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Interim report for BD2114: hedgerow management and rejuvenation

1 INTRODUCTION

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 facilitating the movement of species through intensively managed landscapes (Lawton *et al.* 2010). 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), 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 scheme (ELS; Natural England 2013a) and the conservation of species-rich hedgerows by appropriate management under Higher Level Scheme (HLS; Natural England 2013b). Cutting hedges every two calendar years (EB1/2) has proved to be one of the most popular ELS options to date (Natural England 2009).

Provision of hedgerow berry resources for overwintering wildlife and nectar resources for pollinating invertebrates are major objectives of the current ELS hedgerow cutting options (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). The current project has demonstrated, however, 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 berry availability over winter and hedge flower production (Staley *et al.* 2012a; Staley *et al.* 2012b). 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.

The current project also tests whether these 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 form part of ELS 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 and 'neat' way and avoiding the need to cut in the winter. The value of this practical approach requires further testing.

The invertebrate fauna shows a somewhat mixed response to the effects of timing and frequency of hedge cutting (Maudsley *et al.* 2000; Marshall *et al.* 2001a; Marshall *et al.* 2001b). For example, Psyllidae (plant suckers) were significantly more abundant on uncut hedges, whereas Thysanoptera and Collembola were enhanced by trimming. Indeed it was postulated that regular hedge cutting could result in a greater diversity of invertebrates due to the stimulation of new woody plant growth. However, it was also suggested that late winter cutting was 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 to date there has been little or no research on the effects of hedge cutting regimes on flower-visiting insects (e.g. bees and butterflies).

In addition, there is an urgent need to develop low-cost and effective means of restoring and rejuvenating the increasing stock of hedgerows managed less intensively under the AES. This reflects a number of factors, including a growing number of hedges being left entirely unmanaged (Carey et al. 2008), increasing costs of labour, a growing shortage of skilled practitioners, and insufficient funds under HLS for traditional management practices, such as laying. Traditional hedge-laying techniques improved 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 warrants testing.

1.1 Project aims

1) To examine the effects of simple cutting management 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.

1.2 Hypotheses

i) Cutting hedges every two or three years, and cutting in winter, will improve their provision of resources for pollinators, over-wintering 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 would result in similar rates of regrowth, structure and provision of berries as those achieved with traditional hedge-laying.

2 METHODOLOGY

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

Ongoing treatments manipulating the frequency (once every 1, 2 vs. three years) and timing (autumn vs. winter) of cutting have been applied to hawthorn-dominated hedgerow plots since 2006, at a site in Cambridgeshire (Monks Wood). Results from this experiment have been reported five and six years after management treatments started (Staley *et al.* 2012a; Staley *et al.* 2012b), so it is not the focus of this report. This experiment will run until early 2015, after which results from nine years of management treatments will be reported.

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

2.2.1 Experimental design and field sites

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:
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 over the course of the current experiment annual incremental cutting has allowed a 1 m hedge to increase to approximately 1.4 m, incremental cutting every two years has resulted in a 1.2 m tall hedge and incremental cutting every three years in a 1.1 m tall hedge);
3) Frequency of cutting (one, two and three year cycles).

These experimental treatments are applied in full factorial combinations (2 × 2 × 3) with three replicates of each treatment applied at each site to contiguous plots of between 15 to 20 m in length. The five field sites comprise: two hawthorn 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 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). The winter cutting treatments were not applied at the WB hedge, due to a shortage of suitable hedgerow.

Treat ment	Time of cutting	Intensity of cutting	Frequency of cutting	Cutting dates	Comment
1	Autumn	Standard	1 year cycle	Sept 2010, 2011, 2012, 2013	Cross compliance
2	Autumn	Standard	2 year cycle	Sept 2011, 2013	ELS EB2
3	Autumn	Standard	3 year cycle	Sept 2012	ELS EB3 option
4	Autumn	Incremental	1 year cycle	Sept 2010, 2011, 2012, 2013	
5	Autumn	Incremental	2 year cycle	Sept 2011, 2013	
6	Autumn	Incremental	3 year cycle	Sept 2012	
7	Late winter	Standard	1 year cycle	Jan/Feb 2011, 2012, 2013, 2014	
8	Late winter	Standard	2 year cycle	Jan/Feb 2012, 2014	ELS EB3 option
9	Late winter	Standard	3 year cycle	Jan/Feb 2013	
10	Late winter	Incremental	1 year cycle	Jan/Feb 2011, 2012, 2013, 2014	
11	Late winter	Incremental	2 year cycle	Jan/Feb 2012, 2014	
12	Late winter	Incremental	3 year cycle	Jan/Feb 2013	
13	Control – no cutting				

Table 1: Summary of treatments applied to hedge cutting Experiment 2, and their relation with hedgerow management options under ELS and cross-compliance.

2.2.2 Monitoring of Experiment 2

2.2.2.1 Vegetation composition. The percentage composition of woody species was assessed in each plot in summer 2010, prior to the application of the cutting 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. *Rosa canina* agg., *Rubus fructicosus* agg.) which grow largely on the surface of hedgerows, and structural woody species (e.g. *Crataegus monogyna*).

2.2.2.2 Flower counts. Production of flowers by the main woody species (hawthorn, blackthorn and bramble) was assessed annually at peak flowering from 2011–2013. Percentage cover of blackthorn and hawthorn flowers was estimated in early and late spring respectively, using five 50 x 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.

2.2.2.3 Berry availability over winter. The number and weight of berries were assessed in autumn each year from 2010 – 2013 following the September cutting treatments, to assess the provision of berries for over-wintering wildlife. The numbers of berries for all species were counted in five 50 x 50 cm quadrats per plot positioned as above, and berries of hard-fruited species were collected. Plot height and width were measured as above. Berries were weighed to obtain fresh biomass, dried for 48 h 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.

2.2.2.4 Pollinator visitation rates. Invertebrate pollinators visiting hawthorn, blackthorn and bramble flowers were assessed at peak flowering times in 2011-2013. Timed counts were conducted using 2m x 1m quadrats for visitation to hawthorn and blackthorn, or 10m transects for visits to bramble flowers. The numbers of visits by 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.

2.2.2.5 Invertebrates. Two sampling methods were used annually in early summer 2011-2013 to assess the abundance of invertebrate taxa present within the hedgerow plots. 1) Beating: 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. 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 or family (Coleoptera). 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. In addition, numbers of brown hairstreak butterfly eggs found on blackthorn in hedgerow plots at YC were assessed each winter using intensive timed egg surveys.

2.2.2.6 Hedge structure. The effects of management on woody hedge structure were quantified by taking and comparing high resolution digital images in winter 2010/11 and 2013/14. A white sheet was placed behind the hedge to maximise contrast. Hedge density and gappiness were determined using ERDAS IMAGINE image processing software.

2.3 Experiment 3: Rejuvenation of hedgerows

2.3.1 Experimental design and field sites

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. 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. 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. 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. The hedge was re-shaped into a tall, box like shape by cutting of the sides and top of the hedge using a tractor mounted circular saw. Future management would consist of similar periodic re-shaping every 8-10 years.
5) Coppicing. Hedge stems were cut to approximately 10cm above ground level with a chain saw. Nearly the entire volume of the hedge was removed.
6) Control. No rejuvenation treatment applied.

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. Following the application of rejuvenation treatment, management treatments were applied in a split-plot design, in autumn of subsequent years (2011– 013). Management consisted of no further cutting or cutting once every 2-3 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 12m plot lengths.

Five field sites were used, 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, and the management treatments were not applied at MW due to a shortage of suitable hedgerow.

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

Table 2: Summary of rejuvenation and subsequent management treatments applied to field sites in Experiment 3.

2.3.2 Monitoring of Experiment 3

2.3.2.1 Vegetation composition. This was estimated in summer 2010 prior to application of the rejuvenation treatments and again in summer 2013, as specified for Experiment 2 above (section 2.2.2.1).

2.3.2.2 Cost and speed. At each site, the contractor for each rejuvenation method was asked to estimate the cost of rejuvenating 100 m of that type of hedgerow commercially. 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.

2.3.2.3 Regrowth. Regrowth of hedgerow plots following rejuvenation treatments was assessed annually each winter to measure growth that had occurred the previous summer (from 2011 – 2013 inclusive). Regrowth from basal stools was assessed on the four treatments that had resulted in cuts to the base of hedgerow stems (Midlands hedgelaying, conservation hedging, wildlife hedging, coppicing). The numbers of shoots present were counted for five randomly selected basal stools within each plot. The height and diameter was measured for two shoots randomly selected from each of the five basal stools on each plot (ten shoots assessed in total per plot). Canopy regrowth (excluding regrowth originating from basal stems) was assessed on all rejuvenation treatments and control plots. The quantity of recent regrowth was measured by the number of times it touched a range pole, divided in 30cm divisions. Six range poles were assessed per plot, three vertical poles positioned half-way between the middle and edge of the plot, and three horizontal poles positioned at the mid-point between the ground and top of the plot. Six twigs of the previous summer's growth were collected from each plot, and their length, diameter and biomass recorded.

2.3.2.4 Dead foliage cover. The percentage of each plot containing dead foliage was estimated visually the year following rejuvenation, to assess the proportion of hedge that had been killed as a result of each rejuvenation method.

2.3.2.5 Hedge structure. Digital photographs were taken to assess hedge structure immediately following application of the rejuvenation treatments in winter 2010/11, and in winter 2013/14. These were processed as described above for experiment 2 (section 2.2.2.6).

2.3.2.6 Berry availability over winter. This was assessed annually (2010-2013), as described above in section 2.2.2.3.

2.4 Data analysis of experiments 2 and 3

Where multiple samples of a response variable had been assessed per plot (flower cover, berry availability and canopy 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 the plot surface area values calculated above.

Two types of analyses were conducted for each individual response variable being investigated for Experiments 2 and 3. Firstly, cumulative values over three or four (for berries) 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. ANOVAs were used to test the effects of cutting frequency, timing and intensity and site on cumulative production of flowers, berries, pollinator visitation and invertebrate abundance for Experiment 2. ANOVAs were also used to test the effects of cutting treatments on hedge structure variables in 2014 for Experiment 2. If significant treatment effects were found, Tukey HSD posthoc tests were conducted (Crawley 2007). 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 determine how annual response variables were affected by cutting and rejuvenation treatments for experiments 2 and 3 respectively, and whether these treatment effects varied with year.

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 3.0.3 (R Core Development Team 2014) using packages nlme (Pinheiro *et al.* 2014) and Vegan (Oksanen *et al.* 2013).

3 RESULTS AND DISCUSSION

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

3.1.1 *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 on several occasions due to adjacent HLS/ELS field margins being too wet to drive on. Of the five years when hedgerows were cut in winter during this research project, the cutting was delayed to March on all four sites in two years (2010 and 2014), on one site in 2011 and two sites in 2013. Even with a delayed cutting date in March all or some of the winter plots had to be cut by hand at WC in 2013 and 2014, 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, which necessitates a 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.

3.1.2 *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 (*Rosa canina* agg.*, Rubus fruticosus, Lonicera periclymenum, Bryonia dioca, Hedera helix*). Bramble cover increased slightly at Yarcombe during the course of the experiment, but not at any other site.

	MG	WB	WC	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	0	0	0	0	5.8
Sambucus nigra	0	1.7	0	6.2	1.0
Cornus sanguinea	0	0	0	0	4.2
Euonymus europaeus	0	0	4.3	0	0.4

Table 3: Average percentage cover of the ten most abundant woody hedgerow species at each field site for Experiment 2.

3.1.3 *Flowers*

3.1.3.1 Hawthorn

The frequency of hedge cutting had a significant effect on cumulative hawthorn flower production over three years ($F_{2,129}$ = 15.5, P < 0.001); hedgerow plots cut once in three years had 2.1 times more hawthorn flowers than those cut annually (Tukey posthoc test (TPT), P < 0.001), while those cut every two years did not differ significantly from the annual plots (Figure 1). Cutting to allow incremental growth produced 1.4 times more hawthorn flowers on average than cutting back to a standard height and width ($F_{1,129}$ = 20.9, P < 0.001). In addition, there was a trend towards an interaction between cutting frequency and intensity ($F_{2,129}$ = 2.99, P = 0.054), whereby the frequency of cutting did not affect flower abundance for hawthorn hedges under incremental management, but did alter flower abundance for standard cutting (TPT, P < 0.001). Hedgerows plots that were not cut had 2.9 times more hawthorn flowers than those cut annually in autumn ($t_{1,137}$ = 3.68, P < 0.001). The timing of hedgerow cutting had no effect on the number of hawthorn flowers.

