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Re-structuring hedges: rejuvenation management can improve the long term quality of hedgerow habitats for wildlife in the UK

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Highlights

- Hedgerows benefit wildlife if in good condition with a dense structure.
- Traditional hedge laying rejuvenation is quite expensive and not commonly used.
- A multi-site field experiment tested five rejuvenation methods over three years.
- Cheaper, modern alternatives improved hedge structure and berry provision.
- Conservation hedging could double the length of hedgerow that is rejuvenated.

Abstract

Hedgerows provide key wildlife habitat in intensive agricultural landscapes, but are declining in length and structural condition due to a lack of rejuvenation management, neglect and over-frequent trimming with mechanised flails. Here, we test cheaper, alternative methods to traditional hedge laying methods using a multi-site manipulative field experiment. In the first quantitative test of new approaches to hedge rejuvenation management, hedge regrowth, structure, berry provision for over-wintering wildlife and cost of rejuvenation were assessed in response to five methods, for three years following rejuvenation. Three 'laying' methods and coppicing were effective at improving hedgerow condition by stimulating basal regrowth, thus increasing the density of woody material at the base and reducing gap size. The pros and cons of coppicing are discussed in relation to its impact on different wildlife groups, and it is recommended in limited circumstances. Differences between the three 'laying' methods reduced over time, so a cheaper conservation hedging method is recommended as an alternative to traditional hedge laying. This new approach to hedge management offers the potential to restore twice the length of hedgerow currently rejuvenated under agri-environment schemes.

Keywords

agri-environment schemes; coppicing; Entry Level Stewardship; habitat structure; hedge-laying; hedgerow condition.

1 Introduction

Hedgerows play a significant conservation role within otherwise intensively managed landscapes through the provision of habitat, food and refuges for a wide range of plant and animal species (Wilson, 1979; Fuller et al., 1995; Dover and Sparks, 2000; Merckx and Berwaerts, 2010). In addition, hedgerows support ecosystem services such as pollination (Morandin and Kremen, 2013) and pest control (Morandin et al., 2014), and may act as a dispersal network in future adaptation to climate change (Lawton et al., 2010). Hedges are protected by legislation in several European countries (Baudry et al., 2000) and designated a priority habitat for conservation under the EU Biodiversity Strategy (JNCC, 2012). In several European countries, including England, agri-environment schemes (AES) provide incentives for sensitive management of hedgerows (Fuentes-Montemayor et al., 2011; Natural England, 2013a, b), while in the UK the 1997 Hedgerow Regulation limits the removal of hedges. Despite these measures 6.2% of hedgerow length was lost in the UK over the decade to 2007, mainly due to under-managed hedges turning into “relict hedgerows” or lines of trees (Carey et al., 2008). In addition, in 2007 only 48% of UK hedges were considered as being in ‘good condition’, which includes having few vertical gaps, a minimum height of 1 m and width of 1.5 m (Carey et al., 2008). The stock of hedges in north-west Europe is also deteriorating in quality as a habitat for wildlife due to the modern practice of managing hedges with mechanical flail cutters once every 1 – 3 years as the main form of management (Brooks, 1975; Reif et al., 2001). This has been driven by the high cost of traditional hedge management such as hedge laying, a shortage of labour on farms and the loss of traditional management skills.

The structural condition of a hedgerow has a strong effect on its value as a habitat for wildlife, with several groups showing a positive association with a dense woody hedge structure, consisting of many vegetation layers and few gaps. For example, hedges with a dense shrub layer are more likely to support shade-loving perennial plant species used by bees (Hannon and Sisk, 2009); those with many layers of vegetation are associated with a high diversity of invertebrates (Maudsley, 2000); the number of gaps in a hedge is negatively associated with abundance of bank voles (*Clethrionomys glareolus* Schreber; Gelling et al., 2007) and yellow-necked mice (*Apodemus flavicollis*; Kotzageorgis and Mason, 1997); and the vulnerability of bird nests to predation increases in structurally simple, more open hedges (Fuller et al., 1995). The size of a hedge can also affect its conservation value, as width has been shown to be the main determinant of the diversity and abundance of hedgerow understory plant communities (Roy and de Blois, 2008), the occurrence of ten farmland bird species is positively associated with the width of hedgerows (Hinsley and Bellamy, 2000; Whittingham et al., 2009) and the species richness of Carabid and Staphylinid beetles is greatest on hedges with a tall, wide continuous canopy (Griffiths et al., 2007).

Rejuvenation management, whereby new growth is stimulated at the base of a hedgerow, is necessary periodically to prevent hedgerows from losing their dense woody structure and becoming sparse and gappy (Croxton et al., 2004). Laying is a traditional form of hedge management found in several European countries (France, Germany, Ireland, Belgium and The Netherlands; Tenbergen, 2001; McAdam, 1994; Müller, 2013), and was particularly prevalent in the UK prior to the mechanisation of farm management (Croxton et al., 2004). Hedge laying involves manual cutting and removal of woody material from the hedge in an approximately 40 year cycle. Over the centuries, different parts of the UK, Germany and The Netherlands have developed their own distinctive styles of hedge laying, all based on the same basic theory (Müller, 2013). Within the UK, the most widespread is known as ‘Bullock’ or ‘Midland’ style hedge laying which developed in the traditional beef-rearing counties of lowland England to create robust, livestock-proof barriers (Brooks, 1975). Stems are partially severed at their base and layed over horizontally between stakes to encourage new vertical growth near the base of the hedge while up to a third of the volume of the hedge is removed (Brooks, 1975). The original aim was to create a livestock-proof barrier, rejuvenate the hedge by encouraging new growth from the base and help to improve the overall structure and strength. Importantly, hedge laying reduced the vigour of the hedge and enabled it to be managed in intervening years by hand cutting (Brooks, 1975). In recent years, hedge laying has been encouraged to maintain traditional country skills and to create aesthetically pleasing screens to fields and gardens. It is also recognised that hedge laying creates structural heterogeneity and improves the shelter provided for wildlife, particularly nesting birds and invertebrate species (McAdam et al., 1996).

Another rejuvenation method traditionally used across Europe is coppicing (Reif et al., 2001; Deckers et al., 2004), whereby the stems are cut through close to ground level and most of the above-ground part of the hedge removed to encourage growth at the base of the hedgerow. In the mid 20th century approximately half of hedgerows were layed or coppiced in the UK (Croxton et al., 2004), while by 2007 just 2% of hedges surveyed as part of the UK Countryside Survey had been layed or coppiced in the previous 3 – 5 years (data accessed at http://www.countrysidesurvey.org.uk/), which over a 40 year rotation equates to 16-27% of hedges being rejuvenated. Similar reductions in traditional hedgerow rejuvenation methods have occurred elsewhere in Europe (Reif et al., 2001).

