Article (refereed) - postprint

Staley, Joanna T.; Sparks, Tim H.; Croxton, Philip J.; Baldock, Katherine C.R.; Heard, Matthew S.; Hulmes, Sarah; Hulmes, Lucy; Peyton, Jodey; Amy, Sam R.; Pywell, Richard F. 2012 **Long-term effects of hedgerow management policies on resource provision for wildlife.**

REF: BIOC-D-1-00339R1; Accepted by Biological Conservation

Long-term effects of hedgerow management policies on resource provision for wildlife

Joanna T. Staley[a,*] , Tim H. Sparks[b,c,d], Philip J. Croxton[a], Katherine C. R. Baldock[a,e], Matthew S. Heard[a], Sarah Hulmes[a], Lucy Hulmes[a], Jodey Peyton[a], Sam Amy[a] & Richard F. Pywell[a]

[a] NERC Centre for Ecology & Hydrology, Maclean Building, Wallingford, Oxfordshire, OX10 8BB, UK

[b] Fachgebiet für Ökoklimatologie, Technische Universität München, Hans-Carl-von-Carlowitz-Platz 2, 85354 Freising, Germany

[c] Institute of Zoology, Poznań University of Life Sciences, Wojska Polskiego 71C, 60-625 Poznań, Poland

[d] Department of Zoology, University of Cambridge, Downing Street, Cambridge CB2 3EJ, UK

[e] School of Biological Sciences, University of Bristol, Woodland Road, Bristol, BS8 1UG, UK

* Corresponding author: Tel.: +44 (0)1491 692701, fax: +44 (0)1491 692424, e-mail addresses: jnasta@ceh.ac.uk (J. T. Staley), rfp@ceh.ac.uk (R. F. Pywell)

Keywords

berries; birds; *Crataegus monogyna*; Entry Level Stewardship; flowers; hawthorn;

Abstract

Hedgerows provide important habitat and food resources for overwintering birds, mammals and invertebrates. Currently, 41% of managed hedgerow length in England forms part of three Agri-Environment Scheme (AES) options, which specify a reduction in hedgerow cutting frequency from the most common practice of annual cutting. These AES options aim to increase the availability of flowers and berries for wildlife, but there has been little rigorous testing of their efficacy or estimates of the magnitude of their effects. We conducted a factorial experiment on hawthorn hedges to test the effects of i) cutting frequency (every one, two or three years) and ii) timing of cutting (autumn vs. winter) on the abundance of flowers and berry resources. Results from five years show that hedgerow cutting reduced the number of flowers by up to 75% and the biomass of berries available over winter by up to 83% compared to monitored uncut hedges. Reducing cutting frequency from every year to every three years resulted in 2.1 times more flowers and a 3.4 times greater berry mass over five years. Cutting every two years had an intermediate effect on flower and berry abundance, but the increase in biomass of berries depended on cutting in winter rather than autumn. The most popular AES option is cutting every two years (32% of English managed hedgerow length). If these hedges were managed under a three year cutting regime instead, we estimate that biomass of berries would increase by about 40%, resulting in a substantial benefit for wildlife.

1. Introduction

Hedgerows are important landscape features that have value for wildlife, farming, culture and archaeology. Importantly for wildlife, they provide shelter and food for a range of invertebrate, mammal and bird species, many of high conservation status (Dover and Sparks, 2000; Fuller et al., 1995; Wilson, 1979), and contribute to habitat connectivity. Hedgerows have been defined as rows of woody vegetation that are actively managed to prevent expansion into adjacent fields, the majority of which are cut back in some way (Baudry, et al. 2000). Hedges are found in many parts of the world including northern and southern Europe, Africa and China and have been present in landscapes for centuries (Baudry et al., 2000; Yu et al., 1999) . Historically, type of hedgerow management has often been enforced by local regulations, but increasingly they are subject to national legislation such as Agri-Environment Schemes (AES; Baudry et al., 2000; Natural England, 2010; Fuentes-Montemayor et al., 2011).

