * = statistically significant difference at $P < 0.05$. Results are the same for regrowth from the tops and sides of the plots, unless stated otherwise.

	Blackthorn					
	Number of shoots	Length total regrowth	Recent shoot growth	Maximum diameter	Maximum diameter recent shoot growth	Biomass total woody regrowth
Uncut controls [1]	Fewer***	Longer***	Shorter***	Larger***	Smaller***	Heavier***
Frequency: every two years[2]	Fewer***	Longer***	Shorter***	Larger***	Smaller***	Heavier***
Frequency: every three years[2]	Fewer***	Longer***	Shorter***	Larger***	Smaller***	Heavier***
Timing: winter [3]	Top of plots: more**, Sides: no effect	No effect	No effect	No effect	No effect	Top of plots: heavier*. Sides: no effect
Intensity: incremental [4]	More***	Tops of plots: shorter ***, Sides: non-significant trend	Tops of plots: shorter***, Sides: no effect	Top of plots: Smaller*** (standard plots only). Sides: no effect	Top of plots: smaller***. Sides: no effect	Lighter**
Interactions between treatments	None	Plot tops: Frequency × intensity** Timing × intensity*. Sides: no interactions	Tops of plots: Frequency × timing*, Frequency × intensity*. Side of plots: no interactions	Top of plots: timing × intensity**, three yr × intensity *. Side of plot: no interaction	Top of plots: frequency × intensity**. Sides of plots: no interactions	Top of plots: Timing × frequency* Intensity × frequency × timing*. Side of plots: no interaction
Interaction details	None	Plot tops only: Incremental - effects of cutting frequency stronger than for standard plots, longer shoots if cut in winter (but not for standard).	Plot tops only: winter plots - stronger effects of reduced cutting frequency. Incremental plots: no difference between one and two years (but difference for standard plots).	Plot tops only: winter plots - incremental not smaller than standard (only on autumn plots). Incremental - stronger effect of cutting frequency	Top of plots only: incremental - no effect of cutting frequency	Top of plots only: winter plots - reduced effect frequency.

[1] Comparison is with plots cut every year in autumn at standard cutting intensity;
[2] Comparison is with plots cut every year
[3] Comparison is with plots cut in autumn
[4] Comparison is with plots cut to standard intensity

Table 4.4: Results of statistical analyses of woody regrowth variables for blackthorn. Regrowth assessments were carried out in August 2015, when plots had three, two or one years of regrowth present for assessment, depending on frequency of cutting. All plots were cut the following autumn (September 2015) or winter (Jan / Feb 2016). *** = statistically significant difference at $P < 0.001$; ** = statistically significant difference at $P < 0.01$; * = statistically significant difference at $P < 0.05$. Results are the same for regrowth from the tops and sides of the plots, unless stated otherwise.

	Field maple					
	Number of shoots	Length total regrowth	Recent shoot growth	Maximum diameter	Maximum diameter recent shoot growth	Biomass total woody regrowth
Uncut controls [1]	Fewer***	Longer***	Shorter***	Larger***	Smaller***	Heavier***
Frequency: every two years [2]	Fewer***	Longer***	Shorter***	Larger***	Smaller***	Heavier***
Frequency: every three years [2]	Fewer***	Longer***	Shorter***	Larger***	Smaller***	Heavier***
Timing: winter [3]	No effect	No effect	No effect	No effect	No effect	Top of plots: Heavier*. Side: no effect
Intensity: incremental [4]	Top of plots: more**. Sides: no effect	Shorter*	Shorter**	Smaller*	Smaller***	No effect
Interactions between treatments	None	None	Side of plots: Frequency × intensity**. Top: no interactions	None	Side of plots: Frequency × intensity*** Frequency × timing**. Top of plots: no interactions	None
Interaction notes	None	None	Side of plots only: incremental - weaker effect of cutting frequency	None	Side of plots only: incremental - weaker effect of cutting frequency	None

[1] Comparison is with plots cut every year in autumn at standard cutting intensity

[2] Comparison is with plots cut every year

[3] Comparison is with plots cut in autumn

[4] Comparison is with plots cut to standard intensity

Table 4.5: Results of statistical analyses of woody regrowth variables for field maple. Regrowth assessments were carried out in August 2015, when plots had three, two or one years of regrowth present for assessment, depending on frequency of cutting. All plots were cut the following autumn (September 2015) or winter (Jan / Feb 2016). *** = statistically significant difference at $P < 0.001$; ** = statistically significant difference at $P < 0.01$; * = statistically significant difference at $P < 0.05$. Results are the same for regrowth from the tops and sides of the plots, unless stated otherwise.

5. Experiment 3 Results and Discussion: Rejuvenation of hedgerows

5.1 Costs and speed of rejuvenation methods

Costs (£)	Midlands style laying			Conservation hedging			Wildlife hedging			Circular saw			Coppice			
Site	Cost per m	Brash cost 100 m	Total cost per 100 m	Cost per m	Brash cost 100 m	Total cost per 100 m	Cost per m	Brash cost 100 m	Total cost per 100 m	Cost per m	Brash cost 100 m	Total cost per 100 m	Cost per m	Brash cost 100 m	Fencing per 100 m*	Total cost per 100 m
Upcoate Grange	13.5	75	1425	7	75	775	4.5	0	450	1.12	50	162	2	75	320	595
Monk's Wood	12	75	1275	6	80	680	4.5	0	450	0.97	80	177	3	75	320	695
Newbottle Estate	13	75	1375	6.5	80	730	3	0	300	1.01	80	181	1	75	0	175
Wimpole Hall	12	80	1280	5.5	60	610	4.5	0	450	0.85	60	145	2	75	0	275
Crowmarsh Battle	8	50	850	4.5	75	525							1.5	75	0	225
Average for all sites	11.70	71.00	1241.00	5.90	74.00	664.00	4.13	0.00	412.50	0.99	67.50	166.25	1.90	75.00	320	393.00

Table 5.1: Cost (£) of applying rejuvenation treatments and clearing up brash at each experimental site, as quoted by hedgerow contractors applying experimental treatments in autumn 2010. *At two sites the coppiced plots had to be fenced to reduce deer browsing; this additional cost is included in the total for those sites.

Timing (minutes per metre)	Midlands hedge-laying	Conservation hedging	Wildlife hedging	Circular saw	Coppice
Upcoate Grange	38:45	11:40	00:36	01:45	01:01
Monk's Wood	35:13	16:05	01:21	01:31	04:08
Newbottle Estate	33:37	11:27	00:47	01:35	00:40
Wimpole Hall	33:53	12:05	00:49	01:20	01:45
Crowmarsh Battle	24:10	09:22			02:11
Average for all sites	33:08	12:08	00:53	01:33	01:57

Table 5.2: The average time (mm:ss) taken to apply each rejuvenation treatment to a 1m length of hedge in autumn 2010. Coppice timings are based on coppicing by hand; using a circular saw to coppice took less than half the time.

The cost of applying the traditional style of Midlands hedge-laying was approximately twice that of conservation hedging, and three times the cost of wildlife hedging (Table 5.1). Reshaping with the circular saw was the cheapest rejuvenation method, while the cost of coppicing was intermediate between the circular saw and the three hedging / hedge-laying techniques. At two of the five sites, the coppiced plots had to be fenced to reduce deer browsing. This additional fencing cost more than doubled the price of coppicing.

The wildlife hedging, circular saw and coppice treatments were all comparable in the time they took to apply to a hedge, as they were under two minutes (Table 5.2). The wildlife hedging was the fastest treatment to apply. By contrast, traditional Midland style hedge-laying took an average of 33 minutes/metre to apply. Conservation hedging was intermediate between the three fast rejuvenation methods and the Midlands hedge-laying, taking an average of 12 minutes/metre. The majority of rejuvenation methods were applied by one contractor working alone, while the wildlife hedging required three contractors.

5.2 Regrowth of hedgerows

5.2.1 Canopy regrowth of hawthorn

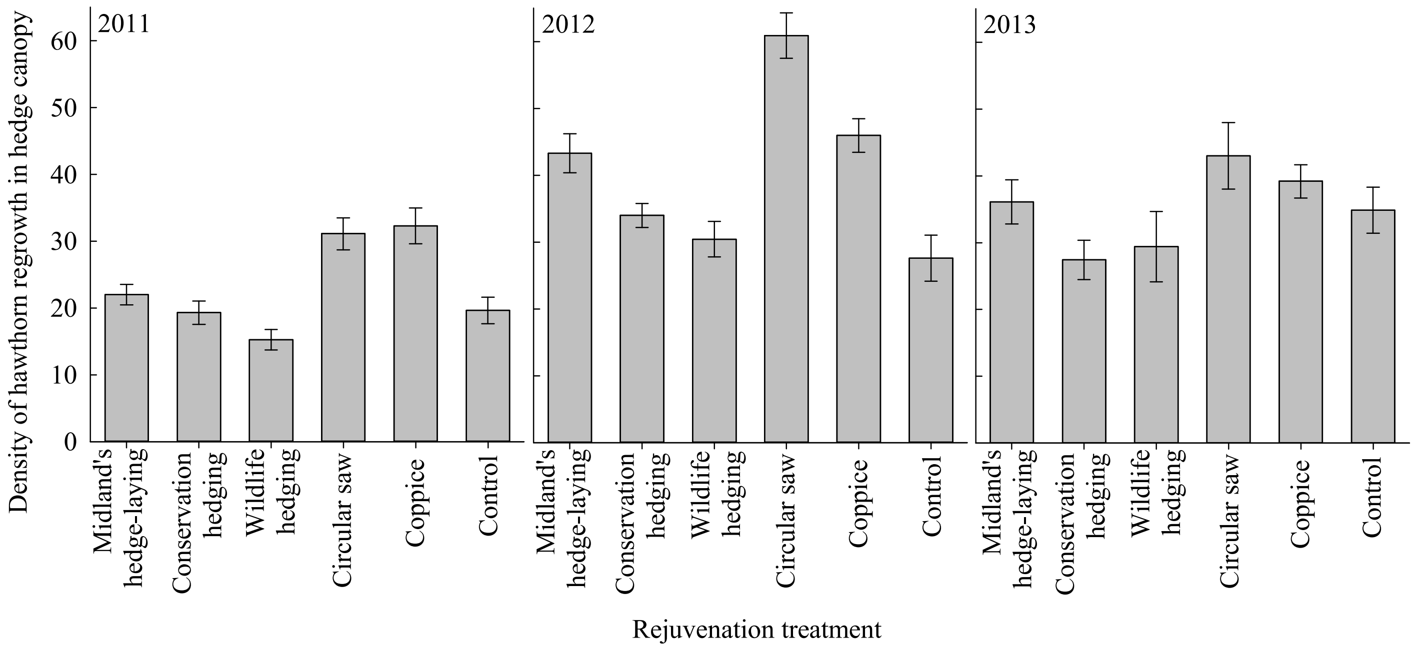

Figure 5.1: Amount of recent hawthorn growth (mean ± SE), measured as number of hits on horizontal and vertical range poles.