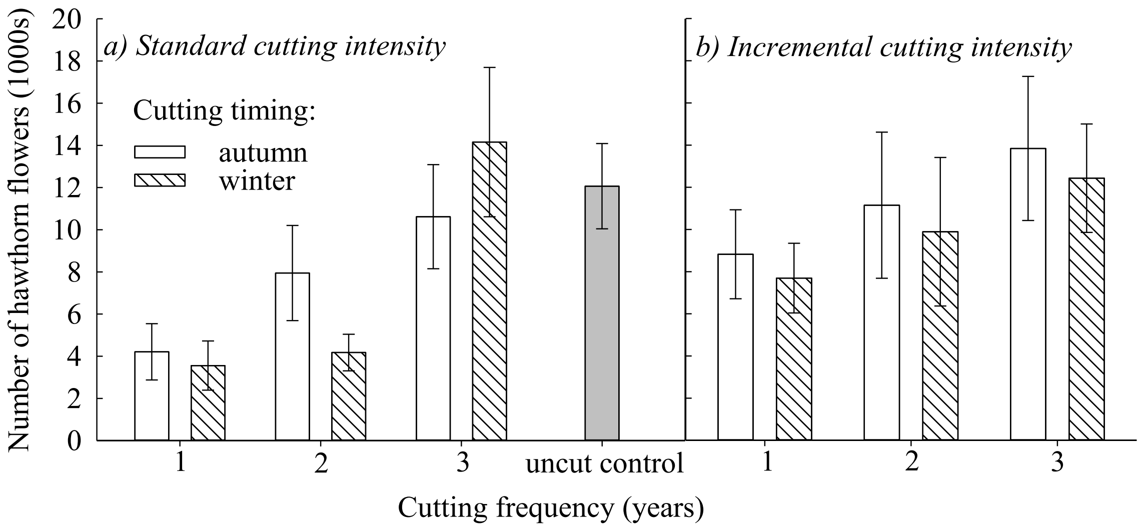

Figure 1. Cumulative number of hawthorn flowers (1000s, mean ± SE) per 1 m hedgerow length under cutting frequency, timing and intensity treatments, produced over three years (2011 – 2013).

Cutting frequency and site interacted with year to significantly affect the abundance of hawthorn flowers (likelihood-ratio test (LRT): χ^2_8 = 22.14, P < 0.05): at all sites except for WM there were fewer flowers on the plots cut every three years in 2013 (the year immediately following cutting), compared with the annually cut plots.

3.1.3.2 Blackthorn

The cumulative number of blackthorn flowers over three years was similarly affected by the frequency of cutting ($F_{2,84}$ = 4.93, P < 0.01). The number of blackthorn flowers was on average 2.4 times greater on plots cut every three years than those cut annually (TPT, P < 0.01), while those cut every two years did not differ from the annual plots (Figure 2). There was also a weak non-significant trend towards more blackthorn flowers on plots cut to allow incremental growth compared with those cut back to a standard height and width ($F_{1,84}$ = 2.94, P =0.090). The timing of cutting did not significantly affect the abundance of blackthorn flowers. The uncut control plots had 3.2 times more flowers than those cut annually ($t_{1,83}$ = 2.18, P < 0.01).

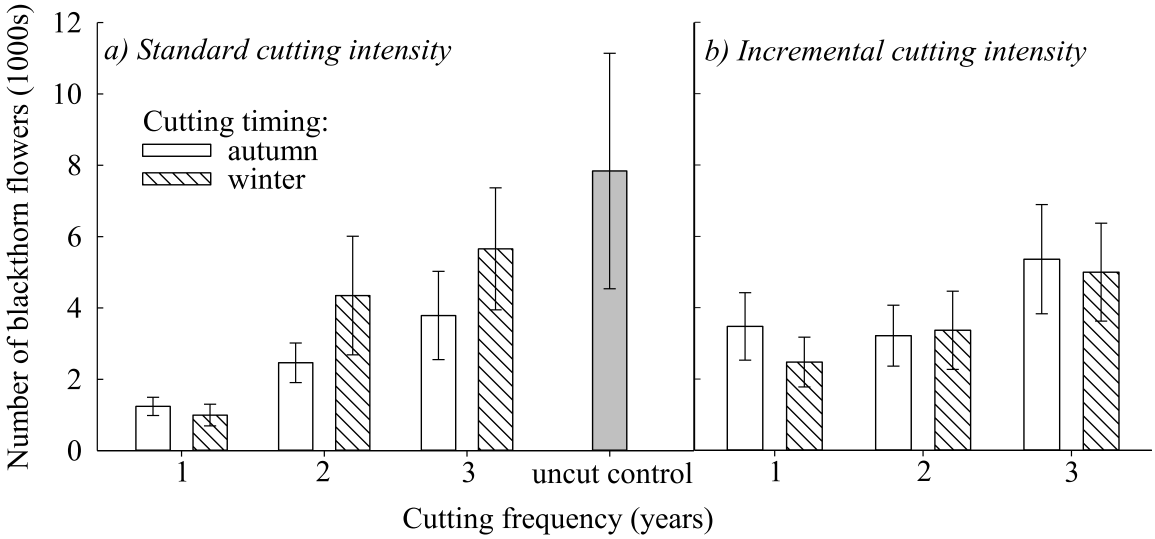

Figure 2. Cumulative number of blackthorn flowers (1000s, mean ± SE) per 1 m hedgerow length under cutting frequency, timing and intensity treatments, produced over three years (2011 – 2013).

The effects of cutting frequency on the number of blackthorn flowers significantly varied with year (LRT: χ^2_4 = 52.59, P < 0.0001). In 2011, plots cut every two ($t_{1,170}$ = 3.30, P < 0.01) or three years ($t_{1,170}$ = 2.00, P < 0.05) both had more blackthorn flowers than those cut annually; in 2012 just those cut every three years ($t_{1,83}$ = 2.52, P < 0.05) had more blackthorn flowers than the annual plots; in 2013 there was no effect of cutting frequency. These yearly differences are due to the stage of each cutting cycle, except in 2013 when there were far fewer flowers (see discussion below). There was also a trend towards an interaction between cutting intensity and year (LRT: χ^2_2 = 5.96, P =0.051), whereby there was a stronger effect of cutting for incremental growth on increased abundance of flowers in 2012 than either 2011 or 2013.

3.1.3.3 Bramble flowers

The cumulative number of bramble flowers produced over three years was strongly affected by the percentage cover of bramble in each plot at the start of the experiment ($F_{1,118}$ = 31.96, P < 0.001). There was a trend towards a greater cumulative number of bramble flowers on the plots trimmed every three years compared with those cut annually ($F_{2,118}$ = 2.79, P = 0.06, Figure 3). There was also a trend towards an interaction between cutting timing and cutting intensity ($F_{1,118}$ = 2.18, P = 0.097), whereby there were more bramble flowers on incremental plots cut in winter than those cut in autumn and under a standard cutting intensity the number of bramble flowers was unaffected by the timing of cutting. Uncut control plots had 1.4 times more flowers than plots cut annually ($t_{1,120}$ = 2.11, P < 0.05).

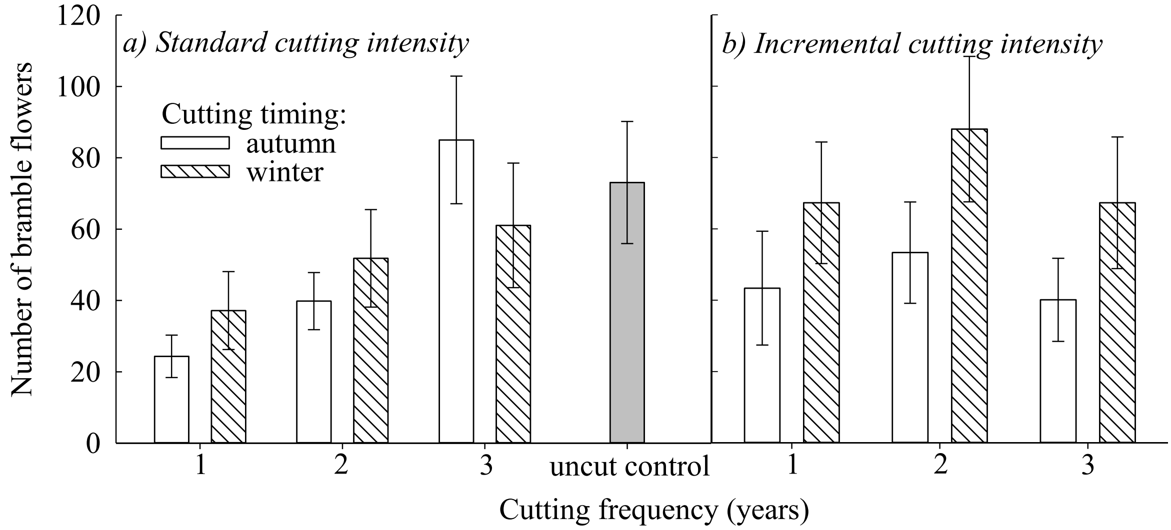

Figure 3. Cumulative number of bramble flowers (mean ± SE) per 1 m hedgerow length under cutting frequency, timing and intensity treatments, produced over three years (2011 – 2013).

The response of bramble flowers to the cutting treatments depended on the year in which they were assessed. In 2012 only, there was a greater number of bramble flowers on plots cut in winter compared with those cut in autumn ($t_{1,242} = 2.43$, $P < 0.05$). Bramble flower abundance was reduced on plots that were cut every three years in 2013 only ($t_{1,242} = 2.55$, $P < 0.05$), just after the three year plots had been cut.

3.1.3.4 Discussion of flower abundance

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, Cambridgeshire (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 (Staley *et al.* 2012a). This is comparable to the 2.1 times increase found above after three years of monitoring. However, 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. This may be partly due to a reduced number of hawthorn flowers in 2013 relative to previous years (see Table 4 below) which is probably due to the cold, late winter. In 2013 there was two years growth on plots cut every 2 years, so a large difference in flower abundance between the one and two year plots might be expected. The low flower numbers produced in 2013 may have made it harder to detect a difference in the numbers of flowers between the one and two year plots. This is also demonstrated by the analysis of annual data for blackthorn described above. In addition, plots cut in winter at Monks Wood had fewer hawthorn flowers than those cut in autumn, but Experiment 2 does not show any effect of timing of cutting on hawthorn flower production.

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 those cut every one or two years, or those cut in autumn compared with winter. Both woody species produced more flowers on plots cut to allow incremental growth of the hedgerow compared with those cut back to a standard height and width, though the response of blackthorn was not quite statistically significant. In addition, the effects of cutting intensity on flower production were smaller than the effects of a one year vs. three year cutting frequency. Bramble also showed a similar trend in response to cutting frequency to hawthorn, though none of the cutting treatments had a significant effect on bramble flower production.

All three species thus provide support for the current ELS EB3 hedgerow option in relation to increased flower production under a three year cutting cycle. However, unlike results from the Monks Wood experiment, the value of cutting every 2 years for increased flower production has not been demonstrated for any of the three species. This may be because flowers have been monitored for three years on Experiment 2, whereas results were published after five and six years from Monks Wood. The low flower numbers on Experiment 2 in 2013 also made detecting effects of a 2 year cutting cycle less likely. Further monitoring on a time-scale comparable to a typical five year ELS agreement may determine whether cutting every two years does increase flower production on a wider range of hedge types than those present at Monks Wood.

3.1.4 *Berry provision over winter*

3.1.4.1 Hawthorn

The effect of cutting treatments on berries differed between experimental sites (four way interactions between the cutting treatments and site: $F_{6,83} = 2.76$, $P < 0.05$), so the hawthorn dominated sites (MG and WO) were analysed separately from the mixed species sites (WM and YC). Hedgerow plots cut to allow incremental growth at MG and WO produced on average a 1.7 times greater cumulative weight of berries than those cut under the standard treatments ($F_{2,65} = 14.69$, $P < 0.001$, Figure 4). At these sites the cumulative weight of berries was also significantly affected by an interaction between cutting frequency and timing ($F_{2,65} = 3.95$, $P < 0.05$); timing of cutting did not affect hawthorn berry provision on plots cut every one or two years, but plots cut every three years had a 2.4 times greater weight of available berries if cut in winter than autumn (TPT, $P < 0.05$). The uncut plots at MG and WO produced a 3.3 times greater weight of hawthorn berries than the annual autumn standard plots ($t_{1,63} = 2.63$, $P < 0.05$).

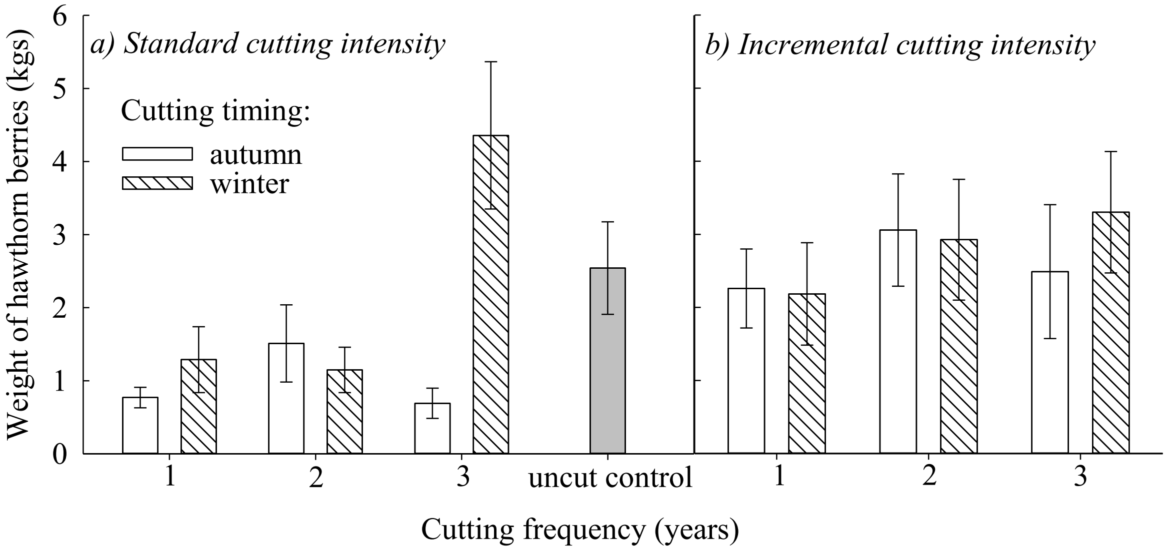

Figure 4. Cumulative fresh weight of hawthorn berries (mean ± SE) available over winter on hawthorn dominated hedges (at MG and WO). Cutting frequency, timing and intensity treatments were applied and berry production assessed over four years (2010 – 2013).