The type of rejuvenation management applied to a hedge can affect the rate of subsequent regrowth (Croxton et al., 2004), hedgerow structure and thus its habitat value for wildlife (Hinsley and Bellamy, 2000). The provision of berries for over-wintering birds and small mammals is the main motivation for some of the hedgerow management options in English AES (Sparks and Croxton, 2007) and can be affected by hedgerow rejuvenation. Hedge laying resulted in hedges containing a greater diversity of invertebrate orders compared with unmanaged controls two years after rejuvenation, while hedges that had been coppiced and replanted with hawthorn did not differ from controls (McAdam et al., 1994). The method of rejuvenation used can also have a long-term effect on hedgerow plant communities; the species richness of understorey plant species that indicate high conservation value of a hedge was reduced over 70 years in coppiced hedges, while those that were layed had a slight increase in species richness (Staley et al., 2013).

Hedgerow rejuvenation is incentivised within English AES to a limited extent. English AES have a two-tier structure. Land owners with a Higher Level Stewardship agreement (HLS) may receive capital grants for hedge-laying or coppicing and replanting, but entry into HLS is restricted to target farmland of high conservation value (Natural England, 2013b). The Entry Level Stewardship (ELS) AES is open to all English landowners and can include grants for hedgerow rejuvenation, but these are limited to a maximum of 200 m of hedgerow over 5 years per ELS agreement (Natural England, 2013a). Between 2005 and 2014, 1268 km of hedgerow were layed or coppiced under English AES (Emily Ledder, pers. comm.), just 0.32% of the total hedgerow length estimated in 2007 at 402,000 kms in England (Carey *et al.*, 2008). This is equivalent to 1.6% of English hedges being rejuvenated under AES over a 40 year rotation.

Due to the widespread, ongoing deterioration in the structure and condition of hedgerows, there is an urgent need to develop cost-effective methods of rejuvenation as an alternative to traditional hedge laying, which result in comparable rates of woody regrowth and dense basal structure. Here, we test the effects of three modern alternative methods of rejuvenation on structure and provision of berries for wildlife and compare them to traditional hedge-laying, coppicing and an unmanaged control, using a large-scale manipulative field experiment. The methods tested included two newly developed, faster alternative to hedge laying (conservation hedging and wildlife hedging), reshaping with a circular saw (further details below), and coppicing to ground level. We hypothesised that: 1) modern alternatives to traditional hedge laying are cheaper to apply to typical hedgerows in intensively managed landscapes; 2) these alternative methods would have a similar beneficial effect on hedge regrowth and structure; and 3) provision of berries by hedgerows for over-wintering wildlife would initially be most reduced by coppicing compared with other forms of rejuvenation, but that any reduction would be relatively short-term. While our results are directly relevant for AES in England, the widespread prevalence of hedgerow coppicing as a management option across Europe, the traditional use of hedge laying in several European countries and the increasing number of countries implementing AES or other forms of hedgerow management regulation (Baudry et al., 2000; Fuentes-Montemayor et al., 2011) mean that our conclusions also have broader geographical significance.

2 Methods

2.1 *Field sites and experimental design*

Five field sites were used across southern UK. Four of these contained mature hedgerows dominated by hawthorn (*Crataegus monogyna* Jacq.): Monks Wood, Cambridgeshire (52°24'N 0°14'W), Newbottle Estate, Northamptonshire (52°01'N 1°12'W); Utcoate Grange, Buckinghamshire (51°58'N 0°37'W); Wimpole Hall, Cambridgeshire (52°08'N 0°01'W) The fifth site contained younger mixed species hedges at Crowmarsh Battle, Oxfordshire (51°36'N 1°05W), where hawthorn (*Crataegus monogyna*) was also the dominant species with small amounts of blackthorn (*Prunus spinosa*), field maple (*Acer campestre*), spindle (*Euonymus europaeus*), buckthorn (*Rhamnus cathartica*) and wayfaring tree (*Viburnum lantana*). Apart from hawthorn (*Crataegus monogyna*) no other woody species was replicated across all the experimental plots at any site, so our assessments focussed on hawthorn (*Crataegus monogyna*), which is the dominant hedgerow species across England (French and Cummins, 2001).

Hedgerow rejuvenation treatments were applied at five sites to 24 m long contiguous hedgerow plots in a randomised block experiment in November 2010:

1) Traditional hedge laying involves cutting and removal of about half of the hedge woody volume. Main stems were partially severed at the base, leaving a small section of living cambium intact, layed over at approximately 35°, and woven into a dense woody linear feature. Remaining branches were then layed 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 (Brooks, 1975; Fig 1a).
2) Conservation hedging, a quicker alternative to traditional hedge laying. Stems were cut at the base as above and layed over. Remaining stems and branches were layed 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 bucket. No brash (woody stems and branches) was removed, and some stems were entirely severed when the hedge was pushed over (Dodds, 2005).
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 close to ground level with a chain saw. Nearly the entire volume of the hedge was removed.
6) Control. No rejuvenation applied.

Each rejuvenation method was replicated two or three times at each of five sites (a total of 12 replicates). Contractors who specialised in each form of rejuvenation commercially were employed to apply the rejuvenation treatments, to ensure that they realistically resemble hedgerow rejuvenation in the wider countryside. Wildlife hedging and circular saw reshaping could not be applied at Crowmarsh Battle as the hedge was not mature enough. As hawthorn was the dominant species across all five sites it was the focus of assessments of hedgerow regrowth and berry provision following rejuvenation.

2.2 *Cost of rejuvenation*

At each site, the contractor employed 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 (branches and leaves) created by each rejuvenation method.

2.3 *Regrowth following rejuvenation*

Regrowth of hedgerow plots following rejuvenation treatments was assessed annually each winter to measure the extent of woody growth that had occurred the previous summer (2011 – 2013 inclusive). Doing the assessments in winter ensured that woody growth was not obscured by leaves. Two methods were used to assess i) regrowth from basal cut stools and ii) extension of existing shoots in the hedgerow canopy in response to rejuvenation.