Approximately half of UK hedges were removed during the 20th century (Barr and Parr, 1994). Data collected for the 2007 Countryside Survey estimated the total length of linear woody features to be 700,000 km in Great Britain and 547,000 km in England (representing losses of 1.7 % and 1.5% respectively since 1998). The length of managed hedgerows in Great Britain is estimated at 477,000 km and 402,000 km in England (losses of 6.2 % and 6.1 % respectively since 1998). These latter losses (31,000 km) were associated largely with a lack of management; unmanaged hedgerows turning into ‘relict hedges’ or ‘lines of trees’ (Carey et al., 2008).

Hedgerows provide nesting, breeding and hibernation sites for wildlife as well as food resources. The abundance (Hinsley and Bellamy, 2000) and probability of occurrence (Whittingham et al., 2009) of several farmland bird species are related to the presence, height, width and plant diversity of nearby hedgerows. Hedgerow berries provide an important source of food for resident and overwintering birds (Hinsley and Bellamy, 2000), especially *Turdus* species such as blackbirds, fieldfares and redwings (Snow and Snow, 1988). Hedgerow flowers provide sources of nectar for pollinating insects such as aculeate Hymenoptera, Lepidoptera and Diptera (Jacobs et al., 2009, 2010). Hawthorn (*Crataegus monogyna* Jacq.) is the dominant woody species in British hedgerows (Cummins and French, 1994) so the abundance of hawthorn flowers and berries is likely to be critical for Britain's farmland fauna.

Reduction in the agricultural labour force and the prevalence of autumn sowing result in hedgerows typically being cut in late summer or early autumn after harvest, which removes berry resources before winter starts. A detailed study of berry depletion found that the majority of hedgerow berries had been naturally depleted by mid-January, and advocated cutting of hedgerows in February or March to allow overwintering birds to forage on them prior to cutting (Croxton and Sparks, 2004).

Across much of the EU farmers are increasingly encouraged to undertake environmentally-sensitive land management as part of agri-environment schemes (AES). In England the Environmental Stewardship scheme was adopted in 2005 (http://www.naturalengland.org.uk/ourwork/ farming/funding/es/default.aspx) and includes specific options that aim to increase the availability of berries to over-wintering birds, by encouraging a reduction in the frequency of hedgerow cutting. Since many key hedgerow plants, such as hawthorn, only flower and fruit on wood that is at least two years old (Sparks and Croxton, 2007) the Entry Level Stewardship (ELS) AES in England includes options that specify cutting hedgerows no more frequently than every two years (EB1 and EB2), or a maximum cutting frequency of every three years (EB3; Natural England, 2010). These options are among the most popular in the ELS with around 163,712 km (41%) of hedgerows in England currently managed under AES, the majority of which (132,626 km or 32 % of managed hedgerows) are managed under the two year cutting options (Natural England, 2009). Several other European contries include hedgerow management in their AES; for example in Scotland hedgerow cutting on farms within AES is limited to a frequency of once in three years (Fuentes-Montemayor et al., 2011).

Despite their popularity, the efficacy of these ELS options in increasing flower and berry availability has received little rigorous testing. Unmanaged hedgerows have been shown to produce more berries than managed hedgerows (Sparks and Martin, 1999), but the effects of timing of management were not assessed. Croxton and Sparks (2002) found that mass of available berries on annually cut hedges was lighter compared with those on hedges that were ‘managed but uncut for at least two years’, but they did not specifically compare biennial and annual cutting regimes.

Here, we investigated the responses of hawthorn hedges to cutting management that altered in both frequency and timing using a factorial experiment that was established in lowland eastern England in 2005 (Sparks and Croxton, 2007). The following questions were addressed: 1) Is there a consistent increase in flower and berry production as the frequency of cutting is reduced? 2) Is the removal of berries by cutting in the autumn mitigated by low frequency cutting? Number of flowers and berry mass were analysed cumulatively for five years (the length of a typical ELS agreement; Natural England, 2010), and for each year to investigate how the effects of cutting frequency and timing on these resources varied over time. The results are discussed in the context of current and future hedgerow management policies under AES and their practical implications for modern farming resources. While our results are directly relevant for current AES in England, the prevalence of hedgerow cutting as a management option 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. Materials and methods

2.1 Experimental design

We used a set of experimental hedges that were planted in 1961 at Monks Wood, Cambridgeshire, UK (52.4026 °N, -0.2357 °W) on former arable land (Croxton et al., 2004). The arable land was converted to grassland and subsequently managed by a mixture of hay cutting and topping and occasional extensive livestock grazing in the absence of fertiliser and pesticide inputs. The hedgerows were managed by autumn or winter cutting on a one or two year cycle to maintain them at a height of 2 – 3 m.