The effects of the frequency and timing of cutting on the weight of hawthorn berries available at MG and WO also varied with year (three way interaction $t_{1,104} = 3.51$, $P < 0.001$). In 2012 plots cut every three years in winter had a greater weight of berries ($t_{1,137} = 2.60$, $P < 0.05$), and in 2013 plots cut in winter every two years had a greater weight of berries ($t_{1,137} = 2.33$, $P < 0.05$), both compared to plots cut annually. These yearly trends reflect the stage of the cutting cycle. When berries were assessed in 2012 there was three years of growth on the plots cut every three years in winter, and in 2013 winter cut two year plots had two years of growth on them. Year had a large effect on overall berry production; the uncut control plots had 1.8 times more berries in 2012 ($t_{1,137} = 9.99$, $P < 0.001$) than 2011, but only 0.12 times as many berries in 2013 ($t_{1,137} = 2.77$, $P < 0.01$) compared with 2011.

The weight of available hawthorn berries on the mixed species hedges (WM) was 2.5 times greater on plots cut every three years ($F_{2,28} = 6.63$, $P < 0.01$), 2 times greater on plots cut in winter ($F_{1,29} = 12.24$, $P < 0.01$) and 1.5 times greater on plots cut for incremental growth ($F_{1,29} = 12.0$, $P < 0.01$) compared with annual, autumn and standard cutting treatments respectively (Figure 5). There was no interaction between the timing and frequency of cutting at WM. Hawthorn is not the dominant species at YC (Table 3) and many of the plots did not provide any hawthorn berries, so the data were too few to show an effect of cutting treatments at this site.

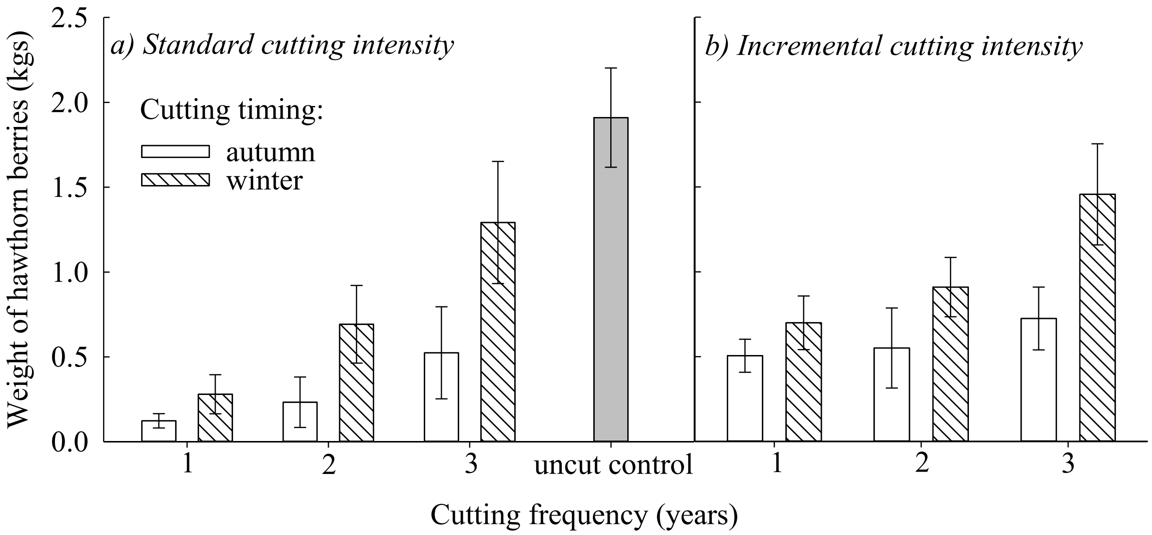

Figure 5. Fresh weight of hawthorn berries (mean ± SE) available over winter at a mixed species hedgerow site (WC). Cutting frequency, timing and intensity treatments were applied and berry production assessed over four years (2010 – 2013).

3.1.4.2 Blackthorn

The cumulative weight of available blackthorn berries over four years was affected by the frequency ($F_{2,44}$ = 3.67, P < 0.05), timing ($F_{2,44}$ = 9.13, P < 0.01) and intensity ($F_{2,44}$ = 5.83, P < 0.05) with which hedges were cut (Figure 6). On average, there was a 2.1 times greater weight of blackthorn berries on plots cut to allow incremental growth compared with those cut back to a standard height and width. In addition, the effect of timing of cutting depended on the cutting frequency ($F_{2,44}$ = 5.81, P < 0.01); timing did not affect 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 (TPT, P < 0.05). Blackthorn berry weight was 3.8 times greater on plots cut every two years in winter compared with those cut every year, and 6.4 times greater on those cut in winter every three years compared with annually cut plots.

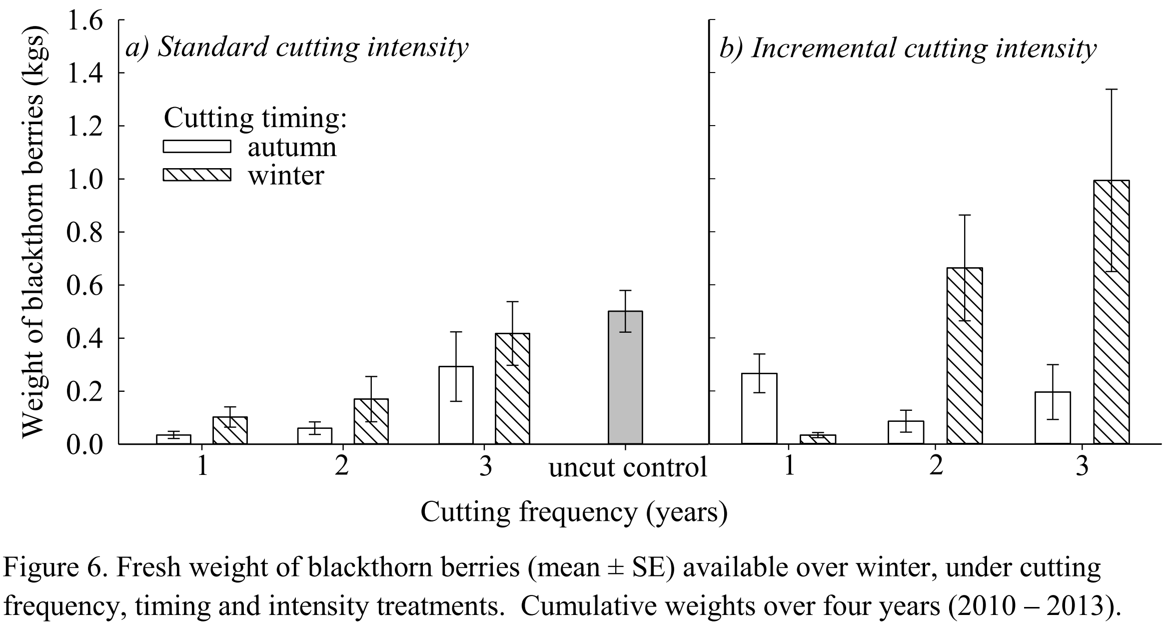

Figure 6. Fresh weight of blackthorn berries (mean ± SE) available over winter, under cutting frequency, timing and intensity treatments. Cumulative weights over four years (2010 – 2013).

3.1.4.3 Bramble

The total number of blackberries available over four years was 2.7 times greater on plots cut in winter compared with those cut in autumn ($t_{1,104}$ = 3.51, P < 0.001, Figure 7). Plots cut every three years had 1.6 times more blackberries than those cut annually ($t_{1,104}$ = 2.48, P < 0.05), and there was a trend towards more blackberries on plots cut every two years compared with those cut annually ($t_{1,104}$ = 1.74, P = 0.085). Trimming intensity did not affect the cumulative number of blackberries.

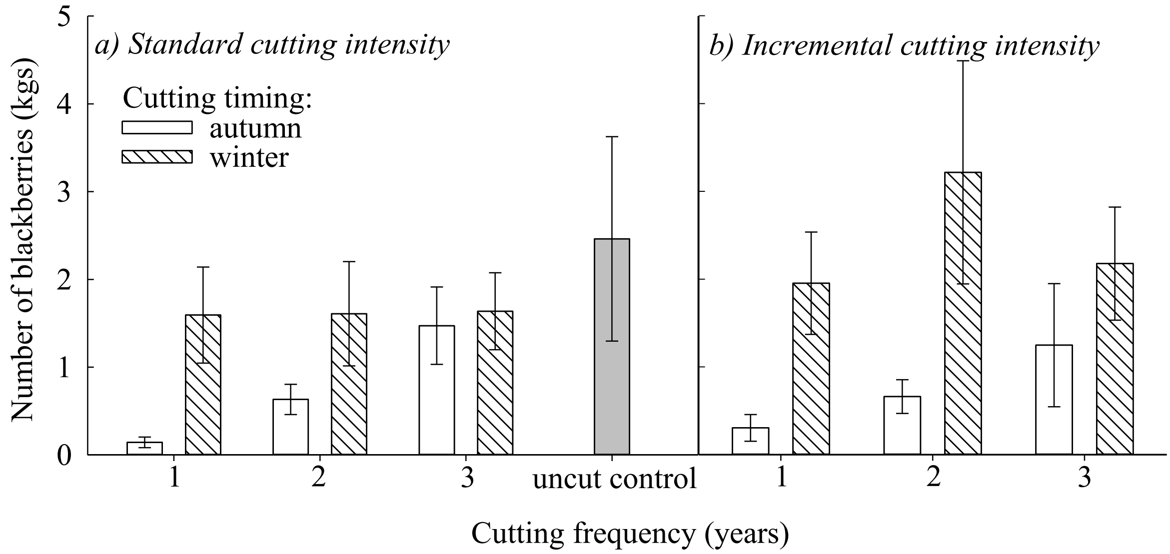

Figure 7. Number of blackberries (mean ± SE) available over winter, under cutting frequency, timing and intensity treatments. Cumulative total numbers over four years (2010 – 2013).

3.1.4.4 Dogrose

Plots cut in winter had a 3.1 times greater weight of dogrose berries than those cut in autumn ($F_{1,78}$ = 15.47, P < 0.001, Figure 8). The effects of cutting timing also depended on frequency ($F_{2,78}$ = 4.72, P < 0.05); berry weight did not differ between autumn and winter cutting for plots cut annually, but did for those cut every two or three years (TPT, P > 0.05).

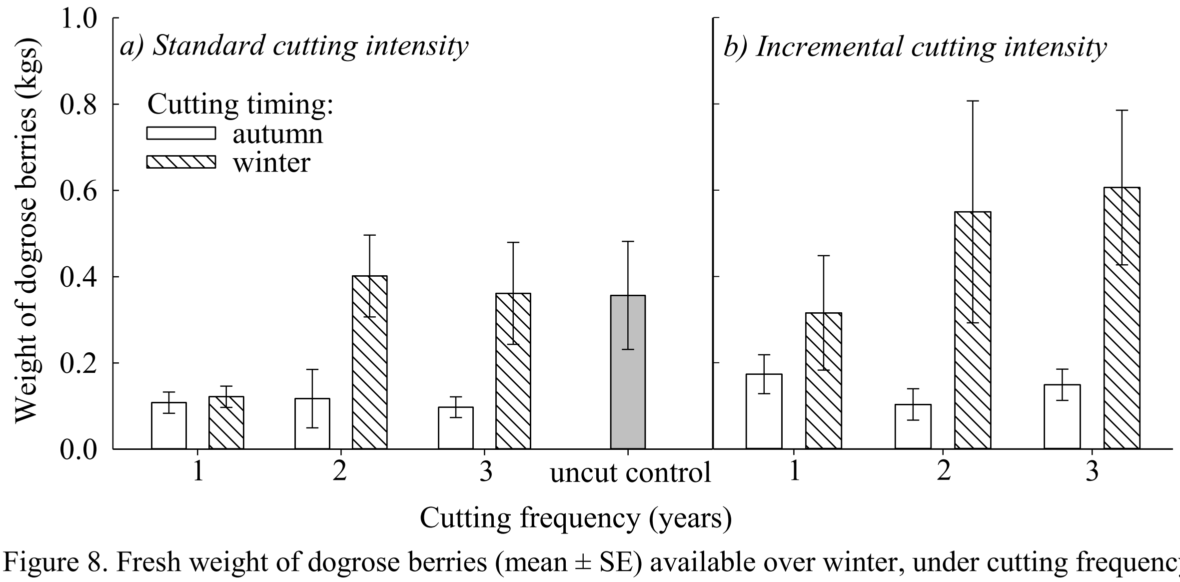

Figure 8. Fresh weight of dogrose berries (mean ± SE) available over winter, under cutting frequency, timing and intensity treatments. Cumulative weights over four years (2010 – 2013).

3.1.4.5 Discussion of berry provision for over-wintering wildlife

The weight of berries available to over-wintering wildlife in response to cutting treatments on Experiment 2 is broadly comparable to results from the Monks Wood experiment (Staley *et al.* 2012a), 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 the two hawthorn-dominated sites in Experiment 2, the increased hawthorn berry weight under a 3 year cutting cycle is limited to those plots that are cut in winter. Blackthorn and bramble follows a similar pattern to hawthorn, but these species show an increase in berry weight and a trend towards greater berry numbers respectively on plots cut every two years compared with those trimmed annually.