2.3.1 *Regrowth from basal cut stools*

Basal regrowth was assessed on the four treatments that had resulted in cuts to the base of hedgerow stems (traditional hedge laying, conservation hedging, wildlife hedging, coppice). 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). The average volume of regrowth per cut stool was calculated from shoot height, diameter and the number of shoots. The number of stools with new shoots present were counted in each 24 m plot.

2.3.2 *Regrowth in the hedgerow canopy*

Growth from existing shoots in the hedgerow canopy was assessed on all rejuvenation treatments and control plots. The density of recent growth (extension of woody twigs in the previous growing season) was measured by the number of times it touched a graduated wooden pole (diameter 28mm, graduations 300mm). Six 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 for each plot, and dry biomass measured.

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.

2.5 *Hedgerow structure*

Woody hedgerow structure was quantified during winter when foliage was not present, using high resolution digital images immediately following application of the rejuvenation treatments in winter 2010/11, and three years later in winter 2014. A white sheet was placed behind the hedge to maximise contrast between the hedge and surrounding habitat or sky. Images were converted to a standard resolution (0.25 cm/pixel) and classified using ERDAS IMAGINE 9.3 image processing software to differentiate between woody hedge material and gaps within the hedge. Area, perimeter and co-ordinate data for each gap were extracted using ENVI 5.1 software, and the ratio of woody material:gap calculated for each 30 cm horizontal section. Basal gappiness in the hedge base was assessed as individual gap area (cm^2), relating to the region from the base of the hedge to 90 cm high. Coppiced plots were not assessed in 2011 as they had no woody shoots until the following spring.

2.6 *Berry provision for overwintering wildlife*

The weight of available berries was assessed annually in September each year from 2010 – 2013, to assess the provision of berries for over-wintering wildlife (Sparks and Croxton, 2007; Staley et al., 2012). Five 0.5 m × 0.5 m quadrats were used to record berries on each side of each hedgerow plot, attached to range poles to allow them to rest against the vertical sides of the hedge. Each quadrat was placed centrally in relation to the height of the hedge and quadrats were approximately evenly placed along the length of each plot, excluding the 1 m at each end to avoid edge effects. The numbers of berries for all species were counted, and berries of hard-fruited species were collected. The height and width of the plots were measured to the nearest 10 cm using graduated poles, at five evenly spaced positions along each plot. These data were used to calculate the surface area of each plot, and to convert berry data to number or biomass produced per m hedgerow length. Berries were weighed to obtain fresh biomass, dried for 48 hours at 80 °C to constant weight and weighed again for dry biomass.

2.7 *Statistical analyses*

Where multiple samples of a response variable had been assessed per plot (regrowth parameters and berry provision), means per plot were calculated prior to analysis. Berry fresh weight data were converted to values per 1 m hedge length using the surface area values calculated above. Generalized Linear Mixed Models (GLMMs) were used to test how rejuvenation method affected annual regrowth and berry provision over time. Rejuvenation method, year of sampling, site and the interaction between rejuvenation method and year were included as fixed effects, and plot as a random effect in each model. The effects of rejuvenation method on hedgerow structural parameters were analysed separately for 2010 and 2014. ANOVAs were used to analyse gap size, and generalised linear models (GLMs) with a Poisson error structure were used to test the rejuvenation effects on the number of gaps. Interactions and factors that did not contribute significantly to GLM and GLMM models were removed one at a time, and changes in the explanatory power of the model were tested using likelihood ratio tests (LRT; Faraway, 2005). If significant treatment effects were found in an ANOVA, Tukey HSD posthoc tests (TPT) were conducted to determine which rejuvenation methods differed (Crawley, 2007). All analyses were carried out in R version

3.0.3 (R Core Development Team, 2014) using packages nlme (Pinheiro et al., 2014) and lmerTest (Kuznetsova et al., 2014).

3 Results

3.1 *Cost of rejuvenating hedgerows*

The cost of applying the traditional hedge laying was approximately twice that of conservation hedging, and three times the cost of wildlife hedging (Table 1). Reshaping with the circular saw was the cheapest rejuvenation method, while the price 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 the regrowth; this additional cost more than doubled the price of coppicing (Table 1).

3.2 *Hedgerow regrowth following rejuvenation*

3.2.1 *Regrowth from basal cut stools*

The number of hawthorn shoots per stool was twice as great on coppice compared with the other three treatments that involved cutting basal stools in all three years following rejuvenation ($t_{1,31} = 5.08$, $P < 0.001$; Figure 2a). 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 traditional hedge laying plots compared with conservation and wildlife hedging ($t_{1,31} = 3.51$, $P < 0.01$ and $t_{1,31} = 2.88$, $P < 0.001$ respectively), but not in 2012 or 2013.

Shoots growing from cut basal stools were 1.4 times taller on hawthorn growing in wildlife hedging plots compared with traditional hedge laying plots in all three years ($t_{1,33}$ = 2.68, P < 0.05; Figure 2b), apart from at one site (Wimpole Hall) in 2013 where height did not differ. In 2011 only, shoots were also taller on hawthorn rejuvenated with conservation hedging compared with coppice or traditional hedge laying (TPT, P < 0.05; Figure 2b). Shoot diameter was larger on basal regrowth growing in wildlife hedging plots compared with traditional hedge laying just in 2012 ($t_{1,72}$ = 2.45, P < 0.05), but there were no other effects of rejuvenation method on shoot diameter.

There was a greater volume of regrowth from the coppice stools than the traditional hedge laying and conservation hedging stools in 2012 and 2013 ($F_{3,33}$ = 4.47, P < 0.05 and $F_{3,33}$ = 3.38, P < 0.05 respectively). The volume of regrowth from the wildlife hedging was intermediate, and not significantly different (Figure 2c). The number of hawthorn (*Crataegus monogyna*) basal new stools with shoots was around 1.4 times lower on conservation and wildlife hedging plots than the traditional hedge-laying and coppice ($F_{3,33}$ = 5.88, P < 0.01, Figure 2d).