In autumn 2005 three hedgerows were divided into 32 contiguous plots of 15m length. The following management treatments were allocated to plots at random in factorial combinations: 1) cutting frequency treatment (annual vs. biennial vs. cut every three years), and 2) cutting timing treatment (autumn vs. winter). In addition, we monitored two unmanaged plots that had not been cut for 15+ years, and were never cut during the current experiment. The autumn cut was conducted in September each year, and the winter cut in January or February. Each treatment combination of cutting frequency and timing was replicated either eight (for annually cut plots) or four times (for biennial and three year cut plots; Sparks and Croxton, 2007). Annual cutting post-harvest (September) is the most common practice for hedgerow management outside the AES, whereas post-harvest cutting on a biennial cycle is the typical management for hedges in AES options EB1 and EB2, and post-harvest cutting every three years typifies AES option EB3. On each cutting occasion all the growth since the last cut was removed, and all cutting was implemented with a tractor mounted flail cutter. The sides of the hedge were cut vertically resulting in a rectangular cross-section.

2.2 Flower production

The cover of hawthorn flowers was assessed annually in May in each plot from 2006 - 2010. Quadrats (0.5 m × 0.5 m) with their base 1m above the ground were attached vertically on range poles, and 5 quadrats were assessed on each side of each plot. Quadrats were approximately equally spaced along the length of each plot, but excluding 2.5 m at each end to exclude edge effects. Each quadrat was divided into 25 cells of 10 cm × 10 cm, and flower cover was estimated in each using a five-point score (0 = none, 1 = < 25 %, 2 = 26 – 50 %, 3 = 51 – 75 %, 4 = 76 – 100%). The sum of the scores for the 25 cells in each quadrat gives an estimate of percentage cover (Croxton et al., 2004; Sparks and Martin, 1999). In 2010, the number of flowers was also counted in the third quadrat on each plot, to further assess the accuracy of the percentage cover estimates.

2.3 Berry availability and individual berry mass

The mass and number of available berries over the winter was assessed annually in September 2006 – 2010, immediately after application of autumn cutting treatments. Ten 0.5 m × 0.5 m quadrats, at the same height and approximately matching the positions used for flower recording, were used to record berries. The berries within each quadrat were collected and counted. Berries were weighed to obtain fresh biomass, dried for 48 hours at 80 °C to constant mass and weighed again. In addition, 50 berries from each quadrat were weighed fresh and dry to determine individual berry mass and % dry matter (Sparks and Martin, 1999).

2.4 Plot surface area

The height and width of the plots were measured to the nearest 10 cm using graduated poles, at 5 evenly spaced positions along each plot in 2010. These data were used to calculate the surface area of each plot, and to convert flower and berry data to number or biomass produced per m hedgerow length.

2.5 Statistical analyses

Means of each response variable (flower cover, berry availability (total fresh biomass), individual berry mass and % dry matter) were calculated from the ten quadrats on each plot. Flower cover was converted to the number of flowers using linear regression (see section 3.1 below). Flower numbers and berry available fresh mass data were converted to values per 1m hedge length using the surface area values calculated above. Two analyses were conducted. Firstly, cumulative flower numbers and available berry mass over 5 years were calculated for each plot. The numbers of flowers were log(x+1) transformed prior to analysis. ANOVAs were used to test the effects of cutting frequency and timing on cumulative production of hawthorn flowers and berries. Where significant treatment effects were found Tukey HSD posthoc tests were conducted to determine which treatment levels differed (Crawley, 2007).