Both hawthorn and blackthorn have increased berry availability for over-wintering wildlife on hedge plots cut in late winter compared with autumn, though this is limited to plots cut every 3 years for the hawthorn-dominated sites and plots cut every 2 or 3 years for blackthorn across all sites. At Monks Wood, available hawthorn berry weight was also greater on plots cut in winter. The intensity of hedgerow trimming affects the availability of berries for over-wintering wildlife from hawthorn, blackthorn and bramble in a similar way at Experiment 2. Berry availability was increased by 1.5 – 2.7 times on plots cut to allow incremental growth for these three hedgerow species, compared with plots cut back to a standard height and width. Blackthorn and blackberry berry provision benefitted to a greater extent from cutting to allow incremental growth than hawthorn, suggesting that these two species are particularly vulnerable to a severe trimming intensity.

The increased provision of berries for over-wintering wildlife under a three year cutting cycle provides further support for ELS hedgerow option EB3. The benefits of a two year cutting cycle for hawthorn berry availability is not currently supported by four years of data from Experiment 2 across a wider range of hedgerow types than those tested at Monks Wood, so the two year winter cutting element of EB3 is not supported in terms of berry provision by the dominant hedgerow woody species. Nonetheless, blackthorn berry availability was increased on a two year cutting cycle, and it is possible that extending Experiment 2 on a time-scale comparable to the six years of published data from Monks Wood will show a similar benefit of cutting in winter every two years for hawthorn berry availability.

3.1.5 *Berry dry matter and berry size*

The cutting frequency, timing and intensity treatments did not alter percentage dry matter or the weight of individual berries for any of the three species assessed (hawthorn, blackthorn, dogrose).

3.1.6 *Pollinator visits to hedgerow flowers*

The greatest numbers of pollinator visits per plot were to bramble flowers, followed by blackthorn and then hawthorn flowers (Table 4), 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 flowers, 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), 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	Prunus spinosa Blackthorn			Crataegus monogyna Hawthorn			Rubus fructicosus 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 - 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. 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.

3.1.6.1 Blackthorn pollinators

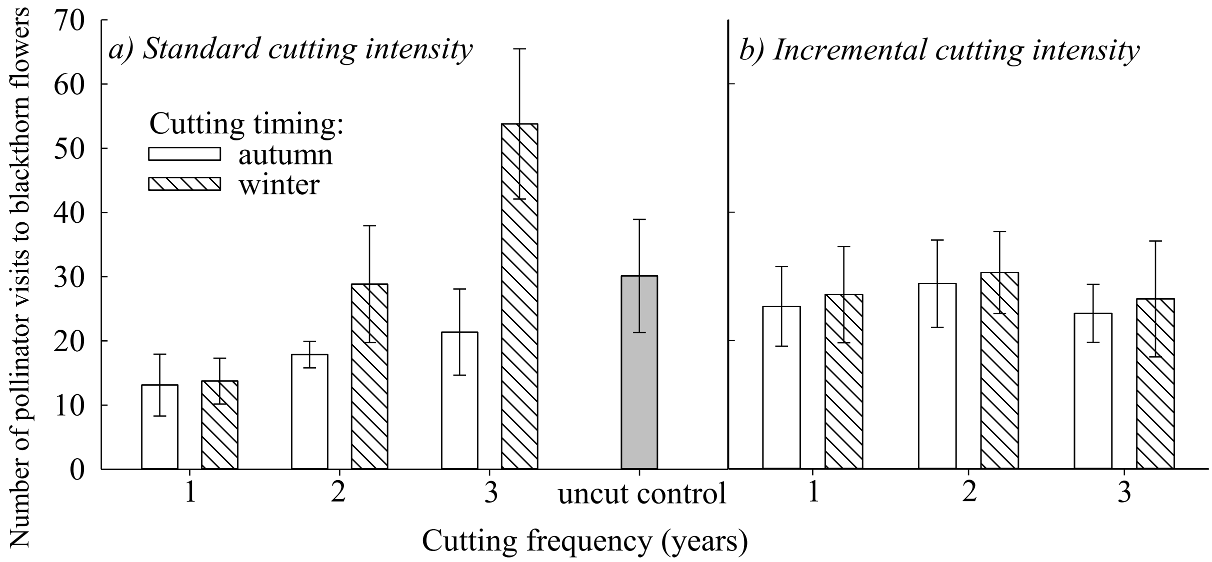

Figure 9. Number of pollinator visits (mean ± SE) to blackthorn flowers, under cutting frequency, timing and intensity treatments. Cumulative number of visits over three years (2011 – 2013).

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 9). The frequency, timing and intensity of hedgerow cutting did not significantly affect the number of pollinator taxa visiting blackthorn flowers, and nor did hedge cutting treatment affect the blackthorn pollinator assemblage.

3.1.6.2 Hawthorn pollinators

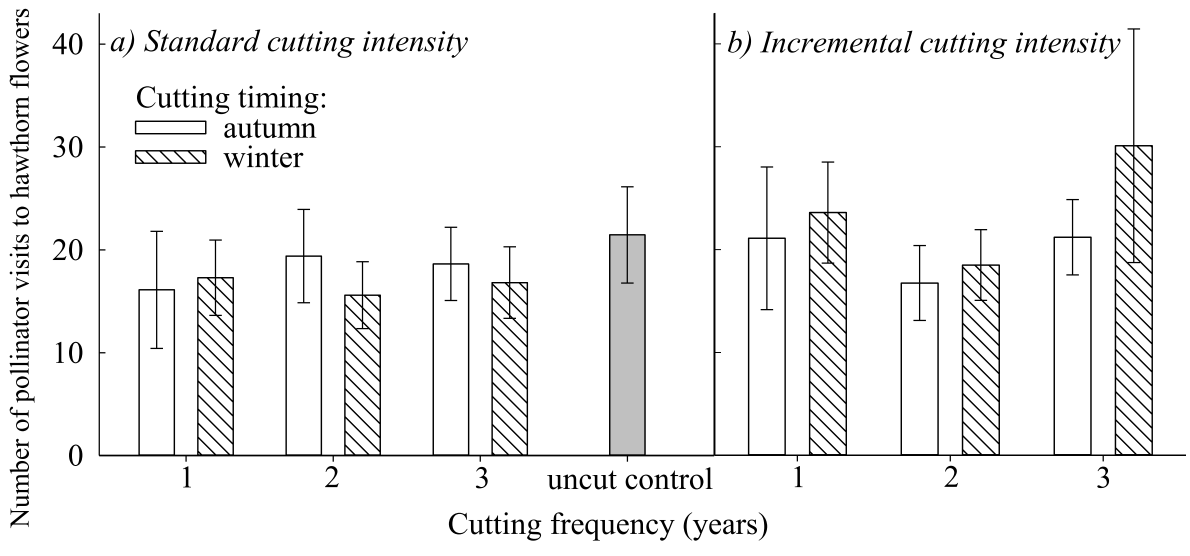

Figure 10. Number of pollinator visits (mean ± SE) to hawthorn flowers, under cutting frequency, timing and intensity treatments. Cumulative number of visits over three years (2011 – 2013).

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 were 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 10), 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.

3.1.6.3 Bramble pollinators

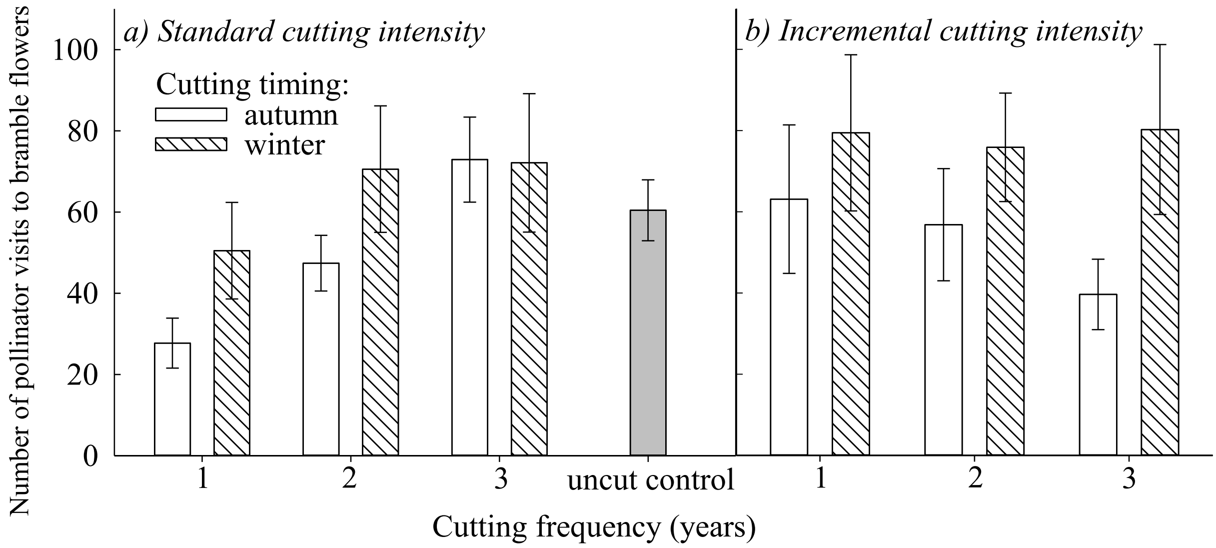

Figure 11. Number of pollinator visits (mean ± SE) to bramble flowers, under cutting frequency, timing and intensity treatments. Cumulative number of visits over three years (2011 – 2013).

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. 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.

3.1.6.4 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 therefore provide strong support for those 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.

3.1.7 *Invertebrates within hedgerows*

3.1.7.1 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. The total abundance of Lepidoptera larvae and adults was not significantly affected by the timing of hedgerow trimming (Figure 12). There was a very strong trend towards an interaction between the frequency and intensity of hedge cutting ($t_{1,160}$=1.97 P = 0.0507); on plots cut to a standard intensity there were 1.2 times more

Lepidoptera if they were cut every three years compared with those cut annually, but there was no effect of cutting frequency on plots cut to allow incremental growth.

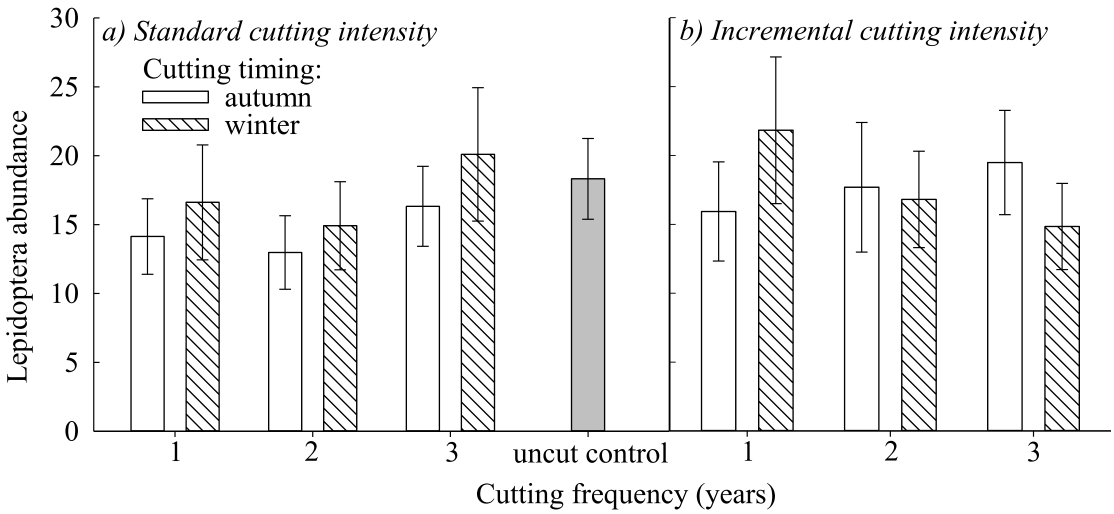

Figure 12. The abundance of Lepidoptera adults and larvae (mean ± SE) on hedges under cutting frequency, timing and intensity treatments. Cumulative data collected over three years (2012 – 2014).

Lepidoptera diversity, measured by the Shannon-Wiener index, was 1.2 times greater on plots cut for incremental growth than those cut to a standard intensity ($t_{1,153}$=2.15 $P < 0.05$, Figure 13). There were no consistent effects of the frequency or timing of cutting on Lepidoptera diversity. Species richness of Lepidoptera was not affected by the frequency or timing of hedgerow cutting. There was a weak trend towards more Lepidoptera species on plots cut to allow incremental growth compared with those cut to a standard intensity ($t_{1,156}$=1.73 P = 0.086).

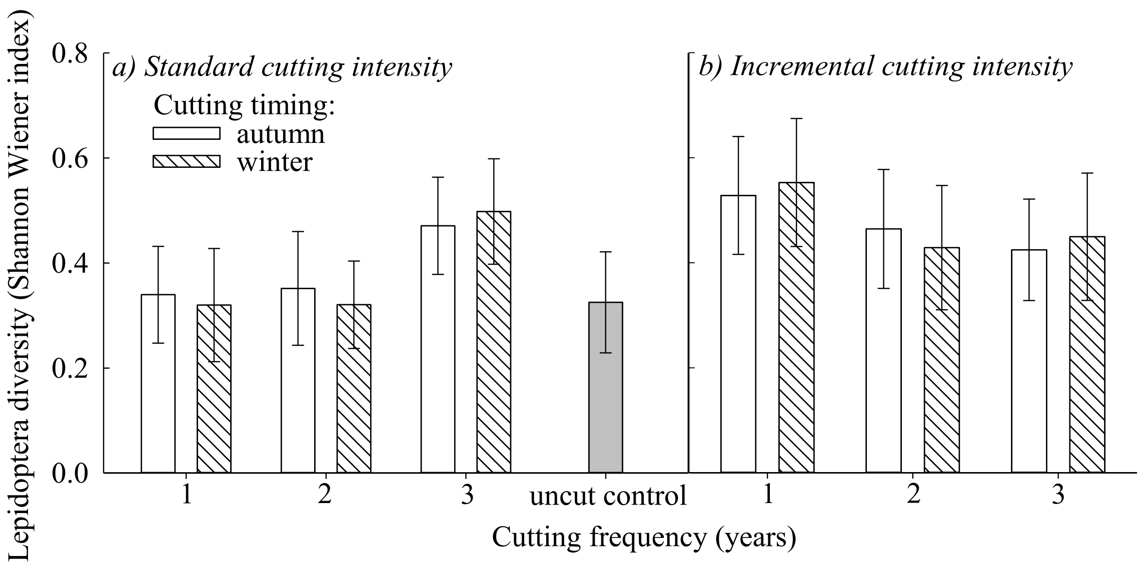

Figure 13. Diversity of Lepidoptera (Shannon diversity index, mean ± SE) on hedges under cutting frequency, timing and intensity treatments. Diversity calculated from cumulative species data over three years (2012 – 2014).