The method of rejuvenation strongly affected the total amount of recent growth on hawthorn in the hedge canopy, measured over three years ($F_{1,106}$ = 28.52, P < 0.001). Total regrowth of hawthorn was greatest on hedges cut with a circular saw, followed by coppiced hedges and those rejuvenated with Midlands hedge-laying (Figure 5.1). Regrowth was least on the control hedges that were not rejuvenated, together with the wildlife hedging and conservation hedging. Midlands hedge-laying resulted in significantly more regrowth than the wildlife hedging (Tukey posthoc tests, P < 0.05). The effect of rejuvenation method on total regrowth differed with year. In 2011 (the year following rejuvenation) and 2012, only the coppice and circular saw plots had significantly more regrowth than the control plots (all $P < 0.05$). In 2012 only, in addition to the coppice and circular saw, the Midlands hedge-laying also had more regrowth than the control plots ($t_{1,230} = 2.82$, $P < 0.001$), and there was a trend towards more regrowth on the conservation hedging plots compared with the control ($t_{1,230} = 1.87$, $P = 0.063$). By 2013 the amount of regrowth did not differ under any of the rejuvenation methods in comparison with the control plots.

Hawthorn regrowth was greater on uncut plots than those cut following rejuvenation ($t_{1,55} = 2.43$, $P < 0.05$). There was also a trend towards the type of rejuvenation affecting the response of hawthorn to subsequent management (two-way interaction LRT: $\chi^2_5 = 9.58$, $P = 0.088$), whereby regrowth was greater on uncut plots that had been rejuvenated by a circular saw, but for other rejuvenation methods the subsequent management did not affect re-growth.

The weight of hawthorn regrowth twigs in the hedgerow canopy was also strongly affected by rejuvenation treatment, and varied over time (Figure 5.2). In 2011, dry weight was 8.3 times greater on hedges cut with a circular saw, and 6 times greater on those rejuvenated with Midlands hedge-laying, compared with control plots ($F_{4,30} = 49.96$, $P < 0.001$). The weight of regrowth on wildlife and conservation hedging plots did not differ significantly from the control plots. By 2012, dry weight of recent regrowth was heavier under all rejuvenation methods compared to the control ($F_{5,36} = 12.59$, $P < 0.001$). By 2013 there were fewer differences between the rejuvenation methods. Recent regrowth was heavier on the coppice compared to the wildlife hedging plots ($F_{5,36} = 9.94$, $P < 0.001$), but none of the other rejuvenation methods differed. Management following rejuvenation did not affect the weight of recent hawthorn regrowth.

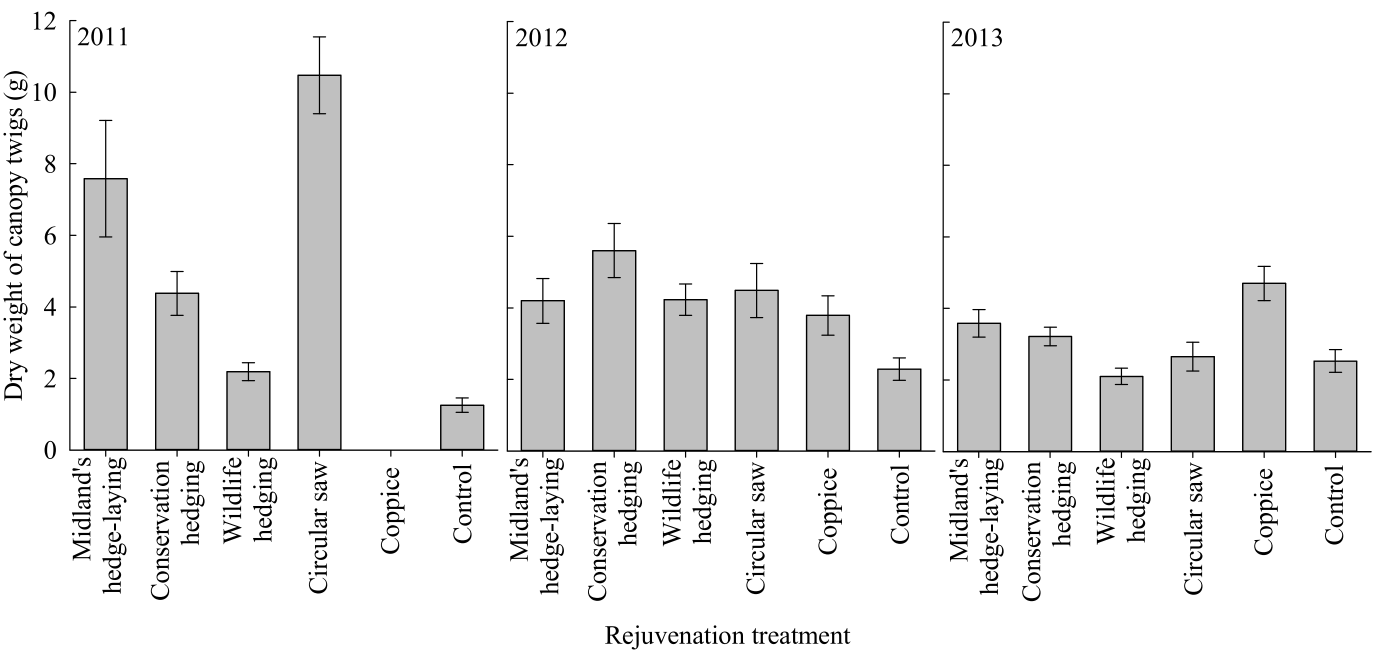

Figure 5.2: Dry weight of recent hawthorn growth each year, g (mean ± SE). Rejuvenation of hedgerows took place in November 2010.

5.2.2 Regrowth from hedgerow basal stools

5.2.2.1 Hawthorn

The number of hawthorn shoots was twice as great on coppice compared with the other three treatments that involved cutting basal stools (Midlands hedge-laying, conservation hedging, wildlife hedging) in all three years following rejuvenation ($t_{1,31}$ = 5.08, P < 0.001; Figure 5.3a). In addition, there was an interaction between year and rejuvenation method (LRT: χ^2_6 = 19.86, P < 0.01); in 2011 there were also more hawthorn shoots per stool on the Midlands hedge-laying plots compared with conservation and wildlife hedging ($t_{1,31}$ = 3.51, P < 0.01 and $t_{1,31}$ = 2.88, P < 0.001 respectively), but this difference was no longer apparent in 2012 or 2013.

Shoots growing from cut basal stools were 1.4 times taller on hawthorn growing in wildlife hedging plots compared with coppice or Midlands hedge-laying plots in all three years (2011: $F_{3,24}$ = 13.05, P < 0.001, 2012: $F_{3,24}$ = 7.88, P < 0.001, 2013: $F_{3,24}$ = 4.04, P < 0.05), apart from at one site (WH) in 2013 where shoot height did not differ between these three rejuvenation methods (Figure 5.3b). In 2011, shoots were also taller on hawthorn that had been rejuvenated with conservation hedging compared with coppice or Midlands hedge-laying (TPT, P < 0.05), but by 2012 and 2013 there were no differences in height between these three treatments. Rejuvenation method did not have a consistent effect on diameter of shoots at mid-height (half way between the base and tip of each shoot).

The average volume of regrowth per cut stool was calculated from shoot height, diameter and the number of shoots (Figure 5.3c). There was a greater volume of regrowth from the coppice stools than the Midlands hedge-laying and conservation hedging stools in 2012 and 2013 ($F_{3,33}$ = 4.47, P < 0.05 and $F_{3,33}$ = 3.38, P < 0.05 respectively). The volume of regrowth from the wildlife hedging was intermediate, and not significantly different from the other treatments. The number of hawthorn basal new stools with shoots was around 1.4 times lower on conservation and wildlife hedging plots than the Midlands hedge-laying and coppice ($F_{3,33}$ = 5.88, P < 0.01, Figure 5.3d).

Management treatment following rejuvenation of hedges had very little effect on the regrowth of hawthorn shoots from cut basal stools. Shoots from uncut wildlife hedging stools were taller than those from cut stools in 2013 only (rejuvenation method × management treatment × year interaction: LRT: χ^2_6 = 14.52, P < 0.05). The number of shoots per stool, number of stools per 10 m and volume of shoot regrowth per basal stool were not affected by management treatment.