Secondly, Generalized Linear Mixed Models were used to determine how annual flower production, available berry biomass, number of berries, berry size and berry dry matter content responded to cutting frequency and timing. To reduce the effect of background inter-annual variation in data (for example due to the weather), numbers of flowers and berry fresh mass in each plot were divided by the mean of the two monitored uncut plots for each year prior to analysis. Cutting frequency, cutting timing, year of sampling and the interaction between these factors were included as fixed effects, and plot as a random effect in each model. Interactions and factors that did not contribute significantly to the model were removed one at a time, and changes in the explanatory power of the model were tested using likelihood ratio tests (Faraway, 2005). All analyses were carried out in R version 2.12 1 (R Core Development Team, 2010) using package nlme (Pinheiro et al., 2011).

3. Results

3.1 Cumulative 5 year flower and berry production in response to hedge cutting

There was a highly significant linear relationship between the count of hawthorn flowers and the percentage flower cover estimate (linear regression: $R^2 = 0.9109$, $F_{1,33} = 337.3$, $P < 0.001$), indicating that the latter is a reliable predictor of flower abundance. There were over six times more flowers on the monitored uncut plots compared to the average of the cut plots in the experiment (Figure 1a). Cutting frequency significantly affected flower production ($F_{2,26} = 27.70$, $P < 0.001$), with 1.7 times more flowers on the hedges cut biennially and 2.1 times more flowers on those cut every three years compared with annual cutting (Tukey HSD tests, all $P < 0.05$; Figure 1a). The number of flowers did not differ significantly between the biennial plots and those cut every three years (Tukey HSD test, $P > 0.05$). Fewer flowers were produced on the hedge sections cut in late winter compared with autumn ($F_{1,26} = 9.98$, $P < 0.01$), but there was no interaction between the frequency and timing of cutting ($F_{2,26} = 1.66$, $P > 0.05$).

Fresh berry mass over five years was 15 times greater on the monitored uncut plots than in the experimental cut plots (Figure 1b). Cutting frequency strongly affected available berry mass ($F_{2,26} = 20.11$, $P < 0.001$), with significant differences between each of the three cutting frequencies (Tukey HSD tests, all $P < 0.05$). Cutting every three years produced 3.4 times the fresh mass of berries of an annual cutting regime, while cutting biennially produced 2.1 times the mass (Figure 1b). Timing of cutting had no significant effect on cumulative available berry mass ($F_{1,26} = 0.29$, $P > 0.05$), nor was there an interaction between cutting frequency and timing ($F_{2,26} = 0.62$, $P > 0.05$).

3.2 Inter-annual response of flower and available berry mass to cutting frequency and timing

The effects of cutting frequency and timing on flower production varied with year, depending on the stage of the cutting cycle (GLMM likelihood-ratio test: cutting frequency × cutting timing × year interaction, $\chi^2_8 = 27.37$, $P < 0.001$; Figure 2). In the first harvest year (2006) all plots were at the same stage in the cutting cycle as they had been cut the preceding autumn or winter. Plots cut every three years produced significantly more flowers than those cut annually in the other four years of the experiment (2007-2010 inclusive; Figure 2 and Electronic Supplementary Material page 1 (ESM p1)). Significantly more flowers were produced on the biennially cut plots compared with the annual plots in 2007 and 2009 which corresponds with the second years of the cutting cycle (biennial plots were cut in autumn or winter 2005/06, 2007/08 and 2009/10).

There was no consistent effect of the timing of cutting on the number of flowers produced. In 2009 significantly fewer flowers were produced on the plots cut every three years in the winter compared with those cut in the autumn. There were no other significant interactions between the timing of cutting and either year or cutting frequency (ESM p1).

The effects of cutting frequency and timing on available fresh berry mass also depended on the stage of the cutting cycle, and thus varied with year (GLMM likelihood-ratio test: cutting frequency × cutting timing × year interaction, $\chi^2_8 = 51.99$, $P < 0.001$; Figure 3). Plots cut every three years (autumn or winter 2005/06 and 2008/09) produced a significantly higher mass than annually cut plots in September 2007 and 2010 and a significantly higher mass on the three year winter plots in 2008 and on the three year autumn plots in 2009 (Figure 3; ESM p2).

Plots cut biennially in the winter (2006, 2008 and 2010) had a significantly higher available biomass of berries compared with all annually cut plots in 2007 and 2009. There was no significant difference between autumn cut biennial plots and annually cut plots in any year. Timing of cutting had no significant effect on the berry mass from annual plots (ESM p2). The number of berries and available fresh mass of berries were closely related (linear regression: $R^2 = 0.982$, $F_{1,285} = 1537.52$, $P < 0.001$), and responded in a very similar way to the cutting treatments.