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

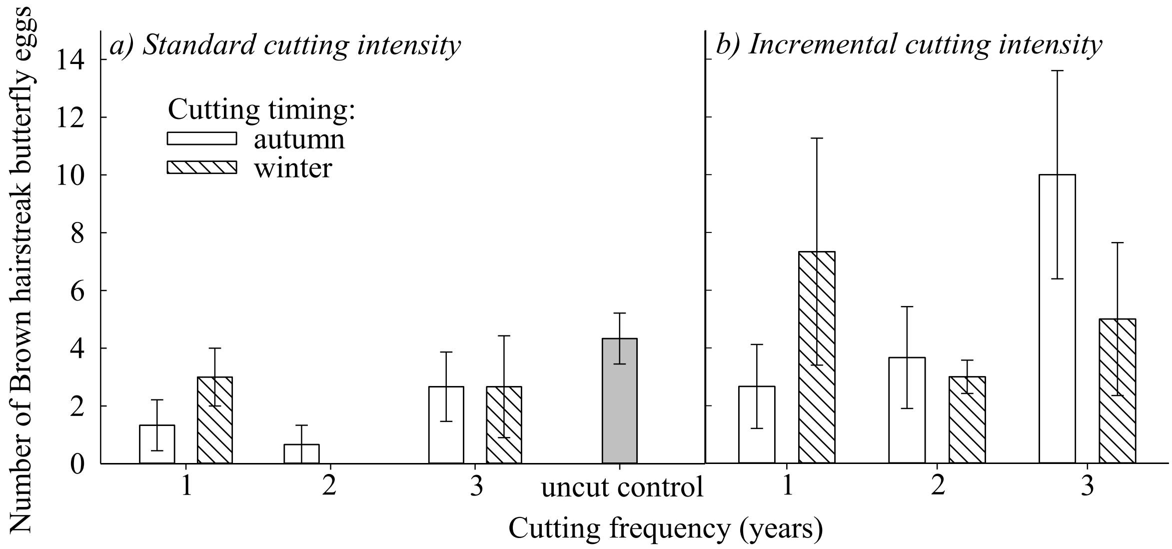

Figure 14: Number of brown hairstreak butterfly eggs (mean ± SE) on blackthorn under cutting frequency, timing and intensity treatments at Yarcombe, Devon. Cumulative number of eggs over three years (2012 – 2014).

There were 3 times more brown hairstreak eggs on blackthorn growing in hedge plots cut for incremental growth compared with plots cut to a standard intensity ($t_{1,29}$=3.68 $P < 0.001$, Figure 14). On average there were 1.4 times more brown hairstreak eggs on those plots cut once every three years compared to those cut every year ($t_{1,29}$=2.32 $P < 0.05$), but the frequency and timing of hedge cutting interacted (LRT: $\chi^2_2 = 7.40$, $P < 0.05$) as the increase in number of eggs under a three year cutting cycle was confined to plots cut in autumn, while there was no significant effect of cutting frequency on plots cut in winter. In 2013 only, there was a trend towards more eggs on the plots cut every 2 years compared with those cut annually ($t_{1,65}$=1.85 $P = 0.069$); the two year plots had not been cut during the year before the 2013 egg survey.

3.1.7.3 Invertebrate abundance

Total invertebrate abundance was not affected by the frequency, timing or intensity of hedgerow trimming. The abundance of Coleoptera (beetles) was also not affected by any of the hedgerow cutting treatments.

3.1.7.4 Discussion of invertebrates 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 in Experiment 2 was increased by cutting once every three years compared with annual trimming on those plots cut to a standard intensity. This increase in Lepidoptera abundance provides support for 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.* in press). However, unlike Experiment 2, there was no effect of cutting frequency at Monks Wood on abundance of free-living Lepidoptera larvae (Facey *et al.* in press). Results from Experiment 2 are likely to be more robust as sampling took place over three years, and from five sites rather than one. Brown hairstreak egg abundance was also increased on plots cut in autumn every three years compared with those cut annually, which again provides support for the three year cutting option within EB3. However, the brown hairstreak egg data are quite variable (not large error bars in figure 14); further monitoring over a longer time-scale may clarify the effects of cutting regime on this species.

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.

The timing of cutting did not affect Lepidoptera abundance or diversity, in contrast to results from the Monks Wood experiment and Marshall *et al.* (2001b). At Monks Wood a strong trend was found towards increased Lepidoptera diversity and species richness on plots cut in winter compared with those cut in autumn (Facey *et al.* in press), though data are only available for one year. Conversely, Marshall *et al.* (2001b) found Lepidoptera abundance to be reduced on hedges cut in February compared with those cut in September.

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 Lepidopera larvae, and may have moved between the contiguous hedgerow plots and used the hedges for short periods rather than as their main habitat. Lepidopera 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.

3.1.8 *Hedgerow structure*

Plots were photographed in 2014 following the winter cutting. In 2014 the cutting frequency treatments were at different stages in their cycle; plots cut annually or every two years had been cut since the last growing season (either in autumn late 3013 or winter early 2014), whilst those cut every three years had one season's additional growth since their last cut (which was in autumn late 2012 or winter early 2013).

3.1.8.1 Basal gappiness

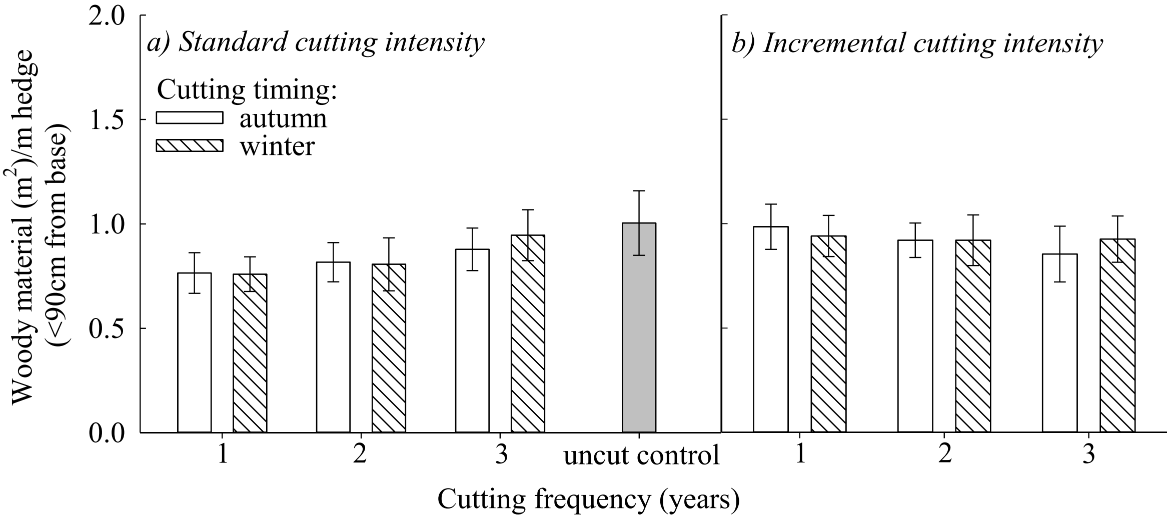

Figure 15: Woody material (m^2/m; mean ± SE) in the basal 90 cm of plots calculated from digital images taken in the winter of 2014 for sites with hedgerows containing hawthorn but not growing on a bank (MG, WO and WM), for each cutting frequency with a) standard cutting intensity and b) incremental cutting intensity. The timing of cutting is represented by the colour of the bars.

Basal gappiness 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. At the three sites with hawthorn present where hedges are not growing on a bank (MG, WO, WM), there was no effect of cutting treatments (timing, frequency or intensity) on the total area of woody material near the base of the hedge (0-90 cm; Figure 15). However, the WM hedge is relatively young in comparison to the other sites, and when this site was analysed separately, an interaction was found between cutting frequency and intensity for the amount of woody material in the hedge base ($F_{2,29} = 7.46$, $P < 0.01$). Plots cut every 3 years to a standard intensity had approximately 35% more woody material near the base than those cut more frequently to the same intensity (TPT $P < 0.05$), whereas this difference was not seen in plots cut incrementally (Figure 16). There was also a trend towards plots cut every 2 years containing more woody material near the base when cut incrementally rather than to a standard intensity (TPT $P = 0.07$).

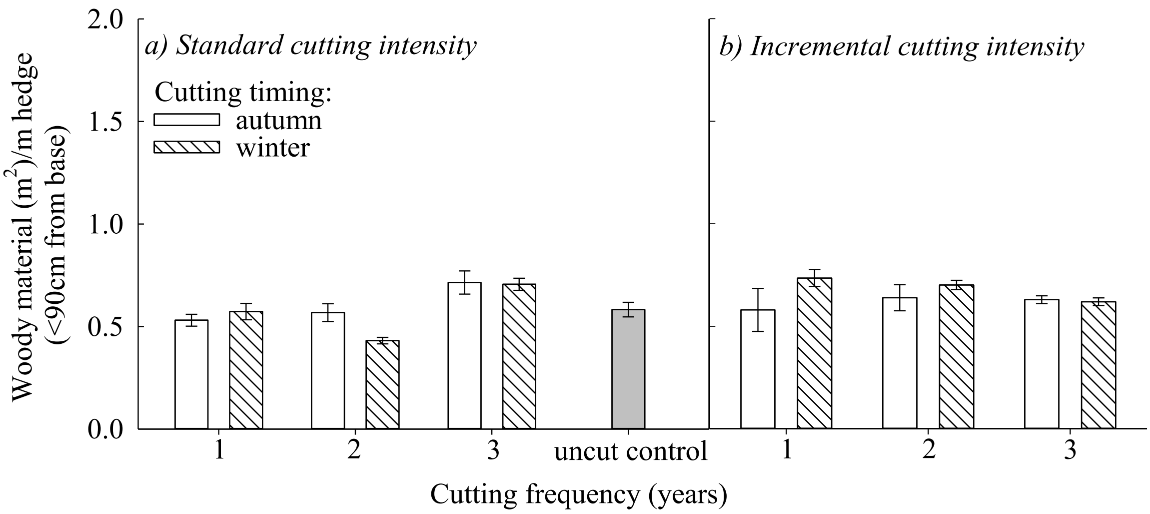

Figure 16: Woody material (m^2/m; mean ± SE) in the basal 90 cm of plots calculated from digital images taken in the winter of 2014 for just the WM site (a mixed species younger hedge), for each cutting frequency with a) standard cutting intensity and b) incremental cutting intensity. The timing of cutting is represented by the colour of the bars.

The size of individual gaps was assessed, in part to determine whether the cutting treatments have an effect on how stock-proof a hedge is. For these three sites (MG, WO and WM) the maximum gap size was affected by an interaction between cutting frequency and timing of cutting ($F_{1,101} = 5.21$, $P < 0.05$). Plots cut every two years were more affected by the timing of cutting than those cut every one or three years, with the maximum gap area on average 2.6 times bigger when cut in winter than in autumn (Figure 17). The relatively low figure for maximum gap size in the uncut control may reflect the fact that branches emerging from higher up the hedge often hang down low, obscuring the presence of gaps through which stock might escape.

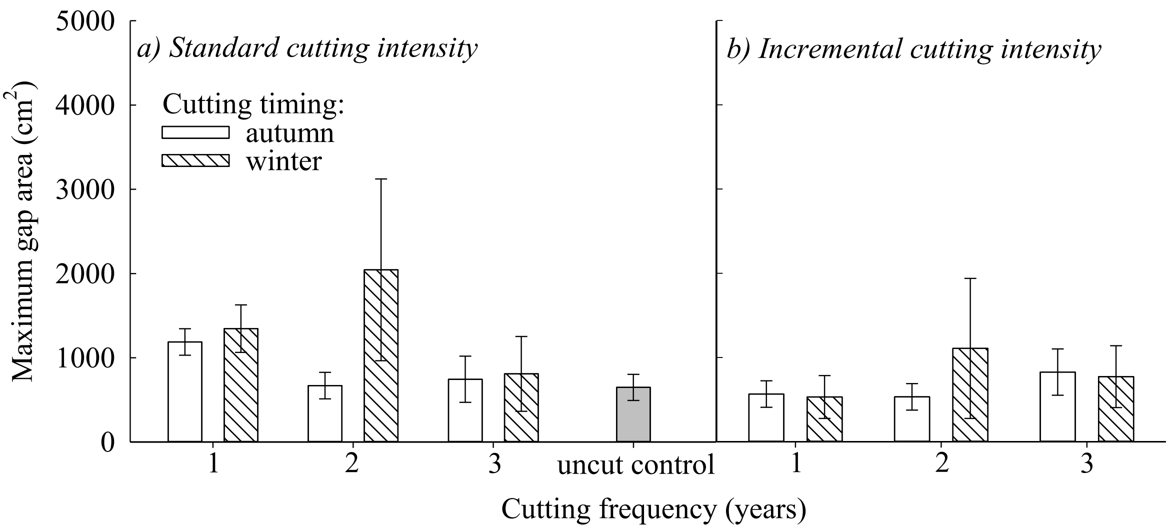

Figure 17: Maximum gap size (cm^2; mean ± SE) in the basal 90 cm of plots in 2014, calculated from digital images spanning 5.2 m of hedge length.