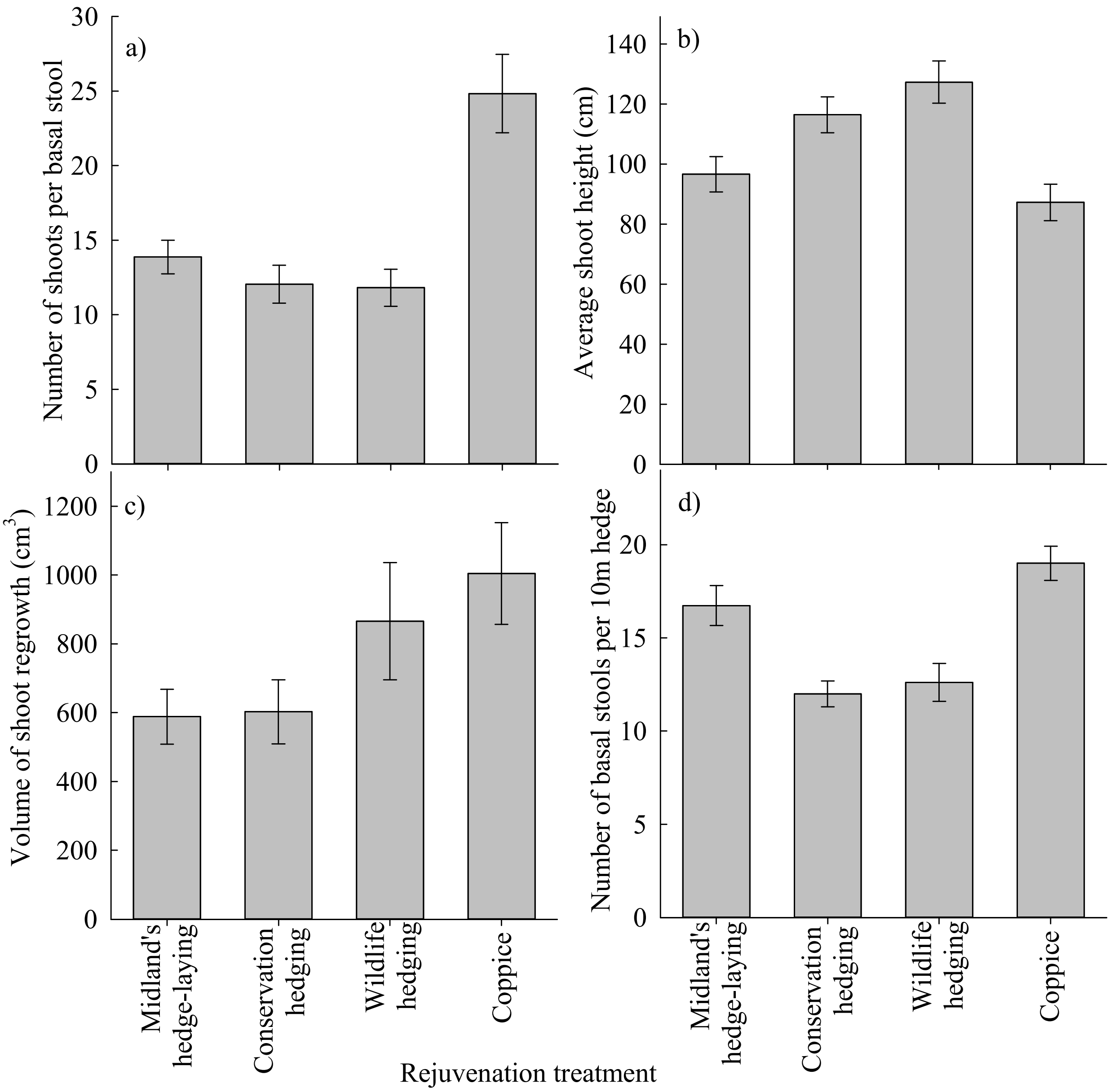

Figure 5.3: Recent hawthorn growth from basal stools cut during rejuvenation (mean ± SE), average over three years (2011-2013). a) Number of shoots growing per basal stool, b) height of shoots, c) average volume of regrowth per basal stool in cm^3 (number of shoots × shoot height × Pi(shoot diameter/2)^2, d) number of basal stools that produced new shoots.

5.2.2.2 Field maple

Field maple was present in all experimental blocks at only one site (WH). Rejuvenation method affected the number of shoots produced per basal stool (LRT: $\chi^2_3 = 12.60$, $P < 0.01$), but did not significantly affect shoot height, shoot diameter or the number of stools per 10 m of hedge. There were more shoots per basal stool on the coppice compared with Midlands hedge-laying ($t_{1,6} = 2.68$, $P < 0.05$), as found for hawthorn.

5.2.3 Discussion of regrowth of hedgerows

Canopy regrowth of hawthorn was generally greater on those hedges where more cut branches remained following rejuvenation (circular saw followed by coppicing and Midlands hedge-laying), as cutting can stimulate production of new shoots (Semple et al., 1994). The largest differences between rejuvenation methods and the control plots were seen in the second year following rejuvenation (2012). Similarly, the weight of regrowth twigs in the hedge canopy was initially greater where rejuvenation had left more cut branches (circular saw and Midlands laying), but by 2012 all rejuvenation methods differed from the controls. By 2013, the only significant difference was between the wildlife hedging and the coppice, which had the heaviest weight of regrowth twigs. Three years on from rejuvenation, the amount and weight of canopy regrowth had started to converge across the rejuvenation treatments, with the exception of the coppice plots.

Both hawthorn and field maple have previously been shown to shoot vigorously following coppicing (Croxton, Franssen, Myhill, & Sparks, 2004), and results from Experiment 3 showed that the number of shoots from hedgerow basal stools where cutting had occurred was by far the highest in the coppice treatment for both of these species. After the second season's growth, the volume of regrowth was also highest in the coppice plots, though contrary to the wildlife hedging this growth was in the form of more numerous but shorter shoots, rather than fewer taller shoots.

Plots rejuvenated by wildlife hedging had taller shoots from cut basal stools than those that were coppiced or rejuvenated using Midlands hedge-laying in all years, and only in 2011 shoots were also taller on conservation hedging. The wildlife hedging and to a lesser extent the conservation hedging plots were denser as no or little woody growth was removed during rejuvenation, so the taller shoots may have been a growth response to try and reach the light under increased shade. The volume of basal shoots from the wildlife hedging was, however, not significantly different to either the conservation hedging or Midlands hedge-laying. The three layed methods (Midlands hedge-laying, conservation hedging and wildlife hedging) showed minor differences in regrowth, and these differences tended to diminish over time.

The lower number of stools that produced new shoots, found on conservation and wildlife hedging compared with the Midlands hedge-laying and coppice, could reflect mortality of some entire stools. In the wildlife hedging this might be attributed to the fact that during implementation of management some entire stems were inadvertently severed, although this did not occur in the conservation hedging. There was a trend towards greater canopy regrowth on conservation hedging plots compared with wildlife hedging in 2012, so it is possible more resources are directed to canopy regrowth and less to shoot production from basal stools following conservation hedging, compared with wildlife hedging.

The only significant effect of subsequent management was a reduction in canopy regrowth on plots that were cut, though a strong trend suggests this may have been limited to plots rejuvenated by circular saw. The general lack of effect of ongoing management on basal regrowth is not surprising, as this management is directed at the canopy. Overall, subsequent management had very little effect on both canopy and basal regrowth compared with the effects of rejuvenation method. This may be partly due to the relatively short time-scale of the experiment; in subsequent years the effects of rejuvenation would be expected to diminish, and management effects to have a stronger effect on hedge growth.

5.3 Dead foliage cover following rejuvenation

Less than 1% of the control and circular saw plots consisted of dead hawthorn foliage in the summer following rejuvenation (control mean ± SE = 0.38 ± 0.27; circular saw = 0.5 ± 0.28). In contrast, nearly 20% of wildlife hedging plots were covered with dead foliage, significantly more than the control plots (19.5 ± 4.97; $t_{1,51} = 6.4$, $P < 0.01$). Dead foliage cover was also slightly greater than the controls in the coppiced (4.5 ± 1.96; $t_{1,51} = 2.3$, $P < 0.05$) and conservation hedging (4.1 ± 1.25; $t_{1,51} = 2.6$, $P < 0.05$) plots, though for both methods average values were under 5%.

5.4 Structure of hedgerows

5.4.1 Basal gappiness

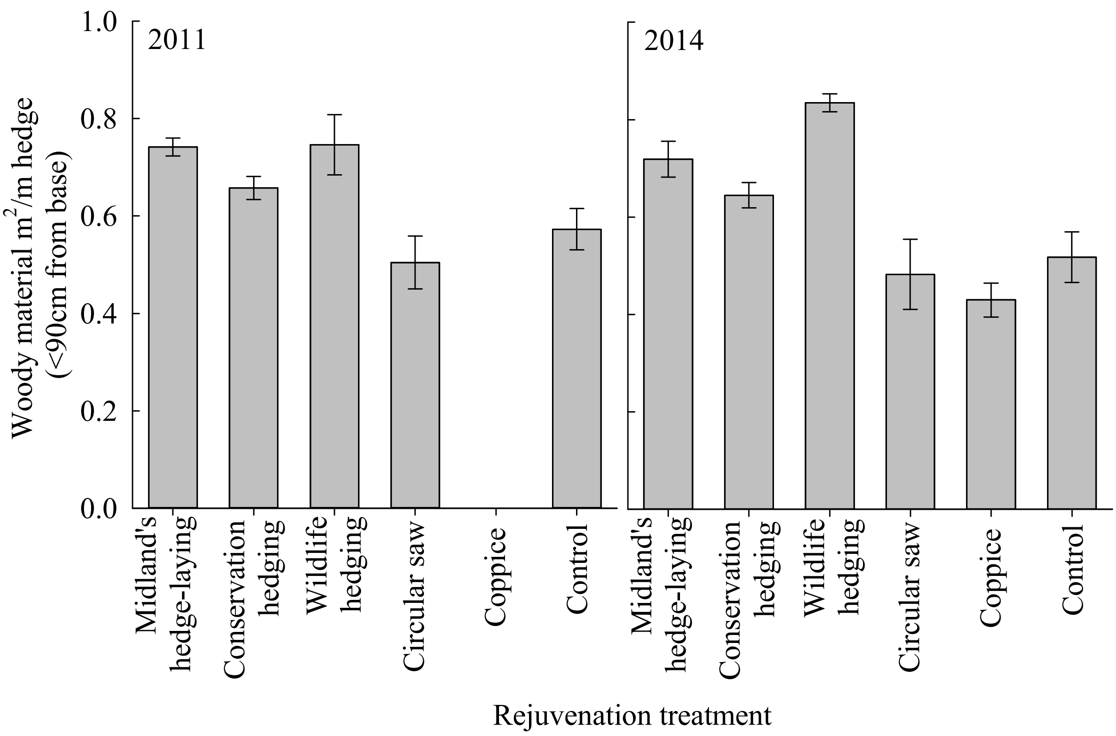

Figure 5.4: Woody material (m^2/m; mean ± SE) in the basal 90 cm of plots calculated from digital images taken in winter in early 2011 and 2014, for main rejuvenation treatments (all sites).