3.2.2 *Regrowth in the hedgerow canopy*

The method of rejuvenation strongly affected the amount of recent growth in the hedge canopy, the effects of which differed with year (LRT: χ^2_{10} = 31.39, P < 0.01). Regrowth was greatest on hedges cut with a circular saw, followed by coppiced hedges and those rejuvenated with traditional hedge-laying (Figure 3), and least on the control hedges which did not differ from the wildlife hedging plots. In 2011 and 2012, the coppice and circular saw plots had more regrowth than the control plots (2011 coppice: $t_{1,230}$ = 4.75, P < 0.001; circular saw: $t_{1,230}$ = 4.68, P < 0.001; 2012 coppice: $t_{1,230}$ = 2.27, P < 0.05; circular saw: $t_{1,230}$ = 2.09, P < 0.05). In

2012 only, the traditional 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, but traditional hedge laying still resulted in more regrowth than the wildlife hedging ($t_{1,230}$ = 2.37, $P < 0.05$)

The weight of hawthorn (*Crataegus monogyna*) regrowth twigs in the hedgerow canopy was strongly affected by rejuvenation treatment, the effects of which varied over time (LRT: χ^2_9 = 83.48, $P < 0.001$). In 2011 and 2012, weight of recent canopy regrowth was heavier under all rejuvenation methods compared with the control (circular saw $t_{1,140}$ = 10.8, $P < 0.001$; traditional hedge laying $t_{1,140}$ = 8.4, $P < 0.001$; conservation hedging $t_{1,140}$ = 6.3, $P < 0.001$; wildlife hedging $t_{1,100}$ = 3.3, $P < 0.01$), and was heaviest on plots rejuvenated by circular saw or traditional hedge laying (Figure 4). Recent regrowth was heavier from plots rejuvenated with traditional hedge laying compared to wildlife hedging and conservation hedging in 2011 ($t_{1,140}$ = 5.4, $P < 0.001$ and $t_{1,140}$ = 2.1, $P < 0.05$ respectively), but did not differ significantly between the three hedge laying techniques in 2012. In 2012, recent regrowth was also heavier on coppiced plots compared to the control ($t_{1,140}$ = 3.3, $P < 0.01$). By 2013, regrowth weight did not differ consistently between the rejuvenated and control plots.

3.2.3 *Dead foliage cover following rejuvenation*

Less than 1% of the control and circular saw plots consisted of dead hawthorn (*Crataegus monogyna*) 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%.

3.3 *Basal hedgerow structure*

In 2011 (the winter immediately following rejuvenation), the amount of woody material in the basal 90 cm of hedge was strongly affected by rejuvenation method ($F_{4,42}$ = 11.11, P <0.001). All three layed treatments (wildlife hedging, conservation and traditional hedge laying) had a larger area of woody material than the circular saw, whilst the wildlife hedging and traditional hedge laying also had a larger area than the control (TPT, P <0.05; Figure 5a). There was also an effect of rejuvenation method on the maximum size of gaps at the base of the hedge ($F_{4,42}$ = 23.45, $P < 0.001$). In 2011, the largest gaps of the control were 4, 7 and 13 times larger than those of the conservation laying, traditional hedge laying and wildlife hedging respectively (TPT P <0.01), and the circular saw did not differ from the controls. 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 5c).

The effects of rejuvenation method in 2014 show a similar pattern to 2011 (Figure 5) for both the area 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 total amount of woody material 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 traditional hedge laying (TPT tests $P < 0.05$; Figure 5b). The largest gaps were larger in both the control and circular saw compared with all other rejuvenation methods, and for the wildlife hedging were smaller than all other methods (TPT $P < 0.05$). The control had the largest maximum gap size which averaged over

2250 cm^2, and the wildlife hedging the smallest maximum gap size at less than 30 cm^2 (Figure 5d). 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 ($F_{15,36} = 3.25$, $P < 0.01$) in 2014, but the main effects described above explain the majority of the variation in these measures.

3.4 *Provision of berries for overwintering wildlife*

Hedgerow rejuvenation method had a strong effect on the weight of hawthorn (*Crataegus monogyna*) berries available over winter (Figure 6), which 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 ($t_{1,51} = 4.5$, $P < 0.001$), circular saw ($t_{1,51} = 4.4$, $P < 0.001$) and traditional hedge laying ($t_{1,51} = 2.49$, $P < 0.05$) compared with the control plots, 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 traditional 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.

4 Discussion

This study is the first quantitative test of new approaches to hedge rejuvenation management. The use of a large-scale manipulative field experiment over three years provides robust evidence for the relative cost of five rejuvenation methods and their effects on the value of hedgerows for wildlife, in terms of hedge structure, regrowth and berry provision. This evidence for the benefits of new, cost-effective methods of hedgerow rejuvenation is urgently needed to halt the decline in hedgerow condition.

Basal hedge structure differed between the three layed methods (traditional hedge laying, conservation hedging and wildlife hedging) three years after the rejuvenation was applied, as the wildlife hedging plots had a greater woody area and smaller maximum gaps than the other two. However, all three layed methods and coppicing achieved the aim of creating a far denser basal structure than mature hedges that were not rejuvenated, with all the benefits this brings for a range of wildlife associated with hedgerows as outlined above (Fuller et al., 1995; Kotzageorgis and Mason, 1997; Maudsley, 2000; Gelling et al., 2007), as well as making hedges more stock-proof.

Differences in regrowth between the three layed methods were greatest in the two years immediately following rejuvenation. The conservation hedging plots had slightly lower rates of canopy regrowth in 2012, and fewer, taller shoots growing from basal cut stools in 2011 compared with traditional hedge-laying, but by 2013 there were no differences in regrowth between these two rejuvenation methods. Wildlife hedging resulted in less vigorous canopy regrowth in the second growth season after rejuvenation (this difference was no longer apparent by the third season), taller basal shoots which may be a result of greater shading, and fewer basal stools with shoots. The latter may be due to stems being completely severed during rejuvenation, as also indicated by the far greater proportion of dead leaves on the wildlife hedging plots. This increase in dead wood following wildlife hedging may pose problems for future rejuvenation, and thus deter some land-owners from using this method. Dodds (2005) states that wildlife hedging has more vigorous regrowth and greater berry provision than traditional hedge laying (without providing any data), but our results show less canopy regrowth for a short period, fewer (though taller) basal shoots, and that the differences in berry provision are relatively short-lived.