When WM was analysed alone an interaction for maximum gap area was found between cutting frequency and intensity ($F_{2,29} = 3.83$, $P < 0.05$); plots cut every two years to a standard intensity had the largest gaps, which were up to 2.5 times larger than those cut incrementally (Figure 18).

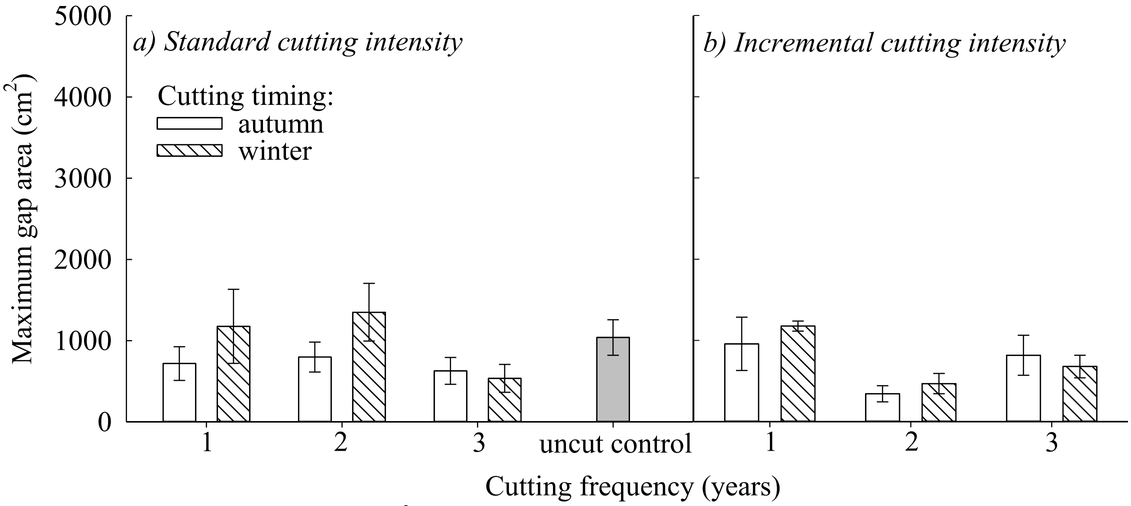

Figure 18: Maximum gap size (cm^2; mean ± SE) in the basal 90 cm of plots in 2014 for just the WM site (a mixed species younger hedge), calculated from digital images spanning 5.2 m of hedge length.

Another variable that may be useful to assess how stock-proof a hedge might be is the number of gaps over a certain threshold area. Figure 19 shows the number of gaps over 20 × 20 cm, which was deemed a likely size through which a lamb might fit (Nigel Adams, personal communication). There was a significant interaction between cutting time and both cutting frequency (LRT $\chi^2_4 = 26.81$, $P < 0.001$) and intensity (LRT $\chi^2_2 = 26.16$, $P < 0.001$). Compared with annual cutting, plots cut every two years had significantly more gaps > 20 × 20 cm when cut in the winter, but slightly lower counts when cut in the autumn. The number of gaps > 20 × 20 cm was lower in plots cut incrementally in winter.

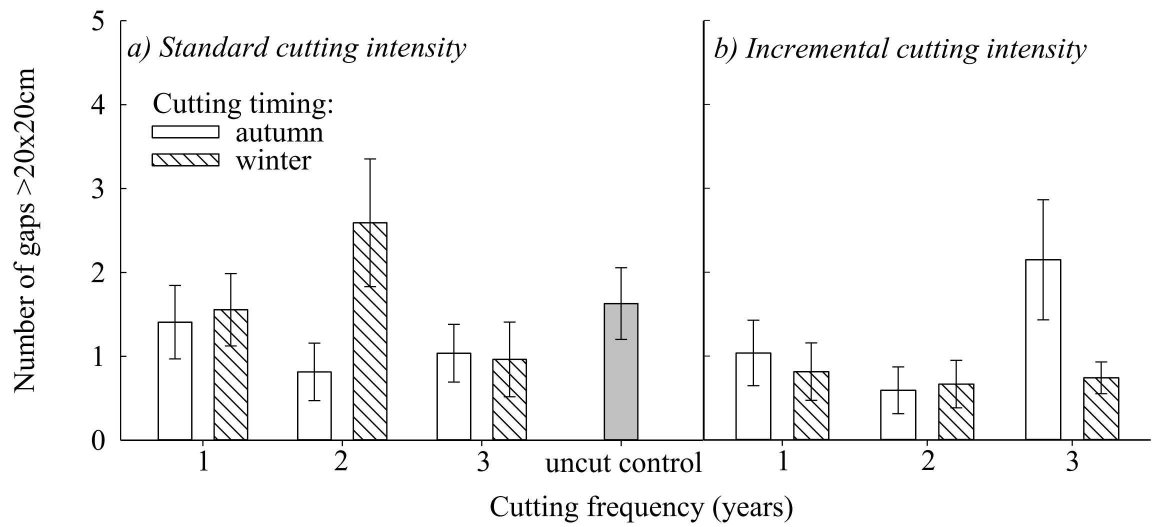

Figure 19: Number of gaps > 20 × 20 cm (mean ± SE) in the basal 90cm of plots in 2014, calculated from digital images spanning 5.2 m of hedge length.

3.1.8.2 Discussion of hedgerow structure

Results from digital image analysis showed that there was no effect of any cutting treatment on the overall amount of woody material in the hedge base, except at WM which is a considerably younger hedge, where on plots cut at a standard intensity a reduced frequency of cutting (once in three years) resulted in significantly more woody material in the hedge base compared with those cut every one or two years. In general, plots cut every two years to a standard intensity in winter had a relatively large maximum gap size at the hedge base as well as significantly more gaps through which stock might fit than those cut to a standard intensity in autumn. At WM, which contains younger, mixed species hedges, differences between timing were not significant, but cutting intensity was important.

As mentioned above, in 2014 the plots were at different stages of their cutting cycles, as the 1 and 2 year plots had just been cut and had no recent growth. If this structural assessment was repeated after six years of treatment application, when all plots have just been cut and have no recent growth, it might clarify if cutting frequency does affect the number and size of gaps. Nonetheless, these results do not generally support anecdotal evidence from farmers that cutting once every three years increases gappiness in the hedge base, as for none of the variables tested did the three yearly cutting cycle prove to be significantly more gappy, and at one site the amount of woody material was increased on plots cut once in three years.

3.2 Experiment 3: Rejuvenation of hedgerows

3.2.1 *Costs and speed of rejuvenation methods*

Costs (£)	Midland's 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. 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)	Midland's 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 6. The average time (mm:ss) taken to apply each rejuvenation treatment to a 1 m 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 Midland's hedge-laying was approximately twice that of conservation hedging, and three times the cost of wildlife hedging (Table 5). 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 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 6). The wildlife hedging was the fastest treatment to apply. By contrast, traditional Midland's style hedge-laying took an average of 33 minutes / metre to apply. Conservation hedging was intermediate between the three fast rejuvenation methods and the Midland's 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.

3.2.2 *Regrowth of hedgerows*

3.2.2.1 Canopy regrowth of hawthorn

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 Midland's hedge-laying (Figure 20). Regrowth was least on the control hedges that were not rejuvenated, together with the wildlife hedging and conservation hedging. Midland's 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 Midland's 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.

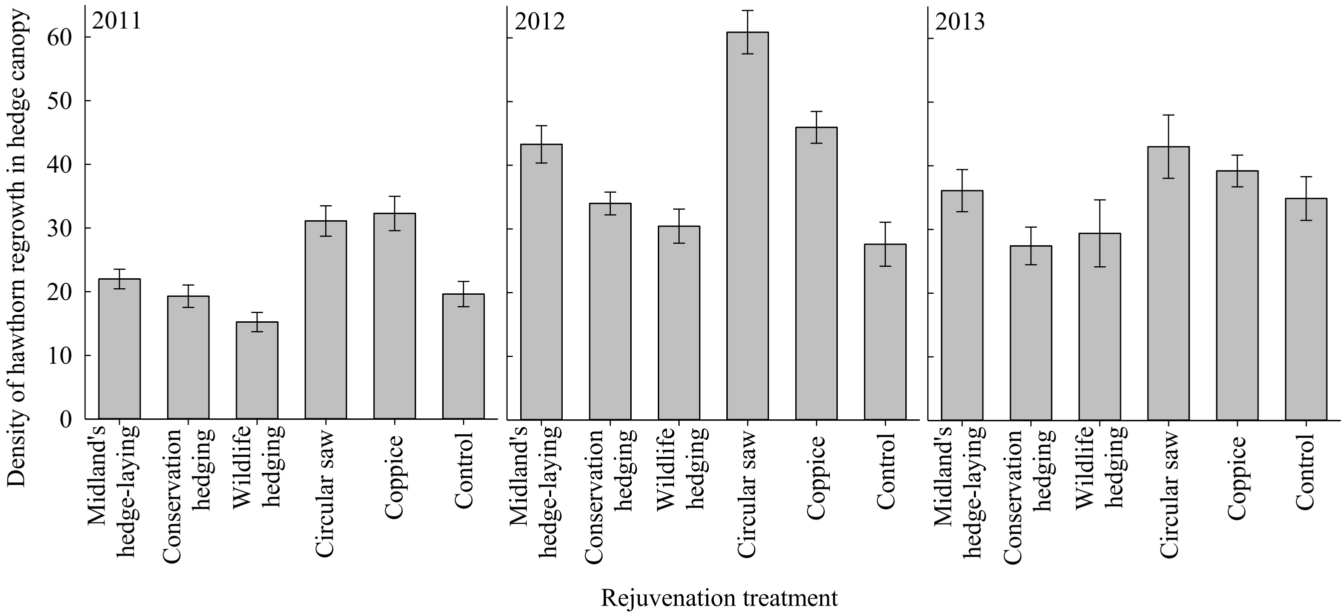

Figure 20. Amount of recent hawthorn growth (mean ± SE), measured as number of hits on horizontal and vertical range poles.

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 21). 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.

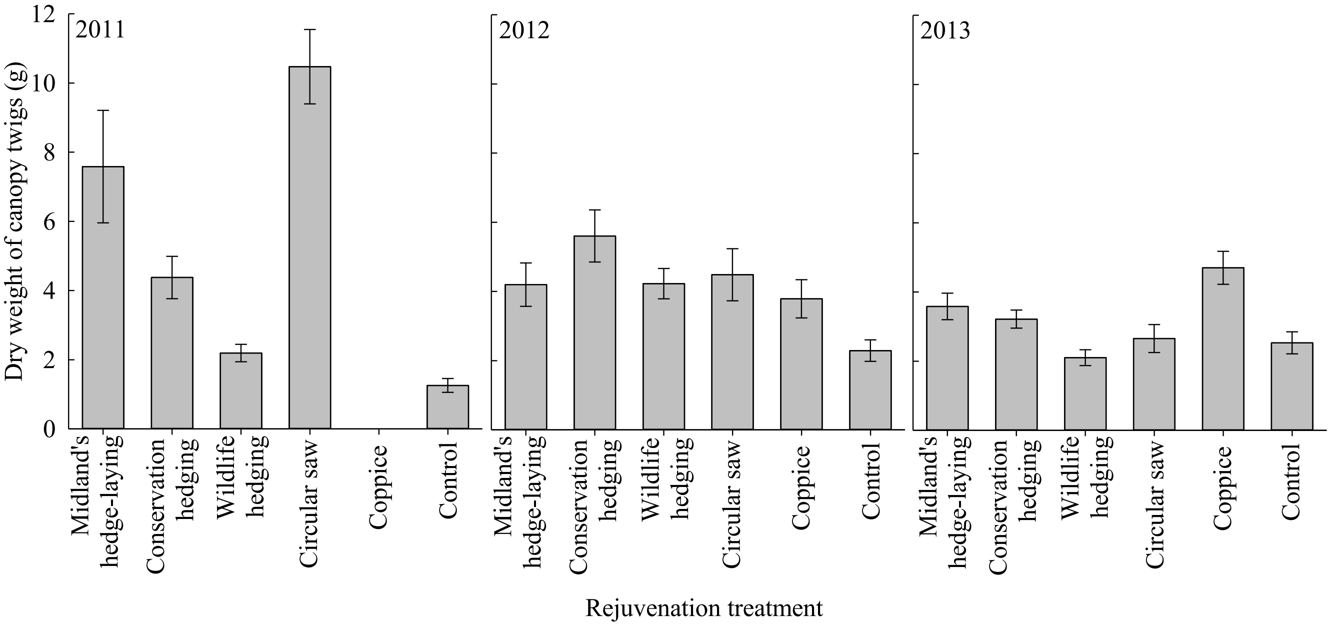

Figure 21. Dry weight of recent hawthorn growth each year, g (mean ± SE). Rejuvenation of hedgerows took place in November 2010.