Gappiness in the hedge base was assessed with data extracted from digital images on individual gap area (cm^2), relating to the region from the base of the hedge to 90 cm high. Coppiced plots were not assessed in 2011 as they had no woody shoots until the following spring. In this first winter following rejuvenation, the proportion of woody material:gap in the basal 90 cm of hedge was strongly affected by main rejuvenation treatment ($F_{4,42} = 11.11$, P <0.001). All three layed treatments (wildlife hedging, conservation and Midlands hedge-laying) had a larger proportion of woody material:gap than the circular saw, whilst the wildlife hedging and Midlands hedge-laying also had a larger proportion than the control (TPT, P <0.05; Figure 5.4).

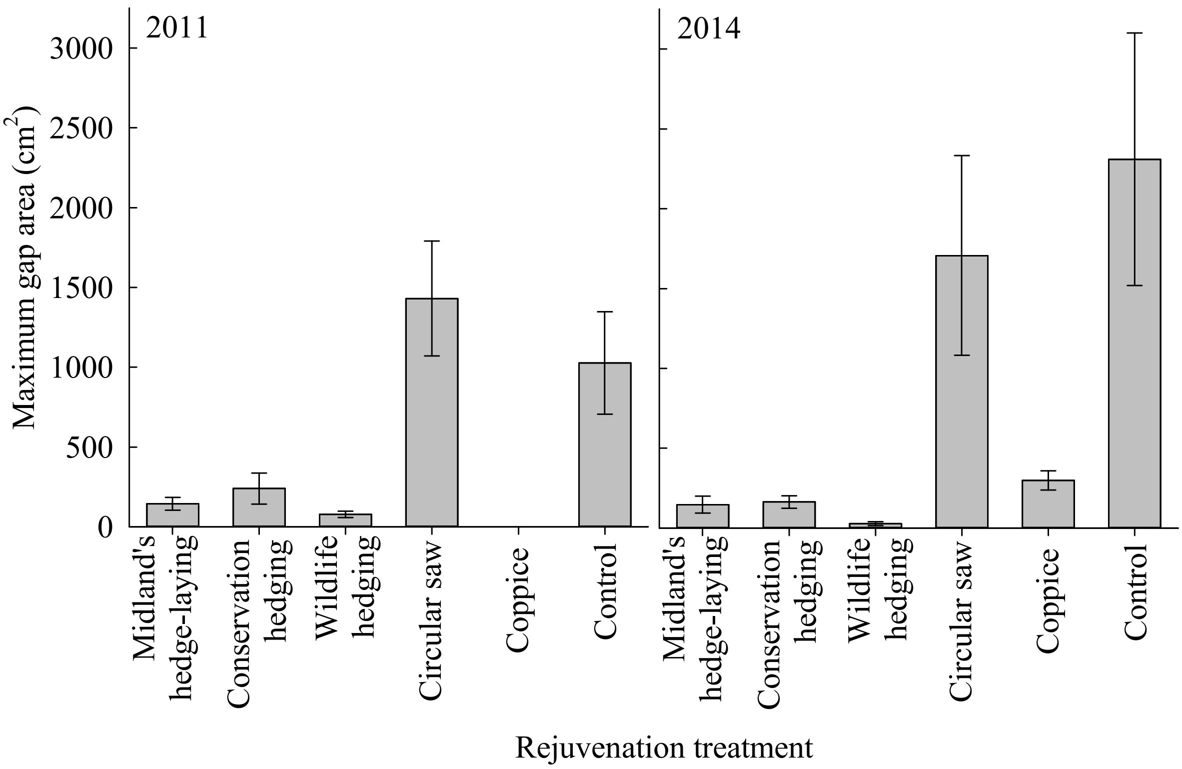

Figure 5.5: Maximum gap area (cm^2; mean ± SE) in the basal 90 cm of plots calculated from digital images taken in winter in early 2011 and 2014, for main rejuvenation treatments (all sites).

There was also a significant effect of the main rejuvenation treatment on the maximum size of individual gaps ($F_{4,42} = 23.45$, $P < 0.001$). In 2011 the largest gaps of all three layed treatments were significantly smaller than the control and the circular saw (Tukey posthoc tests, P <0.01); those of the uncut control were 4, 7 and 13 times larger than the conservation laying, Midlands hedge-laying and wildlife hedging respectively. The largest gaps found in circular saw and control plots averaged over 1,000 cm^2, with this figure less than 250 cm^2 for the three layed treatments (Figure 5.5).

The effects of rejuvenation method in 2014 show a similar pattern to 2011 (Figures 5.4 – 5.5) for the proportion of woody material ($F_{5,36} = 29.49$, $P < 0.001$) and the maximum gap size ($F_{5,36} = 38.79$, $P < 0.001$). The proportion of woody material:gap was larger in the three layed treatments than the control, circular saw or coppice plots, and the wildlife hedging also had more woody material than the conservation and Midlands hedge-laying (TPT tests $P < 0.05$). The largest gaps were significantly larger in both the control and circular saw than all other rejuvenation treatments, and for the wildlife hedging were smaller than under all other rejuvenation treatments (TPT $P < 0.05$). The control had the largest maximum gap size which averaged over 2,250 cm^2, and the wildlife hedging the smallest at less than 30cm^2. Although the extent of rejuvenation treatment effects differed between sites for both the area of woody material ($F_{15,36} = 2.66$, $P < 0.01$) and the maximum gap size ($F_{15,36} = 3.25$, $P < 0.01$) near the base of the hedge in 2014, the main effects described above explain the majority of the variation in these measures.

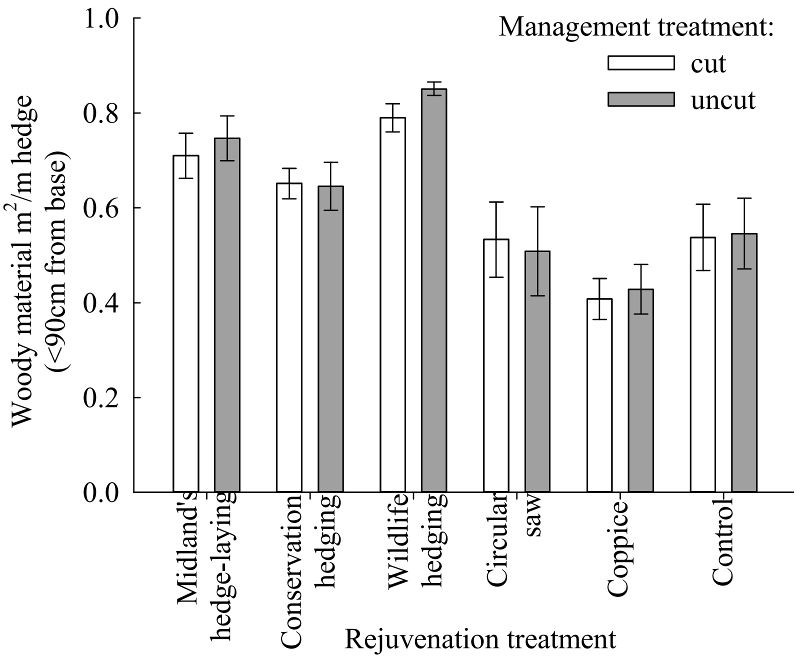

Figure 5.6: Woody material (m^2/m; mean ± SE) in the basal 90 cm of plots calculated from digital images taken in the winter of 2014 for all sites, with ongoing management represented by the colour of the bars.

In 2014, there were no effects of ongoing management on the basal gappiness of hedges; there was no significant difference between uncut plots and those cut following rejuvenation on either the area of the largest gaps, or the total area of woody material in the base of the hedge (Figure 5.6). The three different ongoing management treatments applied to the Midlands hedge-laying plots (cut, uncut or annual cutting) also did not have a significant effect on any of the variables relating to hedge basal gappiness.

5.4.2 Discussion of hedgerow structure

The results for the amount of woody material in the hedge base in the year following management reflect the fact that no woody material was introduced to the hedge base for the circular saw and control plots, in comparison to the three layed treatments. As hedge-laying in its various forms was originally used to create a barrier to livestock (Barr *et al.* 2005), layed rejuvenation methods provide an increased amount of woody material at the base compared with a control. This was also the case when a measure more specific to how stock-proof the hedge might be was assessed; maximum gap size was significantly lower in the layed treatments than the circular saw and control, suggesting that these treatments may be more impervious to stock. Although the coppice plots were comparable to the wildlife hedging, conservation and Midlands hedge-laying in terms of maximum gap size in early winter 2014 three growing seasons after rejuvenation had been applied, the method of image analysis used does not take into account the fact that in these hedges there are no older, woodier stems, and the majority of growth is vertical from the base (i.e. with less horizontal structure) so may not be as stock-proof as the data otherwise suggests.