Coppicing resulted in the most vigorous basal regrowth following rejuvenation, and this continued to differ from the other methods three years after rejuvenation. Coppicing also initially had the second most vigorous canopy regrowth, after reshaping with a circular saw, but by 2013 neither of these methods differed in terms of canopy regrowth from hedges that were not rejuvenated. Some invertebrate groups may benefit from coppicing, for example (Sparks et al., 1996) found a greater abundance of butterflies four years after hedges were coppiced or layed compared with unmanaged control plots, though overall invertebrate diversity has also been shown to benefit from hedge-laying but not coppicing (McAdam et al., 1994). Coppiced hedges have little basal woody material for several years following rejuvenation, and so provide less shelter for mammals and invertebrates than layed hedges immediately following rejuvenation. Recent coppicing has been shown to be potentially detrimental to bat species associated with a well developed canopy understorey (Murphy et al., 2012), and both yellow necked mice (*Apodemus flavicollis*; Kotzageorgis and Mason, 1997) and (dormice *Glis glis* Linnaeus; Capizzi et al., 2003) were absent from coppiced hedges and woodlands respectively. However, small amounts of coppicing on a long rotation to create a mosaic of hedgerow habitat may benefit some small mammals such as dormice (*Glis glis*; Bright et al., 2006). The response of hedgerows to coppicing may also depend on their age, as there is a greater chance that older woody hedgerow plants will die in response to coppicing (McAdam et al., 1994).

Berry provision was not reduced by wildlife hedging or conservation hedging relative to hedges that were not rejuvenated. Traditional hedge laying and reshaping with a circular saw did reduce berry provision for three years, but by 2013 there was no difference. Differences between the three layed methods in berry provision for over-wintering wildlife were also only apparent in the three years immediately following rejuvenation. Coppicing affected hedges over a longer time-scale than the other methods, as differences in berry provision as well as structure and regrowth were still apparent three to four years later. Our third hypothesis, that the reduction in berry provision under coppicing would be relatively short-term, is rejected. Most differences between the rejuvenation methods were relatively short-lived (less than 3-4 years following rejuvenation); differences between the coppice and other methods are expected to reduce over the long term, but may persist for some time.

Conservation hedging cost about half the amount of traditional hedge-laying, while wildlife hedging cost about a third. Wildlife hedging provided many of the same benefits as traditional hedge-laying as well as increasing short-term berry provision, but also resulted in a greater proportion of dead wood. Conservation hedging had very similar medium-term benefits as traditional hedge-laying, in the short term provided a greater berry provision for wildlife, and is thus a cost-effective alternative for rejuvenating hedgerows. These results support our first and second hypotheses, that modern alternatives to traditional hedge laying are cheaper and provide many of the same biological benefits in terms of basal structure, regrowth and berry provision. Nonetheless, traditional hedge laying has a recognised aesthetic and cultural appeal (Bannister and Watt, 1994), and is still likely to have a role in hedgerow rejuvenation when cost is not a driving factor.

Reshaping with a circular saw was the cheapest rejuvenation method tested and stimulated canopy regrowth, but it did reduced berry provision in the short term, and did not improve basal hedge structure. Coppicing was the second cheapest rejuvenation method tested here, but at the sites where fencing was required this doubled the cost to make it more expensive than wildlife hedging, and comparable in cost to conservation hedging. Coppicing may only be a viable alternative to traditional hedge laying in areas where deer browsing is low.

4.1 Conclusions

This study has demonstrated that cheaper alternative methods of rejuvenation can increase the habitat value of hedgerows for a range of wildlife to a similar extent as that of traditional hedge laying, through stimulating regrowth to increase the density of woody material in the hedge base and reduce the size of gaps. In 2007, only 2% of hedges surveyed by the Countryside Survey had been coppiced or layed in the last 3-5 years (data accessed at http://www.countrysidesurvey.org.uk) equivalent to 16-27% of hedges rejuvenated over a 40 year rotation, though over half of English hedges were not in good condition (Carey et al., 2008). If this deterioration in condition continues it is likely to lead to a further loss of hedgerow habitat and increased uniformity. AES are currently limited in the extent of hedgerow rejuvenation they fund, either through restricted entry to the HLS scheme, or through a limit of 40 m length of hedgerow per year through the ELS scheme. We recommend the widespread use of conservation hedging as an alternative or to complement traditional hedge laying. The lower cost of conservation hedging could result in double the length of hedgerow being rejuvenated. The use of coppicing should be restricted to areas with a low chance of deer browsing and carried out on small lengths of hedgerow at any one time in order to minimise short-term impacts on wildlife such as small mammals.

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Table legend

Table 1. Cost (£) of applying rejuvenation treatments and clearing up brash (branches and leaves that had been cut off) along 100m hedgerow length at each experimental site, as quoted by commercial contractors 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.

Figure legends

Figure 1. Hedgerow rejuvenation treatments soon after they were applied in November 2010: a) traditional hedge-laying, b) conservation hedging, c) wildlife hedging, d) hedge reshaped with a circular saw, e) coppiced hedge with brash and stems that were removed in background, f) control hedge that was not rejuvenated.

Figure 2. Recent hawthorn growth from basal stools, which were cut during rejuvenation in November 2010. a) Number of shoots growing per basal stool, b) height of shoots, c) average volume of regrowth per basal stool in, d) number of basal stools that produced new shoots; all mean ± SE. Assessments were made over three years (2011-2013), just the first and last year are shown here.

Figure 3. Density of recent hawthorn growth (mean ± SE) in the hedgerow canopy, following hedgerow rejuvenation in November 2010.

Figure 4. Dry weight of recent hawthorn growth in the hedgerow canopy in response to rejuvenation treatments, g (mean ± SE). Rejuvenation of hedgerows took place in November 2010. Recent coppice growth was not assessed in 2011 as this would have removed all the regrowth from the coppiced stools.

Figure 5. Woody material (m^2/m; mean ± SE) in a) 2011 and b) 2014 and maximum gap area (cm^2) in c) 2011 and d) 2014 in the basal 90cm of hedgerow plots calculated from digital images taken in January/February, following rejuvenation in November 2010.

Figure 6. Cumulative fresh weight of hawthorn berries (mean ± SE) available over winter on 1m of hedge length, in response to rejuvenation treatments applied in November 2010. Assessments were made over four years (2010-2013); just the first and last year are shown here.