3.2.2.2 Regrowth from hedgerow basal stools

3.2.2.2.1 Hawthorn

The number of hawthorn shoots was twice as great on coppice compared with the other three treatments that involved cutting basal stools (Midland's hedgelaying, conservation hedging, wildlife hedging) in all three years following rejuvenation ($t_{1,31} = 5.08$, $P < 0.001$; Figure 22a). In addition, there was an interaction between year and rejuvenation method (LRT: $\chi^2_6 = 19.86$, $P < 0.01$); in 2011 there were also more hawthorn shoots per stool on the Midlands hedgelaying 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 Midland's 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 22b). In 2011, shoots were also taller on hawthorn that had been rejuvenated with conservation hedging compared with coppice or Midland's 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 affect on diameter of shoots at mid-height (half way between the base and tip of each shoot).

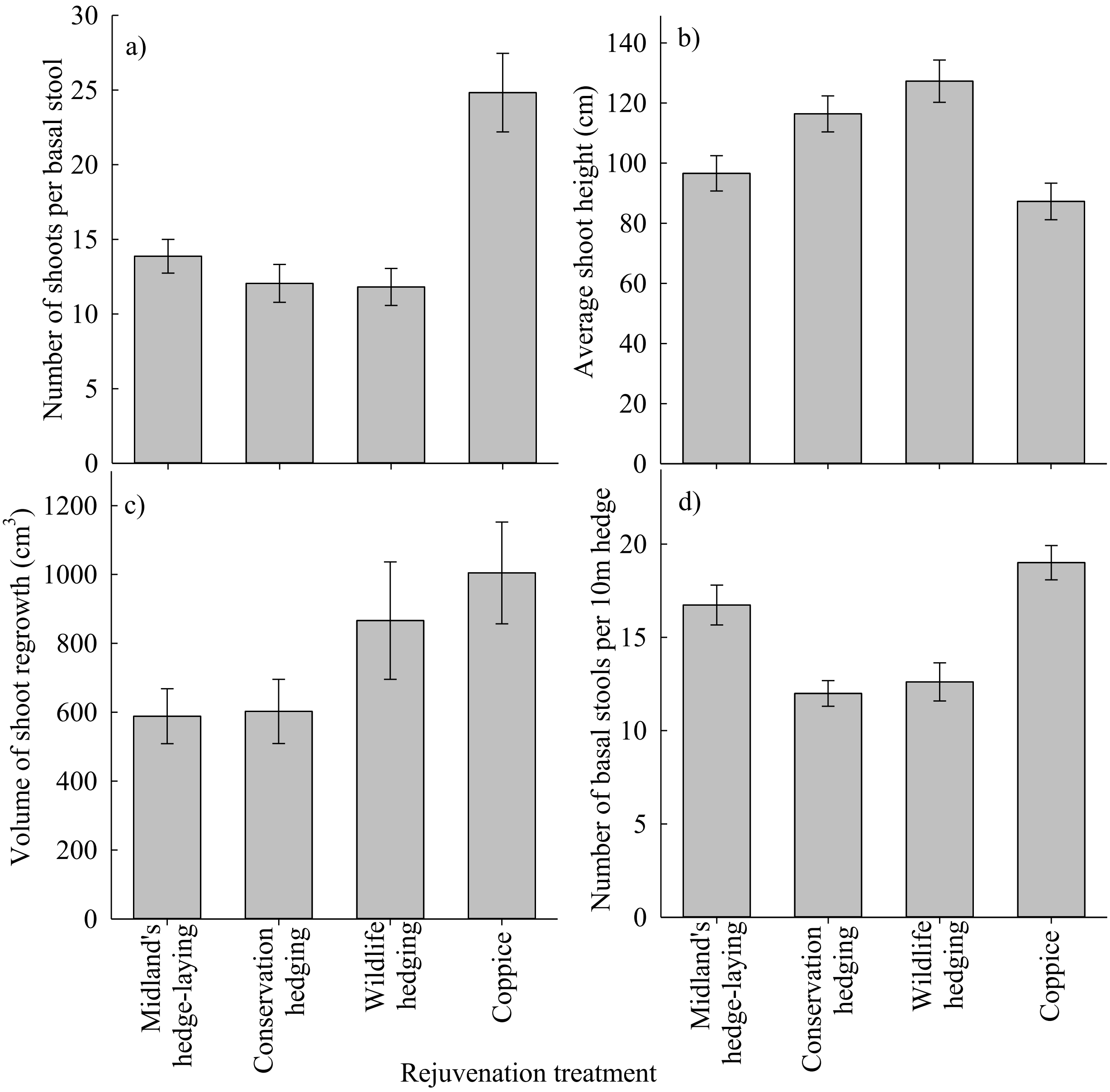

Figure 22. Recent hawthorn growth from basal stools cut during rejuvenation (mean ± SE), average over three years (2011-2013). a) Number of shoots growing per basal stool, b) height of shoots, c) average volume of regrowth per basal stool in cm^3 (number of shoots x shoot height x Pi(shoot diameter/2)^2, d) number of basal stools that produced new shoots.

The average volume of regrowth per cut stool was calculated from shoot height, diameter and the number of shoots (Figure 22c). There was a greater volume of regrowth from the coppice stools than the Midland's 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 difference 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 Midland's hedge-laying and coppice ($F_{3,33} = 5.88$, $P < 0.01$, Figure 22d).

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 x management treatment x year interaction: LRT: $\chi^2_6 = 14.52$, $P < 0.05$). The number of shoots per stool, number of stools per 10m and volume of shoot regrowth per basal stool were not affected by management treatment.

3.2.2.2.2 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 10m of hedge. There were more shoots per basal stool on the coppice compared with Midland hedge-laying ($t_{1,6} = 2.68$, $P < 0.05$), as found for hawthorn.

3.2.2.3 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 Midland's 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 Midland's 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 Midland's hedge-laying. The three layed methods (Midland's 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 Midland's 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.

3.2.3 *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%.

3.2.3 *Structure of hedgerows*

3.2.3.1 Basal gappiness

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 90cm 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 90cm 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 Midland's hedge-laying) had a larger proportion of woody material : gap than the circular saw, whilst the wildlife hedging and Midland's hedge-laying also had a larger proportion than the control (TPT, $P < 0.05$; Figure 23).

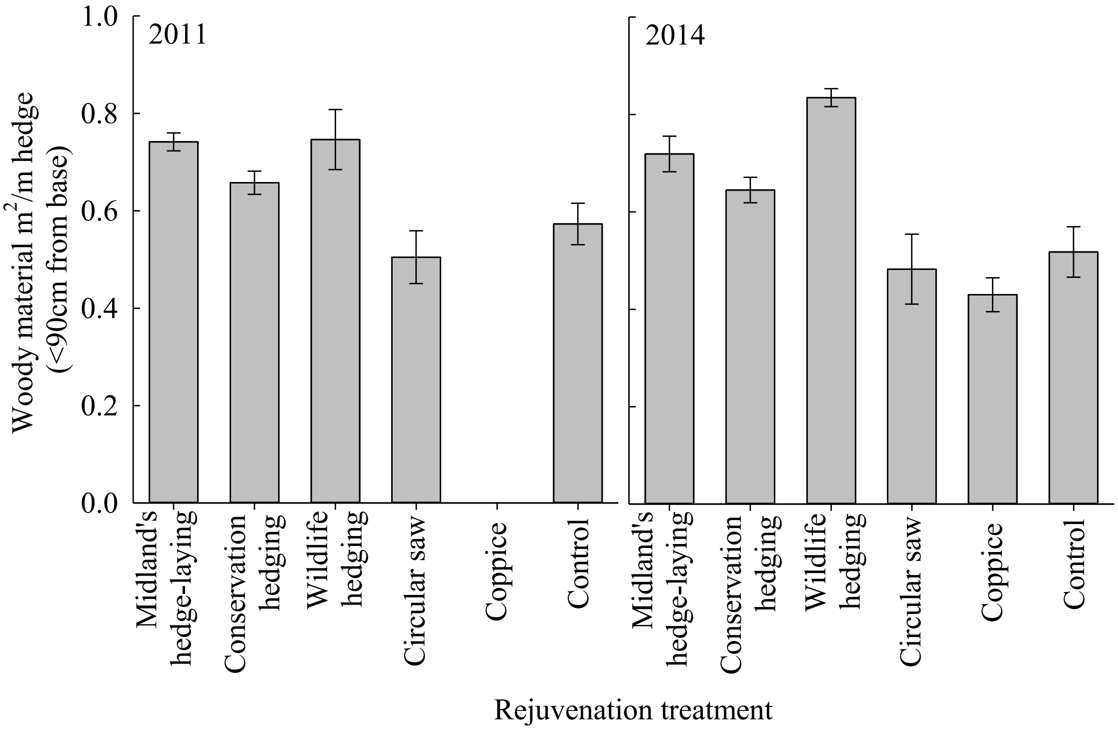

Figure 23. Woody material (m^2/m; mean ± SE) in the basal 90 cm of plots calculated from digital images taken in winter in early 2011 and 2014, for main rejuvenation treatments (all sites).

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, Midland's hedge-laying and wildlife hedging respectively. The largest gaps found in circular saw and control plots averaged over 1000 cm^2, with this figure less than 250 cm^2 for the three layed treatments (Figure 24).

The effects of rejuvenation method in 2014 show a similar pattern to 2011 (Figures 23-24) 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 Midland's 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 2250 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.

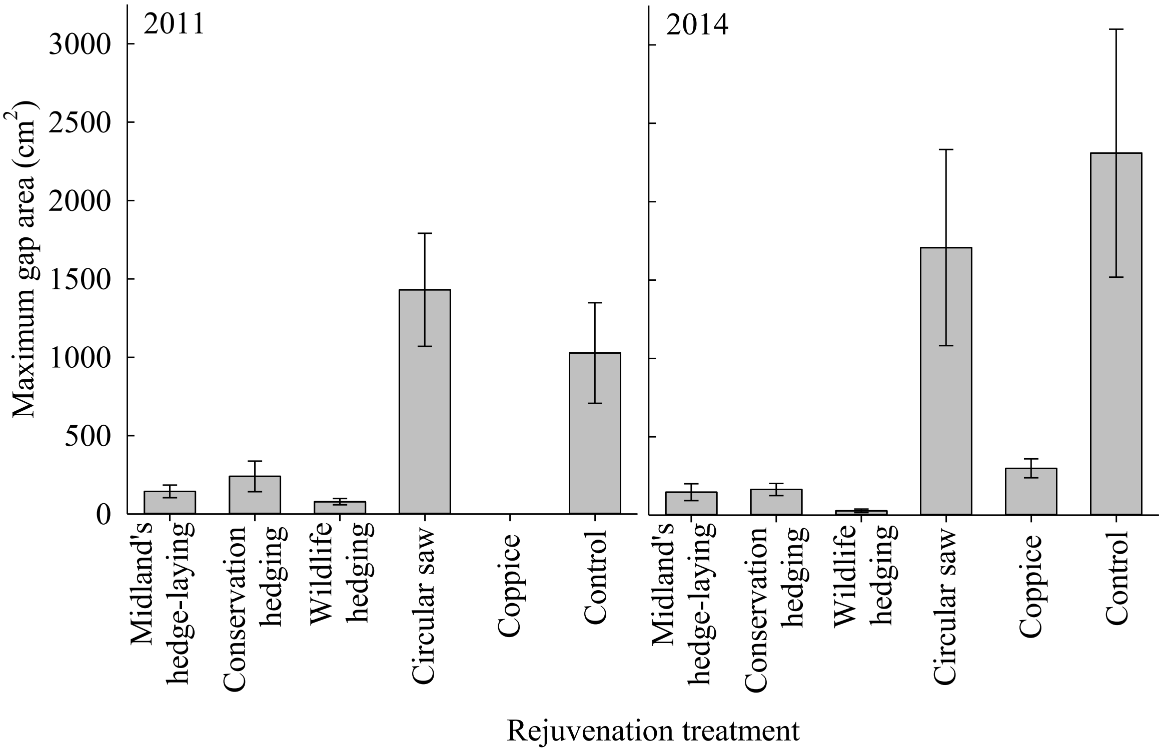

Figure 24. Maximum gap area (cm^2; mean ± SE) in the basal 90 cm of plots calculated from digital images taken in winter in early 2011 and 2014, for main rejuvenation treatments (all sites).

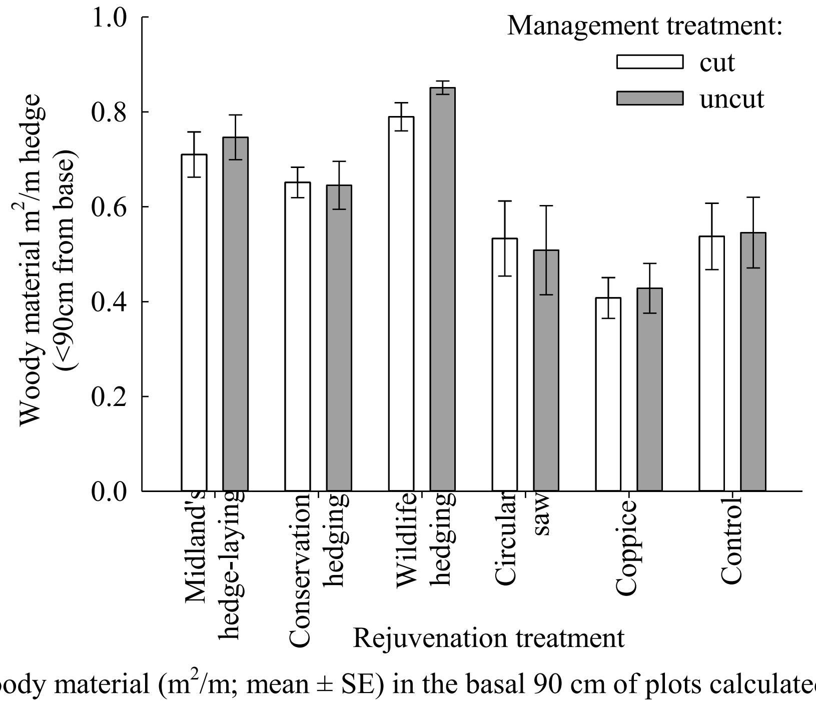

Figure 25. Woody material (m^2/m; mean ± SE) in the basal 90 cm of plots calculated from digital images taken in the winter of 2014 for all sites, with ongoing management represented by the colour of the bars.