The main effects of rejuvenation treatment in 2014 were similar to 2011, although there was a divergence in the amount of woody material between the three layed treatments. Contrary to 2011, the conservation and Midlands hedge-laying had less woody material than the wildlife hedging in 2014, and the conservation hedging also had less woody material than the control in 2014. The wildlife hedging had smaller maximum gaps than the Midlands hedge-laying in 2014 whereas there was no significant difference between the two in 2011. These differences in 2014 were not explained by ongoing management; they may be in part attributable to a slightly lower volume of basal regrowth in the conservation and Midlands hedge-laying treatments (Figure 5.3), although this was not significantly lower than the wildlife hedging. The structure of the conservation hedging plots (in terms of woody area and maximum gap size) was the same as that of plots rejuvenated using Midlands hedge-laying. The interaction between rejuvenation method and site in 2014 may reflect different growth responses to the treatments between sites, perhaps related to the age of the hedge or time since previous management.

5.5 Berry provision over winter

Hedgerow rejuvenation method had a strong effect on the weight of hawthorn berries available over winter ($F_{5,36} = 64.07$, $P < 0.001$, Figure 5.7), and the effects of rejuvenation treatment also varied with year (LRT: $\chi^2_{15} = 32.33$, $P < 0.01$). In the first three years following rejuvenation (2010-2012), available berry weight was reduced on plots rejuvenated with coppice, circular saw and Midlands hedge-laying compared with the control plots (all $P < 0.05$), while berry weight on the wildlife hedging plots did not differ from the controls. There was also a trend towards a lower berry weight on conservation hedging plots compared with controls ($t_{1,51} = 1.78$, $P = 0.082$). By 2013, the circular saw and Midlands hedge-laying plots no longer differed from the controls, so only the coppice plots produced a lower weight of hawthorn berries compared with the control.

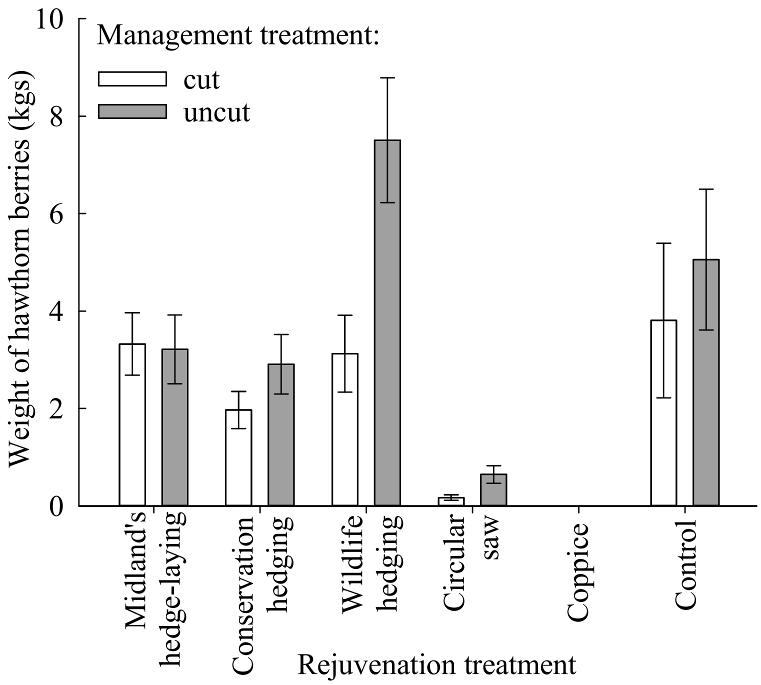

Figure 5.7: Cumulative fresh weight (kg, mean ± SE) of hawthorn berries on 1 m of hedge length available over winter, under rejuvenation and subsequent management treatments.

The effect of subsequent management treatment on hawthorn berry availability depended on the rejuvenation treatment (LRT: $\chi^2_{10} = 30.04$, $P < 0.001$); there was a greater weight of berries on the uncut plots on all the rejuvenation treatments apart from the Midlands hedge-laying and control. The cumulative weight of berries of all species at CB was lower on the coppiced than the control plots ($t_{1,7} = 3.45$, $P < 0.05$), but did not differ between the other rejuvenation treatments and the control.

The effects of rejuvenation on berry weight were apparent for the first three winters following rejuvenation. By the fourth winter, only plots that had been coppiced still had a lower berry weight than the control plots, both for hawthorn and the mixed-species hedge at CB. The reduction in berry provision for overwintering wildlife was therefore fairly short-term under the majority of rejuvenation methods.

6. Conclusions and recommendations

6.1 Summary results tables

Experiments 1 & 2 - Frequency, timing and intensity of cutting	
Flower production, 6 - 8 years data	
Hawthorn	1.9 times more flowers on incremental than standard plots. 1.5-1.9 times more flowers on three-year than one-year plots. More flowers on plots cut once in two years than one-year plots in some sites and years, not consistent. Some sites only, fewer flowers on plots cut in winter than autumn, not consistent. *Trend towards cutting frequency affecting standard but not incremental plots.
Blackthorn	1.8 times more flowers on incremental than standard plots. 1.6 times more flowers on three-year than one-year plots, no significant difference between two and one years.
Bramble	1.4 times more flowers on plots cut in winter compared with those cut in autumn In some years, more flowers on plots cut less frequently than every year, and on incremental plots, but effects not consistent.
Berry availability over winter, 7 - 8 years data	
Hawthorn	1.7 times heavier weight of berries available over winter on incremental than standard plots. 3.1 - 3.5 times heavier weight of berries on three-year plots, but at some sites only if cut in winter. 1.7 times heavier weight of berries on two-year plots at Monks Wood (Experiment 1), not found across sites for Experiment 2. 1.5 times heavier berry weight on plots cut in winter than autumn at Experiment 1 only.
Blackthorn	2.6 times heavier weight of blackthorn berries on incremental than standard plots. 5 times heavier weight of berries on three-year plots cut in winter, compared to annual plots 2.1 times heavier weight of berries on two-year plots cut in winter, compared to annual plots
Bramble	2.5 times more blackberries on plots cut in winter than autumn. 1.4 times more blackberries on plots cut every three years, 1.3 times more on two-year plots.
Dog-rose	Heavier weight of dog-rose berries on winter cut plots if cut every two or three years. *Trend toward heavier weight of dog-rose berries on incremental plots

Table 6.1: Summary of main results for hedgerow flower production and berry availability over winter, from Experiments 1 (Monks Wood experiment; 8 years' data) and 2 (multi-site hedgerow cutting experiment 6-7 years' data). All results are significant at $P < 0.05$ unless listed as *trend ($0.05 < P < 0.1$).

Experiment 2 - Frequency, timing and intensity of cutting	
Pollinator visits to flowers, three years of data	
	Most pollinator visits to bramble flowers, least to hawthorn.
	Very few visits in 2013, especially to blackthorn and hawthorn.
Hawthorn	Number of hawthorn flowers is the strongest determinant of number of pollinator visits and drove the response to cutting, as treatments only affect number of visits if number of flowers was excluded.
	If number of flowers not included in analysis: more pollinator visits to incremental than standard;
	*trend towards more visits to plots cut every three years compared with one year.
	Number of pollinator taxa and assemblage visiting hawthorn unaffected by cutting treatments.
Blackthorn	Number of flowers is the strongest factor affecting number of pollinator visits to blackthorn.
	Under standard cutting intensity, 1.8 times more visits to plots cut in winter than autumn.
	Timing of cutting does not affect number of pollinator visits on plots cut for incremental growth.
Bramble	Number of bramble flowers is the strongest determinant of number of pollinator visits and drove the response to cutting, as treatments only affected number of visits if number of flowers was excluded.
	If number of flowers not included in analysis: more pollinator visits to plots cut in winter than autumn; more visits to plots cut for incremental growth than standard; on standard cut plots only, more visits to plots cut every two or three years compared with one year.
	Number of pollinator taxa and assemblage visiting bramble unaffected by cutting treatments.
Invertebrates - three years of data	
Lepidoptera abundance	Greater abundance of larvae and pupae on plots cut in winter.
	Greater abundance on plots cut every three years.
	*Trend towards greater abundance on winter plots only on those cut every one or two years.
Lepidoptera diversity	Greater diversity on incremental plots
Lepidoptera species richness	*Trend towards greater overall species richness on incremental plots
	Lepidoptera present on hedgerow plants in autumn:
	Three-year autumn plots greater species richness than annual plots
Brown hairstreak eggs	2.3 times more eggs on incremental plots
	Two and three-year plots: 1.9 times more eggs if cut in autumn rather than winter.
Invertebrate abundance	No effect of hedge frequency, timing or intensity treatments on total abundance.

Table 6.2: Summary of main results for invertebrates from Experiment 2 (multi-site hedgerow cutting experiment). Results are significant at $P < 0.05$ unless listed as *trend ($0.05 < P < 0.1$).

Experiment 2 - Frequency, timing and intensity of cutting	
Structure of basal 90cm of hedge after 6 years of cutting treatments	
Woody material	No significant effects of cutting treatments. *Trend suggesting less woody material for standard plots cut in winter compared to autumn.
Maximum gap size	Slightly larger gaps on standard plots compared to incremental.
Number of gaps > 20 × 20cm diameter	Fewer gaps > 20 × 20cm on two-year plots cut in winter plots cut to allow incremental growth.
Regrowth of woody species at end of cutting cycles	
Number of shoots	More shoots on incremental plots.
Shoot dimensions	Longer total shoot length and larger diameter shoots on plots last cut two or three years ago. Shorter total shoot lengths and smaller diameter shoots on incremental plots for blackthorn and field maple (not hawthorn). Recent shoot growth (from last growing season) on one-year plots longer with larger diameters, compared to two or three-year plots. Blackthorn and field maple: smaller diameter for recent shoot growth on incremental plots. Effects of cutting frequency on shoot length more pronounced on standard intensity plots.
Woody biomass	Responses to cutting treatments closely correlated to regrowth shoot length. Heavier regrowth biomass on plots cut every two or three years, compared to every year. Lighter biomass on incremental plots for blackthorn and hawthorn growing from side of plots.