Costs per 100m (£) Site	Midland's style laying			Conservation hedging			Wildlife hedging			Circular saw			Coppice			
	Rejuvenation	Brash	Total	Rejuvenation	Brash	Total	Rejuvenation	Brash	Total	Rejuvenation	Brash	Total	Rejuvenation	Brash	Fencing*	Total including fencing
Utcoate Grange	1350	75	1425	700	75	775	450	0	450	112	50	162	200	75	320	595
Monk's Wood	1200	75	1275	600	80	680	450	0	450	97	80	177	300	75	320	695
Newbottle Estate	1300	75	1375	650	80	730	300	0	300	101	80	181	100	75	0	175
Wimpole Hall	1200	80	1280	550	60	610	450	0	450	85	60	145	200	75	0	275
Crowmarsh Battle	800	50	850	450	75	525							150	75	0	225
Average for all sites	1170	71	1241	590	74	664	413	0	413	99	68	166	190	75	320	393

Figure 1

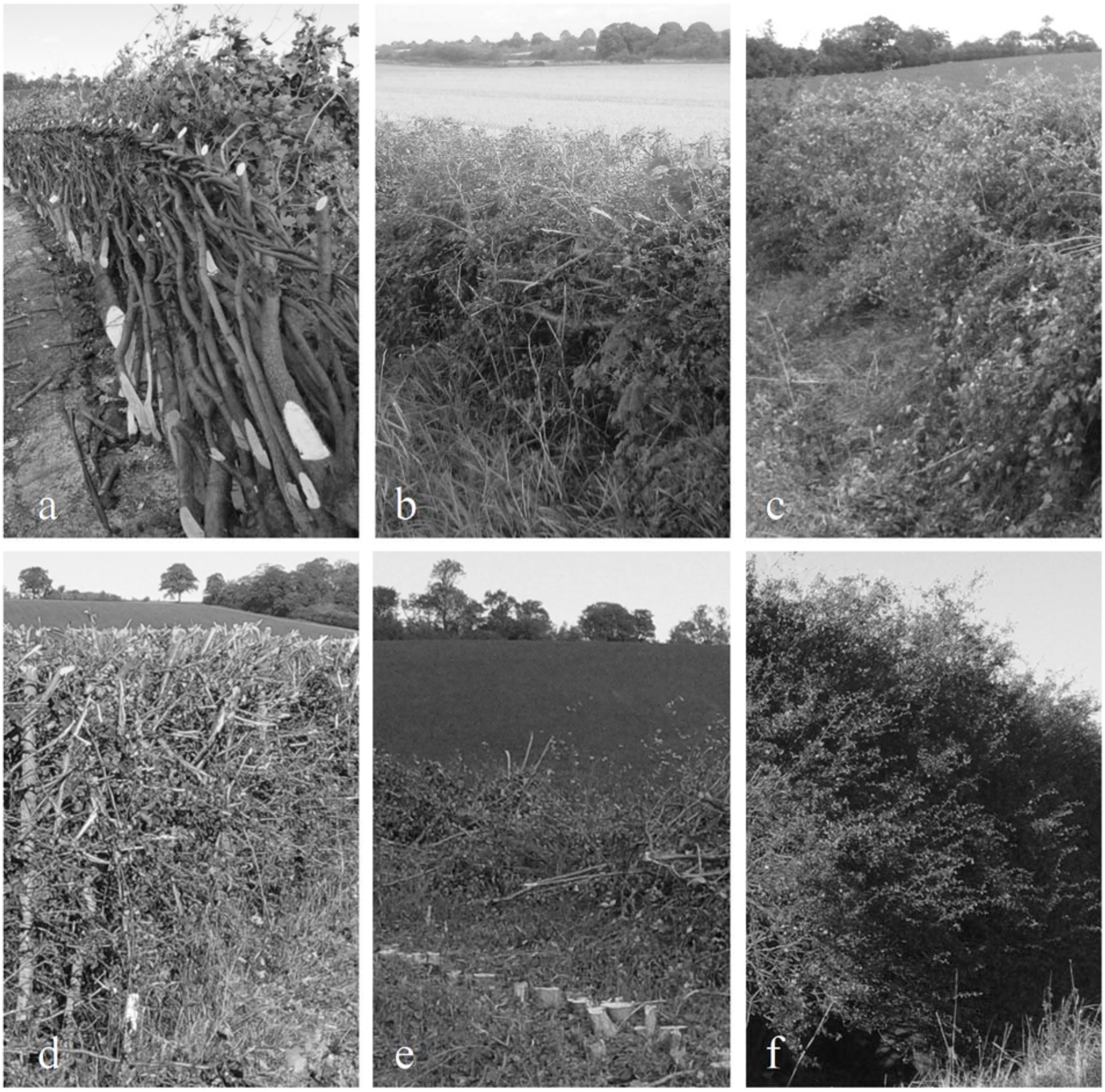


Figure 2

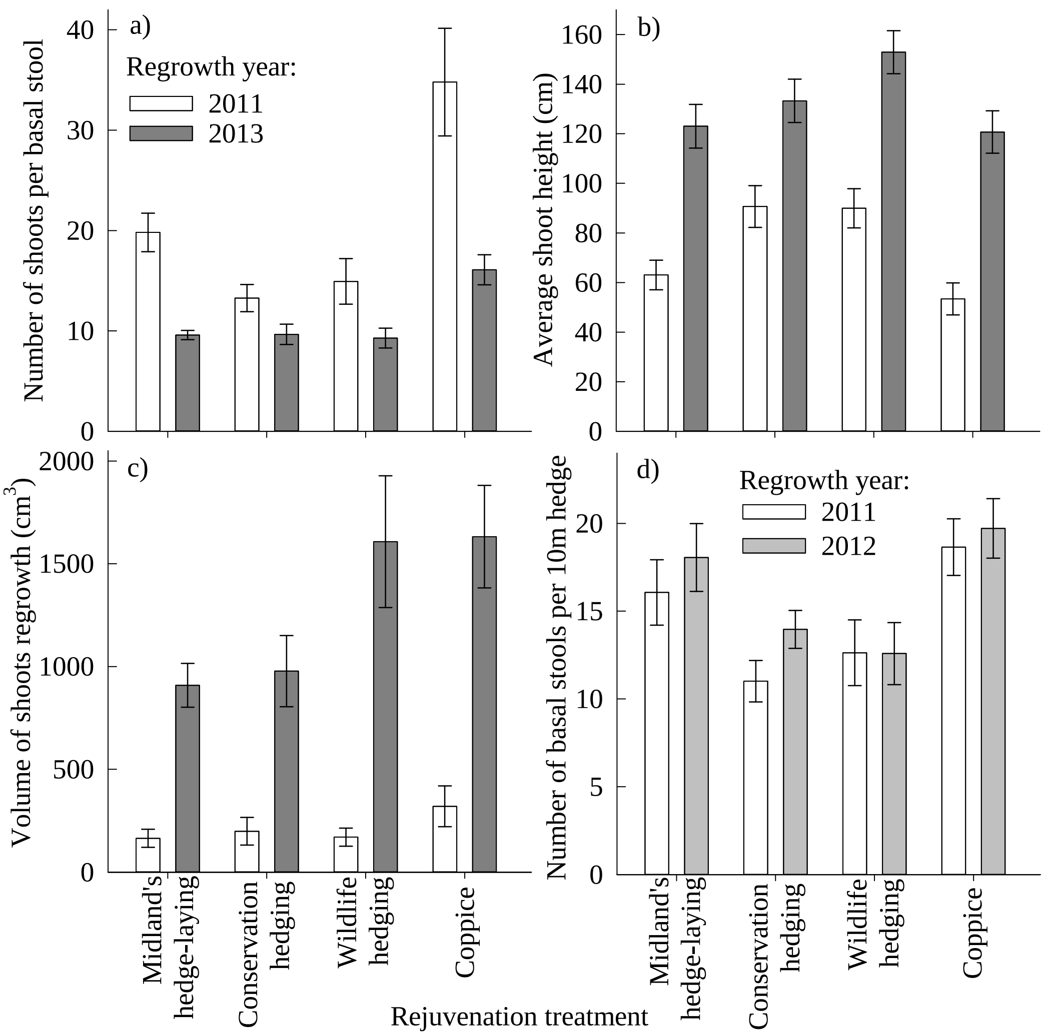

a)
Regrowth year:
2011
2013
Number of shoots per basal stool
0
10
20
30
40
b)
Average shoot height (cm)
0
20
40
60
80
100
120
140
160
c)
Volume of shoots regrowth (cm^3)
0
500
1000
1500
2000
d)
Regrowth year:
2011
2012
Number of basal stools per 10m hedge
0
5
10
15
20
Midland's hedge-laying
Conservation hedging
Wildlife hedging
Coppice
Rejuvenation treatment