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 25). The three different ongoing management treatments applied to the Midland's hedgelaying plots (cut, uncut or annual cutting) also did not have a significant effect on any of the variables relating to hedge basal gappiness.

3.2.3.2 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 hedgelaying 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 Midland's hedgelaying 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 Midland's 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 Midland's 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 Midland's laying treatments (Figure 20), 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 Midland's 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.

3.2.4 *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 26), 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 Midland's 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 Midland's 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.

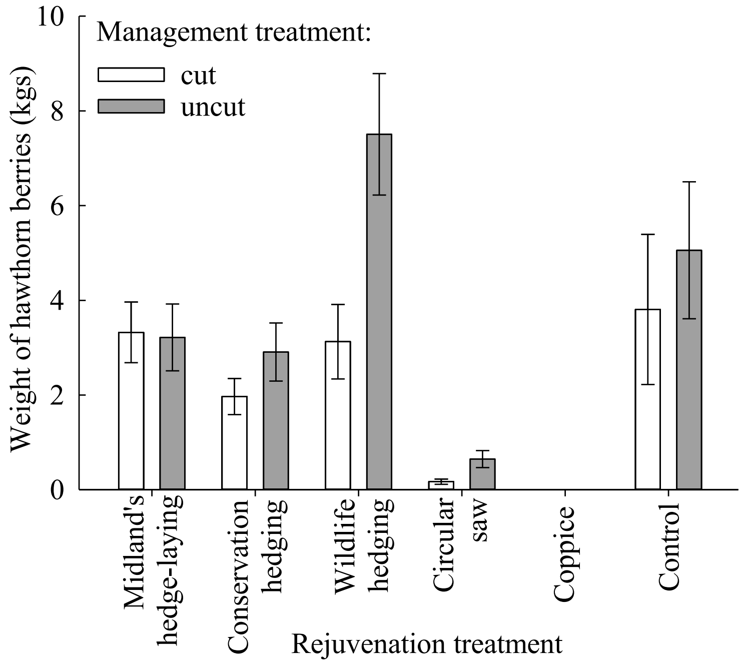

Figure 26. Cumulative fresh weight of hawthorn berries (mean ± SE) on 1 m of hedge length available over winter, under rejuvenation and subsequent management treatments.

The effect of subsequent management treatment on hawthorn berry availability depended on the rejuvenation treatment (LRT: χ^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 Midland's 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 over-wintering wildlife was therefore fairly short-term under the majority of rejuvenation methods.

3.3 **Summary of main results for Experiments 2 and 3**

Experiment 2 - Frequency, timing and intensity of cutting	
Flower production	
Hawthorn	2.1 times more flowers on 3 year than 1 year plots, no significant difference between 2 and 1 years. 1.4 times more flowers on incremental than standard plots. *Trend towards cutting frequency affecting standard but not incremental plots.
Blackthorn	2.4 times more flowers on 3 year than 1 year plots, no significant difference between 2 and 1 years. *Trend towards more flowers on incremental than standard plots.
Bramble	*Trend towards more flowers on 3 year than 1 year plots. *Trend toward more flowers on incremental plots cut in winter than autumn; standard plots unaffected by timing of cutting.
Berry weight	
Hawthorn	Heavier weight of hawthorn berries available on 3 year plots than 1 year (3sites), though at two sites this increase is limited to 3 year plots that are cut in winter. 1.5 - 1.7 times heavier berry weight on incremental than standard plots (depending on site). 2 times heavier berry weight on plots cut in winter than autumn (1 site).
Blackthorn	Heavier berry weight on plots cut in every 2 or 3 years in winter compared with 1 year plots. 2.1 times heavier blackthorn berry weight on incremental than standard plots.
Bramble	2.7 times more blackberries on incremental than standard plots. 1.6 times more blackberries on 3 year plots compared to 1 year plots. *Trend towards more blackberries on 2 year plots compared to 1 year plots.
Dogrose	3.1 times heavier weight of dogrose berries on winter plots compared with autumn plots. Timing of cutting affected dogrose berry weight on 2 and 3 year plots, but not on 1 year plots.
Pollinator visits to flowers	
	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 3 years compared with 1 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 2 or 3 years compared with 1 year. Number of pollinator taxa and assemblage visiting bramble unaffected by cutting treatments.

Table 7a: Summary of main results from Experiment 2, continued below. All results are significant at $P < 0.05$ unless listed as *trend ($0.05 < P < 0.1$). More detailed results are in the results section above.

Experiment 2 continued - Frequency, timing and intensity of cutting	
Invertebrates	
Lepidoptera abundance	*Very strong trend towards 1.24 times more Lepidoptera on 3 year than 1 year plots if cut to a standard intensity. No effect of cutting frequency on incremental plots.
Lepidoptera diversity	1.2 times greater diversity on incremental plots compared with standard plots. *Trend towards greater Lepidoptera species richness on incremental than standard plots.
Brown hairstreak eggs	3 times more eggs on plots cut for incremental growth compared with a standard intensity. 1.4 times more eggs on 3 year than 1 year plots, if cut in autumn. No effect of cutting frequency on eggs found on plots cut in winter. *Trend towards more eggs on plots cut every 2 years compared with 1 year in 2013 only.
Invertebrate abundance	No effect of hedge frequency, timing or intensity treatments on total abundance.
Structure of basal 90cm of hedge	
Woody material	No effects of cutting frequency, timing or intensity across all sites. WM site: standard intensity plots had more woody material if cut once in 3 years than 1 year
Maximum gap size	On plots cut every 2 years, 2.6 times greater gap size if cut in winter rather than autumn. No effect of cutting timing on plots cut every 1 or 3 years. WM: plots cut every 2 years, greater gap size if standard intensity rather than incremental.
Number of gaps > 20 x 20cm diameter	More gaps > 20 x 20cm on 2 year plots cut in winter compared with 1 year plots. On incremental plots, more gaps > 20 x 20cm if cut in autumn.

Table 7b: Summary of main results from Experiment 2 (multi-site experiment manipulating the frequency, timing and cutting of hedgerows), continued from above. All results are significant at $P < 0.05$ unless listed as *trend ($0.05 < P < 0.1$). More detailed results (e.g. variation between years in responses to cutting treatments) are not in this table, and are described in the results section text.

Experiment 3 - Rejuvenation of hedgerows and subsequant 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 subsequantly 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 subsequantly had heavier berry weight than those trimmed, except for MH and C.
All woody species**	Lighter berry weight on CO than C.

Table 8: Summary of main results from Experiment 3. MH = Midland's 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.

4. CONCLUSIONS

4.1 Hedgerow management in relation to the frequency, timing and intensity of trimming and current ELS hedgerow 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 ELS EB3, as opposed to annual hedge trimming. Cutting once in three years resulted in greater numbers of hawthorn and blackthorn flowers (and a trend towards increased bramble 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 over-wintering 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 brown hairstreak butterfly egg abundance (a UK BAP priority species) on plots cut in autumn, and there was a very strong trend towards increased overall Lepidoptera abundance. There was no significant evidence to support the assertion that cutting once in three years results in a more gappy hedge, as sometimes stated by landowners and contractors in opposition to a three year cutting cycle.

In contrast, the results from this project currently provide less support for a cutting regime of once every two years in winter, the other possibility open to landowners currently managing hedgerows in ELS EB3. The abundance of flowers was not significantly increased on hedges cut once in two years, the increase in berry weight was limited to blackthorn, and there was no consistent benefit for Lepidoptera abundance and diversity. This contrasts with 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), and 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, MG and WO, 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. Further monitoring should help determine if there is a benefit of cutting once every two years in the winter. Nonetheless, 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 increased flower and berry provision, as well as enhancing Lepidopera diversity and brown hairstreak butterfly egg abundance. This suggests that cutting for incremental growth should be considered 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 mid-1990s (see section 2.2.1 for further 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 sites and for both hawthorn and blackthorn (sections 3.1.3.1 and 3.1.3.2). Minor exceptions to this include the response of hawthorn berry provision to timing of cutting which differed slightly between some sites; mature hedges were more severely affected by high frequency cutting (once every one or two years), as the winter cutting did not mitigate the effects of frequent cutting on berry provision as it does on younger hedges (section 3.1.4.1). Despite this minor difference berry provision responded broadly in the same way to cutting regimes, as incremental trimming and cutting once in three years increased provision across all sites for both hawthorn and blackthorn (sections 3.1.4.1 and 3.1.4.2). Over two thirds 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.

4.2 Hedgerow rejuvenation and subsequent management

Differences between the three layed methods (Midland's 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 Midland's 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 Midland's 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 Midland's hedge-laying.

These results suggest conservation hedging can have similar medium-term benefits as more traditional hedge-laying styles, and could provide a cost-effective rejuvenation alternative under AES such as HLS.

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.

4.3 Ongoing and future research priorities

4.3.1 *Ongoing assessments on Experiment 2*

The multi-site experiment, on which the frequency, timing and intensity of hedgerow cutting is manipulated (Experiment 2), is continuing to early 2017 to provide evidence to address the following:

1) The current project has demonstrated some benefits to wildlife of a reduced frequency hedgerow cutting cycle, cutting in the winter, and reduced cutting intensity assessed over a three year management cycle. For example, hedges cut on a three year cycle produce more hawthorn and blackthorn flowers than those cut annually, and those cut to allow the hedge to grow up incrementally produce more hawthorn flowers than those cut back to a fixed height and width (sections sections 3.1.3.1 and 3.1.3.2). This increase in the number of flowers results in greater visitation rates by insect pollinators (section 3.1.6). In other cases, results to date have demonstrated a strong trend towards the hedgerow cutting treatments affecting key parameters of flower and berry availability, but the results are not quite statistically significant. For example, hedges cut for incremental growth showed a trend towards greater numbers of blackthorn flowers compared to a standard cutting intensity, and there was a trend towards cutting frequency, timing and intensity affecting the number of bramble flowers produced (sections 3.1.3.2). This is likely to be due to variable distributions of hedge species across the field sites and inter-annual variation in blossom and berry production (discussed in section 3.1.3.4 above). Ongoing monitoring of flower and berry provision for a further three years will provide data that are highly likely to clarify if these trends are statistically significant, providing stronger evidence for hedgerow management policy revision in relation to AES. Most ELS agreements run for five years, so this continued assessment of flower and berry provision will test the benefits of these hedgerow management options on a time-scale comparable to a typical AES agreement.

2) Land-owners and hedgerow contractors anecdotally suggest that a reduced hedge cutting frequency results in larger and more numerous gaps in hedges, and this is sometimes used as an argument against uptake of reduced frequency cutting for hedges in ELS as discussed above (section 3.1.8.2). Results from the current project show that the base of hedges cut every three years do not contain more gaps / less woody material than those cut every year, and on some younger hedges may contain more woody material. However, the structure of woody hedge species is likely to respond to cutting treatments over a far longer timescale than the current project, so structure will be assessed again after 6 years of hedge cutting treatments.

3) Anecdotal evidence suggests a cutting frequency of once every three years could be unpopular, as during the current project a few contractors have raised concerns over the feasibility of cutting hedgerows with large amounts of woody growth. The reduced intensity cutting treatment could result in slower growth rates for woody species, compared to cutting hedges back to a standard height and width, but this has not been assessed. Measurements

will be made of rates of lateral and vertical woody regrowth on hedgerows after six years of cutting frequency, timing and intensity treatments.

4.3.2 *Future research priorities*

The herbaceous flora that grows underneath woody hedgerow shrubs has deteriorated in the UK over the last 20 years, in terms of a reduction in species richness, an increase in the ratio of grasses to forbs and dominance by species associated with fertile soils and low light levels (Critchley *et al.* 2013). The current project does not include assessments of hedgerow basal flora, but the frequency and intensity at which a hedge is cut has the potential to affect these communities through effects on shading. Assessments of the effects of cutting frequency and intensity on communities of basal flora are a future research priority.

5. PROJECT OUTPUTS

5.1 Publications

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

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.

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

Facey SL, Botham MS, Heard MS, Pywell RF & Staley JT (2014). Lepidoptera communities and agri-environment schemes; examining the effects of hedgerow cutting regime on Lepidoptera diversity, abundance and parasitism. *Insect Conservation and Diversity*, published online May 2014. DOI: 10.1111/icad.12077

Amy, S, Heard MS, Hartley SE & Staley JT (in prep.) Hedgerow rejuvenation management affects invertebrate communities through changes to habitat structure

5.2 Presentations to conferences

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.

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.

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.

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.

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.

5.3 Knowledge transfer

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, one example of the hedgerow management experiment (2) and one of the rejuvenation experiment (3).
There were 19 participants, including representatives from Natural England, FWAG, RSPB, GWCT, Devon Hedge Group, Aylesbury Vale district council and local conservation bodies.

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.

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.

5.4 Media coverage

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

“Three year cutting regime is optimum for hawthorn hedgerows” by David Boderke. Farmer’s Guardian article, December 2011

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

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