Table 6.3: Summary of main results for hedgerow structure and regrowth of dominant woody species from Experiment 2 (multi-site hedgerow cutting experiment). Results are significant at $P < 0.05$ unless listed as *trend ($0.05 < P < 0.1$).

Experiment 3 - Rejuvenation of hedgerows and subsequent management	
Cost of rejuvenation	MH was most expensive, and CS the cheapest. Of the layed treatments, MH price was twice that of CH, 3 times that of WH.
Speed	WH was the fastest, MH the slowest. WH, CS and CO all took less than 2 minutes per metre. MH took 2.5 times longer than CH.
Regrowth of hedgerows	
Canopy regrowth frequency	More regrowth on CS and CO, least on C, WH and CH. Of the layed treatments, MH regrowth was greater than CH or WH. 2011 and 2013: CS and CO had more regrowth than C. 2012: MH, CS and CO had more regrowth than C, *trend CH more than C. Plots not cut subsequently had more regrowth than those trimmed, but *trend towards trimming affecting regrowth on CS plots but not others.
Weight of canopy regrowth twigs	Rejuvenation method effects reduced over time: 2011: substantially greater weight on CS and MH compared with C, 2012: all rejuvenation methods had greater weight of regrowth than C, 2013: regrowth heavier on CO than WH, no other methods differed.
Basal shoot regrowth: hawthorn	More hawthorn shoots on CO plots than MH, CH or WH; in 2011 only, also more shoots from MH than CH or WH. Taller shoots on WH plots than CO or MH; in 2011 only, taller shoots on CH than CO or MH. Greater volume of regrowth from CO than MH or CH in 2012 and 2013.
field maple	More shoots from CO basal stools than MH.
Structure of hedgerows	
Woody area	2011: MH, CH and WH had greater woody area than CS, also greater woody area on MH and WH than C. 2014: MH, CH and WH had a greater woody area than CS, CO and C; also WH had a greater woody area than MH and CH.
Maximum gap size	2011: MH, CH and WH had smaller maximum gaps than CS and C; also smaller maximum gap size on WH than CH. 2014: MH, CH, WH and CO had smaller maximum gaps than CS and C; also WH had smaller maximum gaps than all other treatments.
Berry weight available over-winter	
Hawthorn	2010-2012: Lighter berry weight on MH, CO, CS, (*trend CH) than C. 2013: Lighter berry weight on CO and CS only compared with C. Plots not cut subsequently had heavier berry weight than those trimmed, except for MH and C.
All woody species**	Lighter berry weight on CO than C.

Table 6.4: Summary of main results from Experiment 3 (hedgerow rejuvenation treatments). MH = Midlands hedge-laying, CH = conservation hedging, WH = wildlife hedging, CS = circular saw, CO = coppice, C = control. All results are significant at $P < 0.05$ unless listed as *trend ($0.05 < P < 0.1$). **Crowmarsh Battle mixed species site only.

6.2 Conclusions in relation to the frequency, timing and intensity of cutting and current AES options

Results from this project provide strong support for the benefit of a cutting frequency of once every three years, which is currently one of two possibilities in CS option BE3 and ELS EB3, as opposed to annual hedge trimming. Cutting once in three years resulted in greater numbers of hawthorn and blackthorn flowers regardless of the timing of cutting, and these increased floral resources were clearly linked to an enhanced utilisation of hedgerow resources by pollinating invertebrates. Berry provision for overwintering wildlife was also increased by cutting once in three years for hawthorn, blackthorn and bramble, though at some sites the increase in hawthorn berry provision was limited to plots cut in winter. In addition, cutting once in three years increased the abundance of Lepidoptera larvae and pupae, the diversity of part of the Lepidoptera community, and also brown hairstreak butterfly egg abundance (a UK conservation priority species) on plots cut in autumn. There was no significant evidence to support the assertion that cutting once in three years results in a hedge with more or larger gaps at the base.

The results from this project provide weaker support for a cutting regime of once every two years in winter, the other possibility open to landowners currently managing hedgerows in CS BE3 and ELS EB3, as the benefits were fewer than for cutting once in three years. The abundance of hawthorn flowers was increased on hedges cut once in two years at some sites, but not at all experimental sites. The increase in berry weight under a two-year cutting cycle was limited to one species (blackthorn) on plots cut in winter. This contrasts with stronger support provided by results from the Monks Wood Experiment, which demonstrated an advantage of cutting once in two years in winter for hawthorn flower and berry resource provision (Staley et al., 2012a; Staley et al., 2012b), in addition to the abundance of some Lepidoptera groups (Facey et al., 2014). The Monks Wood experiment uses relatively young hedgerows (planted in the 1960s), and the results may not be widely applicable to older hedges, such as those at the hawthorn-dominated Experiment 2 sites, Marsh Gibbon and Woburn, which were planted in the 1840s and 1790s respectively. As discussed above, flower and berry abundance were much lower in 2013 across Experiment 2, which may also have reduced the likelihood of detecting significant differences between a one and two-year cutting regime in that year. Nonetheless, if there were strong benefits of cutting once every two years, these would probably have been demonstrated across the six years that Experiment 2 was conducted.

The difficulties encountered in undertaking winter cutting on this project, with derogations for late cutting required in four of five years, bring into question whether cutting in late winter is a practical option for many landowners. Experiment 2 also tested the effects of a reduced cutting intensity for the first time, which allows hedges to grow up incrementally to gradually become taller and wider. The results provide strong evidence for a benefit of cutting for incremental growth across all cutting frequencies, as it substantially increased flower and berry provision for the main woody species (hawthorn and blackthorn), as well as enhancing Lepidoptera diversity and brown hairstreak butterfly egg abundance. The current management guidance for CS BE3 includes “cutting incrementally, rather than trimming back to the same point, allows hedges to increase in height and width by several centimetres at each cut, encouraging a dense, healthy hedgerow.” However, this does not constitute part of the required management prescriptions for this option. Results from this project show that cutting for incremental growth can have strong benefits for resource provision for wildlife and Lepidoptera, and should be considered as a potential management prescription when hedgerow options in AES are next revised.

Experiment 2 was implemented at five separate field sites covering a range of hedgerow types and ages, from mature hawthorn-dominated hedges that are over 160 years old to a young mixed species hedge planted under Countryside Stewardship AES in the mid-1990s (see Section 2.2.2 for details). Despite the range in the type and age of hedgerow, the responses of many of the biological parameters to cutting regimes were consistent across experimental sites and woody hedgerow species. For example, the cumulative number of flowers produced was greater on plots cut once every three years compared with annually cut plots, but not on plots cut once every two years, across all Experiment 2 sites and for both hawthorn and blackthorn (Sections 4.3.1 and 4.3.2). The majority of British hedges are dominated by hawthorn or blackthorn (French & Cummins 2001), so the consistent response of the two dominant species across a range of hedgerow types and ages suggests that results from Experiment 2 are likely to be broadly applicable to a majority of hedges across England.

6.3 Hedgerow rejuvenation and subsequent management conclusions

Differences between the three layed methods (Midlands hedge-laying, conservation hedging and wildlife hedging) in regrowth and berry provision were greatest in the two years immediately following rejuvenation. Wildlife hedging resulted in less vigorous canopy regrowth in the second growth season following rejuvenation, though this difference was no longer apparent by the third season. Regrowth from basal stools also differed between layed treatments, as wildlife hedging resulted in taller shoots, and fewer basal stems with shoots. There were differences in the basal hedge structure between these three methods in 2014, as the wildlife hedging plots had a greater woody area and smaller maximum gaps than the other two. While the wildlife hedging was far quicker to apply than the other two layed methods (less than 1 minute vs. 12 and 33 minutes), it still cost 62% of the price of conservation hedging and 33% that of Midlands hedge-laying. Wildlife hedging requires three people and heavy machinery, which may be why the time it took was reduced more than price.

The conservation hedging plots had slightly lower rates of canopy regrowth in 2012 and a heavier berry weight in 2010-2012, but by 2013 did not differ from plots rejuvenated using Midlands hedge-laying in terms of regrowth, structure or berry provision. The conservation hedging was twice as quick to apply and about half the cost of Midlands hedge-laying. These results show that conservation hedging has similar medium-term benefits as more traditional hedge-laying styles, and thus could provide a cost-effective rejuvenation alternative under AES such as HLS and the Hedgerows and Boundaries grant under CS.

Reshaping with a circular saw was the cheapest rejuvenation method tested, and had longer term effects on canopy regrowth and berry provision than the three layed methods. Circular saw plots continued to produce greater canopy regrowth compared with the control plots three years after rejuvenation and still had reduced berry weights four years later. The structure of circular saw plots was more similar to that of control plots than the other rejuvenation methods, as the density of woody material in the hedge base was not increased. Coppicing was the second cheapest rejuvenation method tested if fencing was not required, and showed the most vigorous basal regrowth following rejuvenation. Coppice affected hedges over a longer time-scale than the other methods tested, as shown by the differences in regrowth, structure and berry provision that were still apparent three to four years later. Reshaping with a circular saw and coppicing do have benefits as cost-effective rejuvenation methods by which to encourage canopy and basal regrowth respectively. However, they both reduced berry provision even four winters following rejuvenation. In addition, reshaping with a circular saw does not increase the density of hedge bases, and immediately following rejuvenation coppice also has little basal woody material. Both may therefore provide less shelter for mammals and invertebrates than the three layed rejuvenation methods.