3.3 Individual berry size and dry matter content

Individual berry masses were significantly affected by an interaction between year and the timing and frequency of cutting (GLMM likelihood-ratio test: cutting frequency × cutting timing × year interaction, $\chi^2_8 = 24.39$, $P < 0.01$). Heavier berries were produced on plots cut every two years in the winter in 2008 and lighter berries on plots cut every three years in the winter in 2010 , compared to annually cut plots (ESM p3). The percentage dry matter content of hawthorn berries was not significantly affected by the frequency (GLMM likelihood-ratio test: $\chi^2_2 = 0.003$, $P > 0.05$) or timing ($\chi^2_1 = 0.59$, $P > 0.05$) of cutting (ESM p4).

4. Discussion

Cut hedges produced considerably fewer flowers (-75 %) and a lower biomass of berries (-83%) in all years than the monitored uncut hedges. The magnitude of these differences confirms that uncut hedgerows provide far greater resources for wildlife than cut hedgerows, even those cut under a reduced cutting frequency. However, it is unlikely that the majority of hedgerow length could be left unmanaged given the practical demands of farm management.

Significantly more flowers were produced on plots cut every three years compared with those cut annually in four years of the experiment, whereas the biennially cut plots (typical AES practice) only produced significantly more flowers than those cut annually (typical non-AES practice) in two of the five years. However, the magnitude of total increase in flower production over 5 years was not significantly different between the biennial and three year treatments (1.7 and 2.1 times more flowers than annually cut plots respectively). The timing of cutting only significantly affected flower production in spring 2009, when the three year hedgerow plots that had been cut the preceding winter had fewer flowers than those cut in autumn. Cutting timing may alter hawthorn physiology and growth patterns; for example, cutting hawthorn in the late summer results in a greater number of shoots the following year than winter cutting (Bannister and Watt, 1994).

Available biomass of berries was significantly heavier on hedgerows cut every three years compared with annual plots in four out of five years of the experiment, though in two years the increase was modified by the timing of cutting. In 2008, only winter cut three year plots had a significantly greater mass of berries, since the three year autumn plots had just been cut. The decrease in mass on the three year winter cut plots in 2009 was unexpected, though it links to the decreased flower production that year. Winter cutting thus had a detrimental effect on subsequent flower and berry formation on the plots cut every three years, but not those cut annually or biennially. The frequency of cutting may affect hedge structure and stem density, and this is the subject of ongoing research.

The timing of cutting had a strong effect on available biomass of berries on plots cut biennially, as berry mass was only significantly increased on winter biennial plots in the second year of the cutting cycle. Cutting biennial plots in autumn removes the berries which form on two year old growth before they can be utilised as a food source by overwintering birds and mammals. ELS two year cutting options (EB1 and EB2) may thus offer limited benefit for wildlife if cutting is carried out in autumn, which is the more typical time for hedge cutting.

Our results on available berry mass appear to contrast with those of Maudsley et al. (2000) who found more berries on woody species cut biennially compared to those cut annually or every three years. However, they only presented data on berry production from one year of sampling, in which the biennially cut plots had not been cut but both the annual and three year plots were cut (Maudsley et al., 2000). Their findings therefore related to the immediate response of woody species to the cutting regime that year. The current study used five years of data (the typical length of an AES agreement) to investigate the effect of cutting cycle on inter-annual variation in the response of hedgerows to cutting, thus providing much stronger evidence for the medium term response of hawthorn hedgerows to cutting frequency.