Figure 3

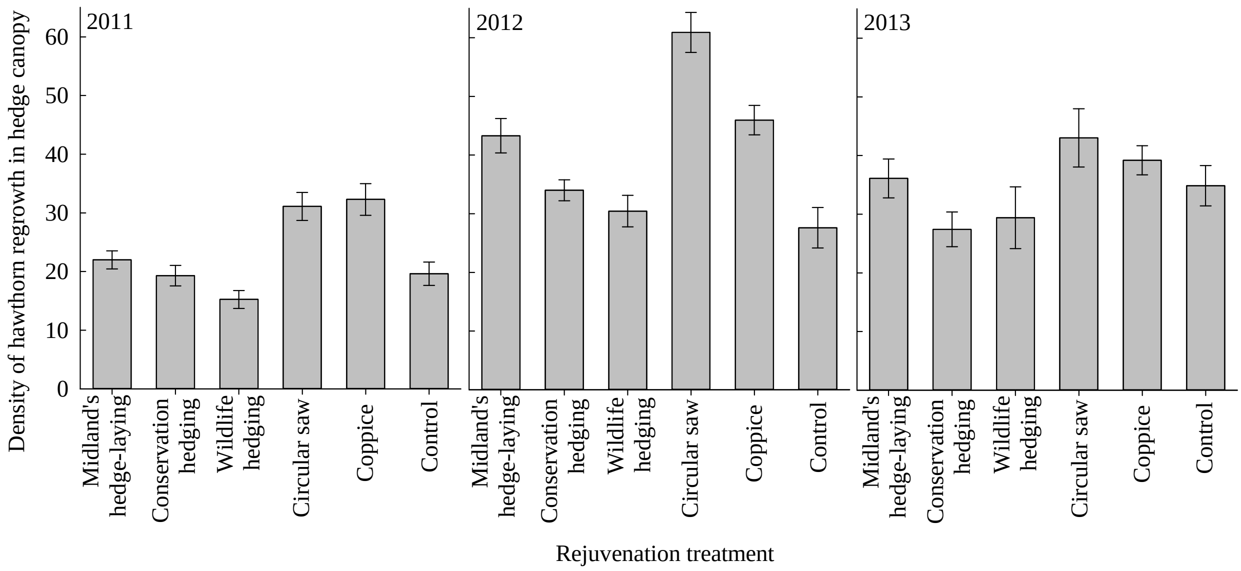


Figure 4

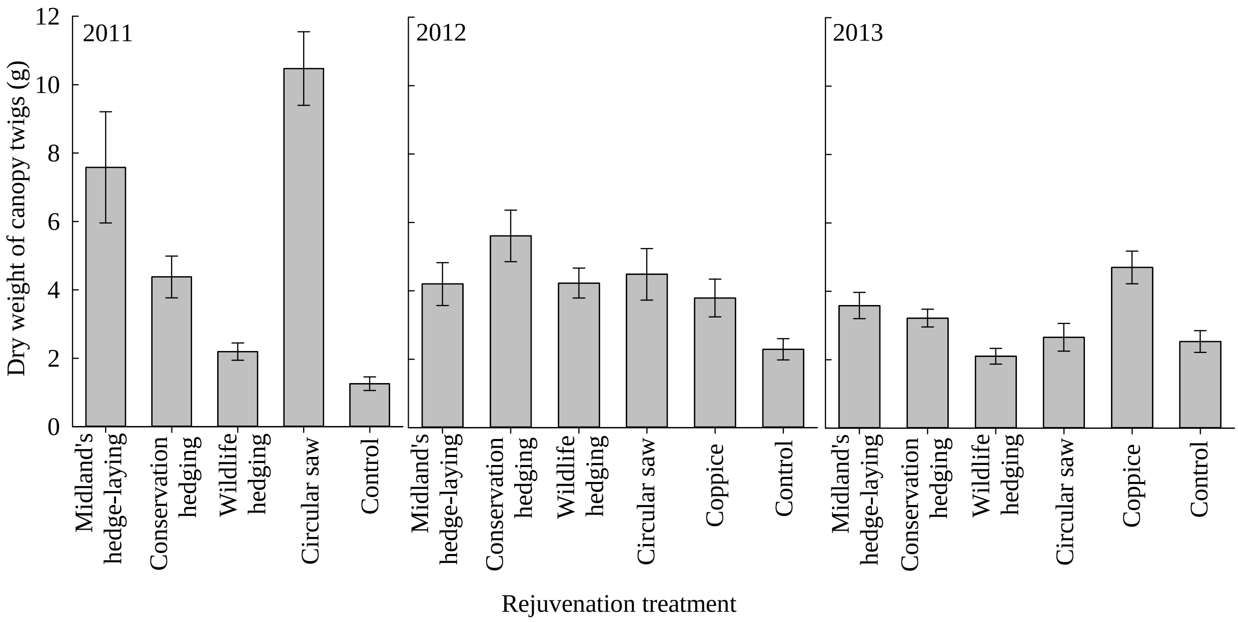
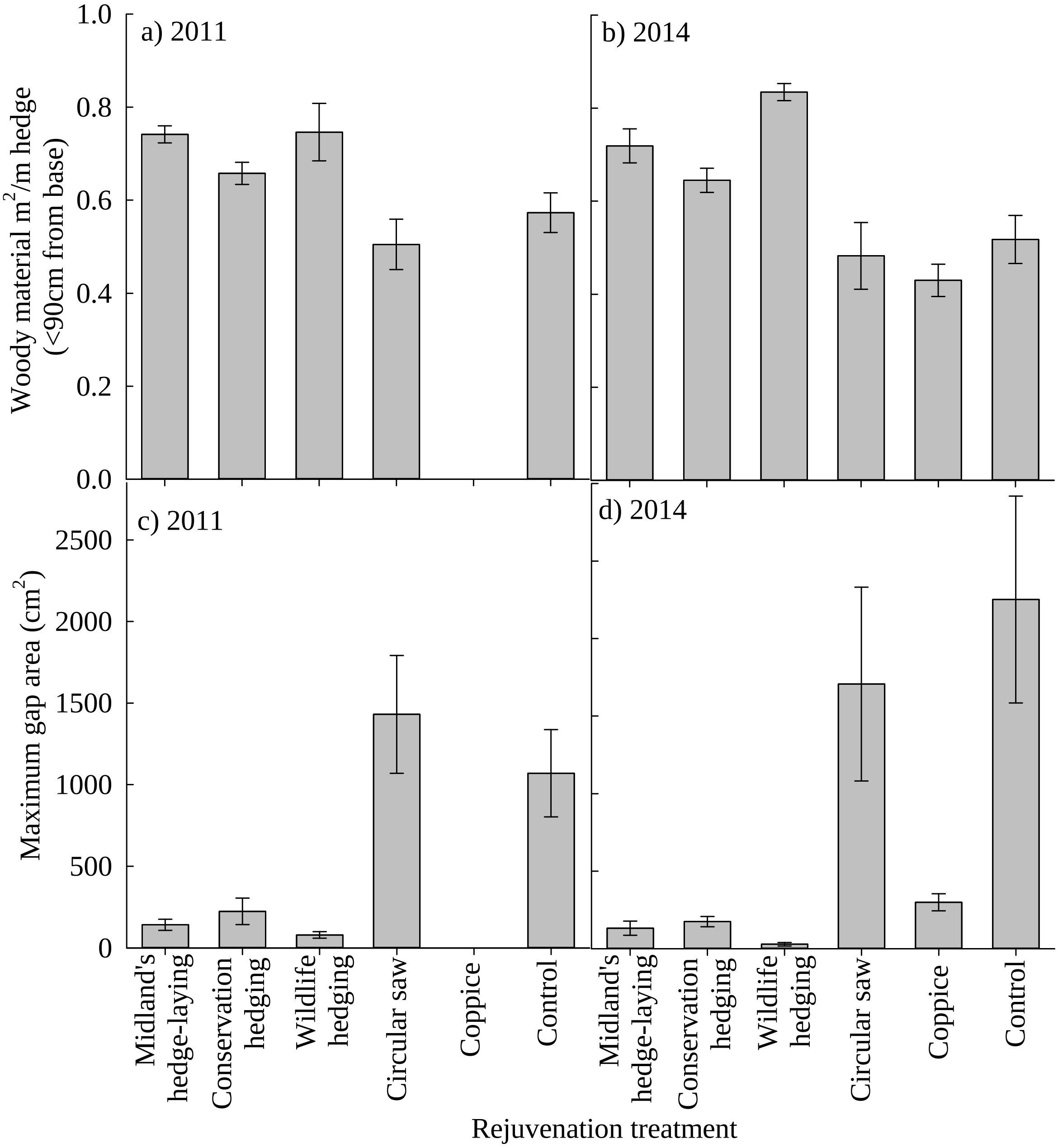
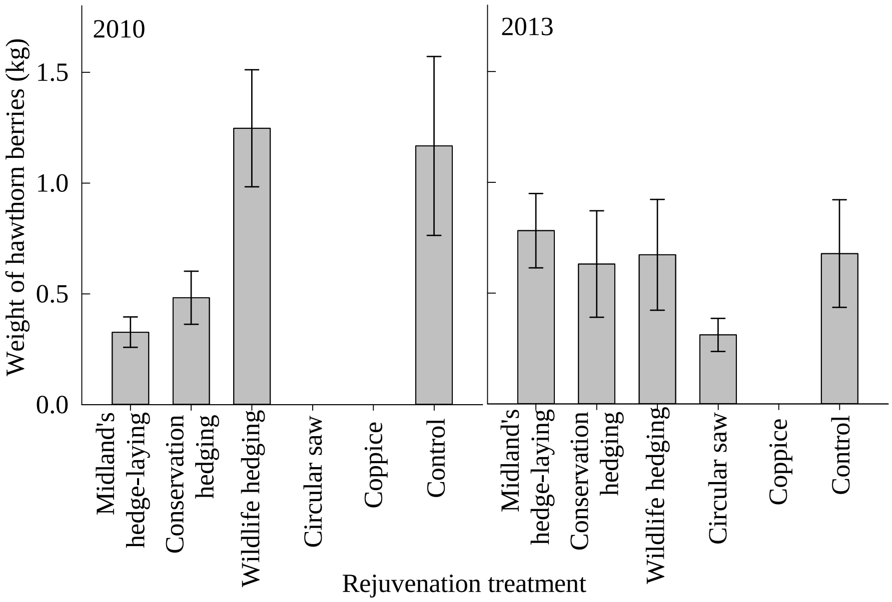


Figure 5



a) 2011
b) 2014
c) 2011
d) 2014
Woody material m2/m hedge (<90cm from base)
1.0
0.8
0.6
0.4
0.2
0.0
Maximum gap area (cm2)
2500
2000
1500
1000
500
0
Midland's hedge-laying
Conservation hedging
Wildlife hedging
Circular saw
Coppice
Control
Rejuvenation treatment

Figure 6


2010
2013
Weight of hawthorn berries (kg)
1.5
1.0
0.5
0.0
Midland's hedge-laying
Conservation hedging
Wildlife hedging
Circular saw
Coppice
Control
Rejuvenation treatment