Management of hedgerows following rejuvenation had few effects on regrowth, structure and berry provision compared with initial rejuvenation method. This partly reflects the time-scale of the project, as each plot was cut only once in the three years following rejuvenation, as per the advice under HLS to cut twice in five years. In subsequent years management would be expected to have a stronger effect on regrowth and berry provision, as the relative effects of rejuvenation method diminish over time (though this will not be assessed in the current project). Where management did affect hedgerows in Experiment 3, the response depended on the rejuvenation method that had been used. For example, in one of three years basal hedgerow shoots were shorter following further management (cutting) on plots that had been rejuvenated with wildlife hedging, but not on those that had been rejuvenated by other methods (section 3.2.2.2.1). Post-rejuvenation management may be important to landowners, for example to reduce the width of hedges following wildlife hedging in order to maintain field margins and ditches, and results from Experiment 3 suggest that it is unlikely to be detrimental to hedge regrowth or structure. In addition, if management is specified in hedgerow rejuvenation options within AES, it should be specific to the rejuvenation method used.

6.4 Summary of recommendations

6.4.1 Hedgerow management within AES

This is a summary of the key recommendations for changes to hedgerow management both within AES and more generally, from the findings of this project discussed in more detail above.

- Cutting at a reduced intensity to allow incremental growth has been shown to have strong benefits for resource provision for wildlife and Lepidoptera, and should be considered as a potential management prescription when hedgerow options in AES are next revised.
- Conservation hedging has been shown to have similar medium-term benefits as more traditional hedge-laying styles, and thus provides an alternative hedgerow rejuvenation method that is cost-effective, both within AES and more widely.
- If ongoing management following hedgerow rejuvenation is specified within AES prescriptions, the management should be specific to the rejuvenation method used.
- Planting of mixed species hedgerows will provide floral resources across a longer season for pollinating invertebrates. The inclusion of early (e.g. blackthorn) and late (e.g. bramble) -flowering may be particularly important, as flowers of these species were visited relatively more by pollinating invertebrates than hawthorn flowers.

6.4.2 Future research on hedgerow management and the role of hedgerows in the agri-environment

This project has provided answers to key questions about the effects of hedgerow management on wildlife, some of which have already been integrated into changes to hedgerow AES options. There is a need for future research into several areas of hedgerow management and ecology, to answer questions which were not the main focus of this project. Some of these areas include:

- This project was designed predominantly to test the response of small-scale parameters and relatively immobile invertebrates to hedgerow management. There is a need for further research at larger spatial scales, into how mobile invertebrates are affected by both hedgerow management and hedgerow connectivity (Cranmer et al., 2012). This is particularly relevant for invertebrate pollinators, given current concerns about their declining populations (e.g. Dicks et al., 2015), and in the context of climate change (Lawton et al, 2010).
- Adjacent field margins or grassy buffer strips form a continuous semi-natural habitat with hedgerows, and are often managed under AES margin options. Further research on the combined effects of hedgerow and margin management is needed to inform how these two types of management interact to affect wildlife.

7. Project outputs

7.1 Publications in peer-reviewed journals

1. Staley JT, Sparks TH, Croxton PJ, Baldock KCR, Heard MS, Hulmes S, Hulmes L, Peyton J, Amy SR & Pywell RF (2012). Long-term effects of hedgerow management policies on resource provision for wildlife. *Biological Conservation*, 145, 24-29. DOI: 10.1016/j.biocon.2011.09.006

2. Staley JT, Amy SR, Facey SL & Pywell RF (2012). Hedgerow conservation and management: a review of 50 years of applied research in the UK. In: *Hedgerow Futures* (ed. Dover JW). Published by the Tree Council for Hedgelink, Staffordshire University, Stoke-on-Trent, UK, pp. 111-133.

3. Staley JT, Bullock JM, Baldock KCR, Redhead JW, Hooftman DAP, Button N & Pywell RF (2013). Changes in hedgerow floral diversity over 70 years in an English rural landscape, and the impacts of management. *Biological Conservation*, 167, 97-105. DOI: 10.1016/j.biocon.2013.07.033

4. Facey, S.L., Botham, M.S., Heard, M.S., Pywell, R.F., & Staley, J.T. (2014) Lepidoptera communities and agri-environment schemes; examining the effects of hedgerow cutting regime on Lepidoptera diversity, abundance and parasitism. Insect Conservation and Diversity, 7, 543-552. Doi: 10.1111/icad.12077

5. Staley JT, Amy SR, Adams NP, Chapman RE, Peyton JM, Pywell RF (2015). Re-structuring hedges: rejuvenation management can improve the long term quality of hedgerow habitats for wildlife. *Biological Conservation*, 186:184-196. doi: 10.1016/j.biocon.2015.03.002

6. Amy SR, Heard MS, Hartley SE, George CT, Pywell RF, Staley JT (2015). Hedgerow rejuvenation management affects invertebrate communities through changes to habitat structure. *Basic and Applied Ecology*, 16: 443-451 doi:10.1016/j.baae.2015.04.002

7. Staley JT, Botham MS, Chapman RE, Amy SR, Heard MS, Hulmes L, Savage J, Pywell RF (2016). Little and late: how reduced hedgerow cutting can benefit Lepidoptera. *Agriculture, Ecosystems and Environment*, 224: 22-28 doi: 10.1016/j.agee.2016.03.018

8. Staley JT, Botham MS, Amy SR, Hulmes S, Pywell RF (2018) Experimental evidence for optimal hedgerow cutting regimes for brown hairstreak butterflies. *Insect Conservation and Diversity*, 11:213-218, doi: 10.1111/icad.12239

9. Graham, L, Gaulton, R, Gerard, F, Staley, JT (2018) The influence of hedgerow structural condition on wildlife habitat provision in farmed landscapes. *Biological Conservation*, 220: 122-131 doi: 10.1016/j.biocon.2018.02.017

7.2 Presentations at conferences

1. Pywell RF, Sparks TH, Amy S & Staley JT (2012) Hedgerow Management. Invited keynote talk at Hedgerow Futures Conference, Staffordshire University, Stoke-on-Trent, September 2012.

2. Staley JT, Sparks TH, Amy S, Heard MS & Pywell RF (2012) How do the frequency and timing of hedgerow cutting regimes affect resource provision for wildlife? Oral presentation at Hedgerow Futures Conference, September 2012.

3. Facey SL, Botham MS, Heard MS, Pywell RF & Staley JT (2012) Hedgerows managed under agri-environment schemes have the potential to benefit some groups of Lepidoptera. Poster presentation at Hedgerow Futures Conference, September 2012.

4. Amy S, Heard MS, Pywell RF, Hartley SE & Staley JT (2012) Investigating the effect of hedgerow rejuvenation management on invertebrate community composition. Poster presentation at Hedgerow Futures Conference, September 2012.

5. Amy, S, Heard MS, Hartley SE, George CT, Pywell RP & Staley JT (2013) Invertebrates in rejuvenated hedgerows: effects of management technique and habitat structure. Poster presentation to International Congress of Ecology, Imperial College London, August 2013.

6. Staley JT (2014) The role of hedges in climate change and resilience. Invited keynote address at NERC Impact workshop, jointly organised by Hedgelink and Imperial College London, December 2014

7. Staley JT, Amy SR, Botham M, Heard MS, Pywell RF (2014) Hedge management under agri-environment schemes benefits Lepidoptera communities European Congress of Entomology, University of York, August 2014

8. Staley JT, Botham MS, Amy S, Heard MS, Pywell RF (2015) Little and late: how reduced hedgerow cutting can benefit Lepidoptera. British Ecological Society Annual Meeting, Edinburgh, December 2015

9. Graham L, Staley JT, Gerard F, Gaulton R (2016) Hedgerow habitat structure for biodiversity; Developing and testing LiDAR-based structural condition models. British Ecological Society Annual Meeting, Manchester, December 2016

7.3 Knowledge transfer events and resources

1. Hedgerow Management Workshop, Sept 2011 at Woburn Estate Bucks, organised by CEH.

Talks: “Hedgerows and environmental stewardship” Emily Ledder (Natural England); “The cities of wildlife” Louise Jane (RSPB); “What have we learnt about over-winter resource provision for wildlife from a long term hedgerow experiment?” Jo Staley (CEH); “Current hedgerow management and restoration research” Nigel Adams (Hedgelink) / Jo Staley
Field visit - to two experimental sites on Woburn Estate.

There were 19 participants, including representatives from Natural England, FWAG, RSPB, GWCT, Devon Hedge Group, Aylesbury Vale district council and local conservation bodies.

2. Devon Hedge Group Training Day, April 2012, organised by Rob Wolton.

Talks: "Understanding the hedge management cycle, and assessing management options" Rob Wolton (Hedgelink); "Options for rejuvenating hedges, including conservation laying, wildlife laying, coppicing and use of shaping saw" Nigel Adams (National Hedgelaying Sociey and Hedgelink); "Hedge cutting research. The emerging results of the effects of different trimming frequencies on flower and berry production" – Joanna Staley (CEH).
Field visit - to the hedgerow management experimental site at Yarcombe, Devon.

There were 40 participants, including representatives from Natural England, Natural Trust, RSPB, Plymouth University, FWAG, East Devon District Council, Devon Rural Skills Trust and Blackdown Hills AONB.

3. Butterfly Conservation Upper Thames Branch Conservation Review Day, Feb 2014, organised by Butterfly Conservation/CEH

Talk: “Hedgerow management and restoration research project” Sam Amy (CEH)

There were 50 participants, including representatives from Natural England, The National Trust, The Wildlife Trust and members/volunteer recorders of Butterfly Conservation.

4. Spring Recorders Day, February 2016, organised by Thames Valley Environmental Records Centre.

Invited talk “Effects of hedgerow management and restoration on biodiversity” Sam Amy (CEH). Over 80 participants.

5. Hedgerows in the Blackdown Hills: management and funding, April 2016, organised by Blackdown Hills AONB / FWAG south-west, over 50 participants.

Invited talk “Effects of hedgerow management and restoration on biodiversity” Jodey Peyton (CEH)

6. Annual Moth Recorder’s Meeting, Birmingham, January 2017, organised by Butterfly Conservation

Invited talk: “Hedgerow management for moths” Jo Staley and Marc Botham (CEH)

There were over 200 participants, including county moth recorders.