Our results suggest that English hawthorn hedgerows managed under the AES 3 year option EB3 (Natural England, 2010) are likely to achieve the aim of substantially increasing resources for overwintering birds and pollinators in the majority of years. The increase in biomass of berries under the most popular AES biennial cutting options EB1 and EB2 (Natural England, 2010) only occurs if cutting is delayed to the winter, and are smaller than the increase under EB3. We used a simple model to explore the impacts of the results of this experiment to the national situation (Figure 4). By extrapolating the mean masses of berries across all five experimental years to national uptake figures for AES we show that if the current uptake of options EB1 and 2 were converted to EB3, total biomass of berries on managed hedgerows in England could be increased 1.4 fold to 63 488 tonnes. Conversion of all managed hedgerows (including those not currently in AES schemes) to EB3 would increase the berry mass available during winter 2.4 fold to 106 769 tonnes, though this would be much more difficult to achieve. Both scenarios would represent a considerable increase in the food resource available for overwintering birds and mammals. This model is based on the assumption that results for hawthorn can be extrapolated to other species, which is yet to be tested.

The timing and frequency of hedgerow cutting have additional conservation impacts beyond the provision of winter food resources for wildlife. Several Lepidoptera species lay eggs in the late summer or early autumn, a large proportion of which may be trimmed off and die during annual hedgerow cutting. For example, the decline of brown hairstreak (*Thecla betulae* L.) populations, a priority Biodiversity Action Plan species in the UK, has been partly attributed to annual cutting of hedgerows (Merckx and Berwaerts, 2010). The abundance of several passerine species increases with increasing hedgerow height (Hinsley and Bellamy, 2000). A few species (e.g. linnet and yellowhammer) have a higher abundance on shorter hedgerows during the breeding season (Green et al., 1994), but the majority of passerine populations are limited by the availability of food over the winter rather than by breeding sites (Davey et al., 2010). In addition, ELS options EB1, EB2 and EB3 specify that not all hedgerows managed under each option within an ELS agreement should be cut in the same year (Natural England, 2010), ensuring a heterogenous hedgerow resource structure across a farm.

In the absence of AES, the most common practice among farmers in England was annual trimming of hedgerows. A reduced frequency to cutting once every three years is likely to save farmers' money on the cost of hedgerow cutting, but may also have effects on crop yields at the edges of fields. To our knowledge, there are no published studies on the reduction of crop yield in response to hedgerow cutting regimes, though it is possible that slightly taller hedgerows with three years of growth may shade cereal crops more than those cut annually (Kuemmel, 2003). Many farmers in ELS are paid to leave 6m margins to benefit wildlife at the edges of their fields next to hedgerows (Natural England, 2010), in addition to the ELS hedgerow options, which may mitigate the proximate effects of reduced frequency hedgerow cutting on crop yield.

Further studies based across several field sites would be needed to cover both a greater geographical area and a wider range of hedgerow species, in order to determine whether our findings are broadly applicable, and this is the subject of current work. Nonetheless, our results from a well-replicated single site experiment monitored over five years suggest that hawthorn hedgerows managed under ELS option EB3 are more likely to provide substantial increases in food resources for wildlife than those cut annually or managed under AES options EB1 and EB2. Furthermore, results suggest that the benefits of the most popular autumn biennial cut AES hedgerow options are likely to provide relatively little benefit to wildlife above typical management practiced by farmers outside of the scheme.

Acknowledgements

This project was funded by a commission from the Department for the Environment, Food and Rural Affairs (BD2114) and core funding from the Natural Environmental Research

Council. The authors would like to thank members of the Hedgerow Habitat Action Plan Committee for stimulating this research. Thanks also to Dave Myhill and Mike Stevenson for managing the experiment; Jo Savage, Kerstin Huber, Lizzie Carroll, Vicky Mallot and Nadine Mitschunas who helped with data collection; and to Steve Freeman for statistical advice.

References

Bannister, N.R., Watt, T.A., 1994. Hedgerow management: past and present, in: Watt, T.A., Buckley, G.P. (Eds), Hedgerow Management and Nature Conservation. Wye College Press, Wye College, University of London, pp. 7-15.

Barr, C.J., Parr, T.W., 1994. Hedgerows: linking ecological research and countryside policy, in: Watt, T.A., Buckley, G.P. (Eds), Hedgerow Management and Nature Conservation. Wye College Press, Wye College, University of London, pp. 119-136.

Baudry, J., Bunce, R.G.H., Burel, F., 2000. Hedgerows: An international perspective on their origin, function and management. Journal of Environmental Management 60, 7-22.