7.3.1 Knowledge transfer resources

Two leaflets summarising results from the project as presented in the BD2114 Interim Report were produced by CEH and Nigel Adams at the request of project steering group:
Rejuvenation of hedgerows – June 2015
Increasing the value of hedges for wildlife with relaxed cutting regimes – June 2015 and updated February 2018.

These are available on the Hedgelink and CEH websites, and have been used at several of the events above. Most recently several hundred leaflets were posted to landowners in late 2017, and in 2018 FWAG (Farming and Wildlife Advisory Group) used 2000 of the updated relaxed cutting regime leaflets to promote sympathetic hedgerow management practice at Campaign for the Farmed Environment events. Both briefing papers are below.

Increasing the value of hedges for wildlife with relaxed cutting regimes

Why is hedgerow management important?

- Hedges provide key semi-natural habitat and resources for wildlife in agricultural landscapes, and support pest control and pollination of crops.
- Most hedges are cut with a mechanical flail, often every year in early autumn.
- Cutting regimes substantially alter the condition of hedges and their value as wildlife habitats. For example, farmland birds and mammals rely on berries as a food source over winter, but most hedgerow species only flower and fruit on wood that is at least two years old.
- We tested cutting regimes (the frequency, timing and intensity of hedgerow trimming) on five farms across southern England over six years. Here are our key findings.

Berries on two years growth on a hawthorn hedge (left) and the same hedge after cutting in autumn (right).

Frequency and timing of hedgerow cutting

Cutting once every 3 years compared with every year:

- 1.5 - 2 times more hawthorn and blackthorn flowers are produced.
- The increased flower abundance attracts more pollinating insects such as hoverflies, bees and butterflies.
- More hawthorn, blackthorn and black berries are provided for overwintering wildlife (e.g. farmland birds and small mammals), especially if hedges are cut in late winter.
- More butterfly and moth (Lepidoptera) caterpillars and pupae.

Cutting once every 2 years compared with every year:

- Timing of cutting is important. On hedges where there was an increase in berries from cutting every two years as opposed to every year, this was only found for cutting in late winter (and not in autumn).
- There were more butterflies and moths if hedges were cut in late winter every 2 years, but not in autumn.
- Fewer benefits than cutting once every 3 years. For example, increase in berry provision found at some sites on hedges cut once in 2 years, but not at all sites.

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Intensity of hedgerow cutting

- Hedge trimming in late winter may not be possible on wet ground where access is difficult. An alternative is to reduce the intensity of trimming in early autumn.
- We tested reducing the intensity of hedge trimming by cutting around 10cm higher and wider than the previous cut. This allows hedges to grow up and out incrementally.

A reduced cutting intensity compared with cutting back to the same height and width results in:

- 2-3 times more berries for overwintering wildlife on hawthorn and blackthorn.
- Increased diversity of butterfly and moth species.

Incremental trimming retains some leaves and berries in autumn.

Standard cut in autumn removes foliage and berries.

Hedgerow management summary

- Our results show strong evidence of benefits for wildlife of reducing the frequency of hedgerow trimming to once every three years, compared with the standard practice of trimming every year.
- Cutting once every two years had weaker benefits for wildlife, and timing was critical, as little advantage was found for trimming once every two years in autumn.
- Relaxing the intensity of trimming to allow incremental growth also delivered substantial benefits for wildlife, and is a practical option where access to hedges is difficult in late winter.
- This evidence supports the more relaxed cutting regimes which are available under Agri-Environment Schemes in England.
- Across the most common types of hedgerow, these relaxed management regimes provide multiple benefits to wildlife.

Photos: Marc Botham, CEH

Left: The Chestnut moth and right: a Brown hairstreak butterfly (a Biodiversity Action Plan priority species), examples of the many insects who feed on hedgerows.

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Rejuvenation of hedgerows

Why rejuvenate hedges?

- Less than half of UK hedges are in good condition (with few vertical gaps, a minimum height of 1m and width of 1.5m) partly due to over-frequent trimming with mechanised flails.
- Traditional rejuvenation methods such as hedge-laying and coppicing reduce gaps and stimulate growth from the base of hedgerows.
- Wildlife such as perennial plants, small mammals, farmland birds and some invertebrates benefit from dense hedges with few gaps.
- We developed and tested cheaper, modern alternative rejuvenation methods and traditional methods on five farms across southern England. Here are our results:

	Traditional Midland hedge-laying	Conservation hedging	Wildlife hedging	Coppicing	Circular saw
Cost (per 100m)	£1241	£664	£413	£225 (exc. fencing) £645 (inc. fencing)	£166
Timing (minutes per m)	33:08	12:08	0:53	1:33	1:57
Height (m)	1.50	1.40	2.05	0.05	1.90
Width (m)	1.05	1.55	3.40	0.05	1.80

Average cost (£ per 100m of hedge including clearing up brash), timing (minutes per metre), height & width (in metres) of rejuvenated hedges across five sites in 2010.

Traditional Midland style hedge-laying

- Main stems were partially severed at the base, laid over and woven between stakes to form a stock proof barrier. Up to 50% of the woody volume (side branches) was cut and removed. Remaining branches were laid towards one side of the hedge.
- Hedge condition was improved by reducing gap size and increasing hedge density.
- Growth of new stems was stimulated from the cut stumps in the hedge bottom, as well as growth of the laid main stems.
- Berry provision was reduced compared with hedges that were not rejuvenated, but only over a short time scale (2-3 years following rejuvenation).

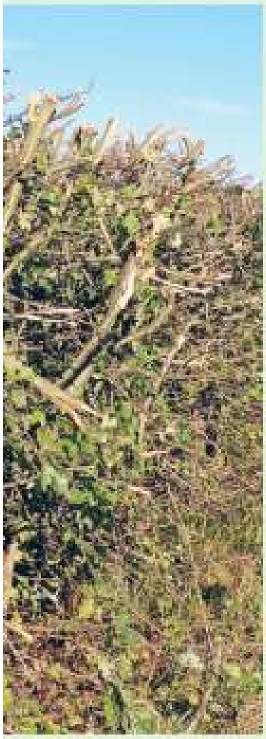
Traditional Midland style hedgelaying

Conservation hedging

- Stems were cut at the base as for traditional Midland style hedge-laying. Less woody volume was removed. Remaining stems and branches were laid along both sides of the hedge. Stakes were used sparingly and no top binding was used.
- Three years after rejuvenation, hedge structure and rates of woody re-growth were as good as traditional hedge-laying in improving hedge condition.
- Berry provision for overwintering wildlife was slightly better than for traditional hedge-laying immediately following rejuvenation.

Wildlife hedging

- Each stem was partially cut with a chainsaw and a mechanical digger used to push the hedge over along its length. No woody volume was removed, and some stems were entirely severed when the hedge was pushed over.
- The average width was more than twice that of the traditional and conservation laid hedges.
- Three years after rejuvenation, wildlife hedging resulted in slightly less vigorous woody re-growth than traditional hedge-laying, but a greater density of woody material with smaller gaps in the hedge base.
- Immediately after rejuvenation there was more dead wood in the hedge (up to 40%) due to the severed stems.
- Berry provision was as good as from hedges that were not rejuvenated.



Re-shaping with a circular saw

- The hedge was re-shaped into a tall, box like shape by cutting the sides and top using a tractor mounted circular saw. The branches were cut cleanly, avoiding the damage caused by a flail.
- Resulted in vigorous growth in the hedgerow canopy, but did not stimulate basal woody growth or reduce gaps at the base.
- Three years after rejuvenation, berry provision was as good as from hedges that were not rejuvenated.

Coppicing

- Hedge stems were cut close to ground level with a chain saw. The entire volume of the hedge was removed apart from 5cm high stools.
- Resulted in vigorous growth of woody stems and a dense woody structure at the base of the hedge three years after coppicing.
- Very few berries were produced even four years after coppicing.
- Fencing was needed at two of the five sites to prevent deer browsing the exposed re-growth from cut stools.

Photos: Front - Jo Staley, CEH.
Back - as credited, others by Jo Staley CEH

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7.4 Media coverage

1. "Hedgerows can be better managed for wildlife" by Adele Rackley. Planet Earth online article, December 2011

2. "Three year cutting regime is optimum for hawthorn hedgerows" by David Boderke. Farmer's Guardian article, December 2011

3. "Managing Hedgerows" – Planet Earth online interview and podcast with Jo Staley (CEH) and Nigel Adams (Hedgelink / National Hedgelaying Society), February 2012

4. "Hedgerow management for wildlife". Article in Woodland Trust *Wood Wise* News magazine, summer 2014.

5. "Rejuvenation management to improve hedgerow habitats for wildlife" by RSPB Conservation Management Advice, British Wildlife Habitat Management News, March 2016

7.5 Linked Masters and PhD student projects / theses

The following students used the experimental infrastructure funded under this project to collect extra data, additional to the data collection funded as part of the core research project. These student projects resulted in three papers in refereed journals (listed above), with a fourth in preparation in February 2018:

1. Lyndsey Graham (jointly co-supervised with University of Newcastle and France Gerard, CEH, 2014 – present). Optimising hedgerow structure for biodiversity; developing and testing lidar-based structural condition models. Ongoing PhD, funded by IAPETUS (NERC)

2. David Stanbury (jointly co-supervised with University of Reading and Oli Pescott, CEH, 2016 – 2017). How does Hedgerow Management under Agri-Environment Schemes Affect Hedgerow Basal Flora? MSc dissertation.

3. Sam Amy (jointly co-supervised with University of York and Matt Heard, CEH, 2011 – 2014). Structuring agri-habitats to maximise predator potential. MRes dissertation.

4. Sarah Facey (jointly co-supervised with University of York and Marc Botham, CEH, 2011). The effects of hedgerow management on Lepidoptera communities. MRes dissertation.

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