Carey, P.D., Wallis, S., Chamberlain, P.M., Cooper, A., Emmett, B.A., Maskell, L.C., McCann, T., Murphy, J., Norton, L.R., Reynolds, B., Scott, W.A., Simpson, I.C., Smart, S.M., Ullyett, J.M., 2008. Boundary and linear features, in: Countryside Survey: UK Results from 2007. Centre for Ecology and Hydrology, Natural Environment Research Council, UK.

Crawley, M.J., 2007. The R Book. John Wiley & Sons, Chichester, UK.

Croxton, P.J., Franssen, W., Myhill, D.G., Sparks, T.H., 2004. The restoration of neglected hedges: a comparison of management treatments. Biological Conservation 117, 19-23.

Croxton, P.J., Sparks, T.H., 2002. A farm-scale evaluation of the influence of hedgerow cutting frequency on hawthorn (*Crataegus monogyna*) berry yields. Agriculture Ecosystems & Environment 93, 437-439.

Croxton, P.J., Sparks, T.H., 2004. Timing of berry depletion rates of three common hedgerow shrubs. Agriculture Ecosystems & Environment 104, 663-666.

Cummins, R.P., French, D.D., 1994. Floristic diversity, management and associated land use in British hedgerows, in: Watt, T.A., Buckley, G.P. (Eds), Hedgerow Management and

Nature Conservation. Wye College Press, Wye College, University of London, pp. 95-106.
Davey, C.M., Vickery, J.A., Boatman, N.D., Chamberlain, D.E., Siriwardena, G.M., 2010. Entry Level Stewardship may enhance bird numbers in boundary habitats. Bird Study 57, 415-420.
Dover, J., Sparks, T., 2000. A review of the ecology of butterflies in British hedgerows. Journal of Environmental Management 60, 51-63.
Faraway, J.J., 2005. Extending the Linear Model with R: Generalised Linear, Mixed Effects and Nonparametric Regression Models. Chapman and Hall, Florida, USA.
Fuentes-Montemayor, E., Goulson, D., Park, K.J., 2011. The effectiveness of agri-environment schemes for the conservation of farmland moths: assessing the importance of a landscape-scale management approach. Journal of Applied Ecology 48, 532-542.
Fuller, R.J., Gregory, R.D., Gibbons, D.W., Marchant, J.H., Wilson, J.D., Baillie, S.R., Carter, N., 1995. Population declines and range contractions among lowland farmland birds in Britain. Conservation Biology 9, 1425-1441.
Green, R.E., Osborne, P.E., Sears, E.J., 1994. The distribution of passerine birds in hedgerows during the breeding season in relation to characteristics of the hedgerow and adjacent farmland. Journal of Applied Ecology 31, 677-692.
Hinsley, S.A., Bellamy, P.E., 2000. The influence of hedge structure, management and landscape context on the value of hedgerows to birds: A review. Journal of Environmental Management 60, 33-49.
Jacobs, J.H., Clark, S.J., Denholm, I., Goulson, D., Stoate, C., Osborne, J.L., 2009. Pollination biology of fruit-bearing hedgerow plants and the role of flower-visiting insects in fruit-set. Annals of Botany 104, 1397-1404.

Jacobs, J.H., Clark, S.J., Denholm, I., Goulson, D., Stoate, C., Osborne, J.L., 2010. Pollinator effectiveness and fruit set in common ivy, *Hedera helix* (Araliaceae). Arthropod-Plant Interactions 4, 19-28.

Kuemmel, B., 2003. Theoretical investigation of the effects of field margin and hedges on crop yields. Agriculture Ecosystems & Environment 95, 387-392.

Maudsley, M.J., West, T.M., Rowcliffe, H.R., Marshall, E.J.P., 2000. The impacts of hedge management on wildlife: preliminary results for plants and insects. Aspects of Applied Biology 58, 389 - 396.

Merckx, T., Berwaerts, K., 2010. What type of hedgerows do Brown hairstreak (Thecla betulae L.) butterflies prefer? Implications for European agricultural landscape conservation. Insect Conservation and Diversity 3, 194-204.

Natural England, 2009. Agri-environment schemes in England 2009: a review of results and effectiveness. DEFRA, UK.

Natural England, 2010. Entry Level Stewardship - Environmental Stewardship Handbook. Third edition, February 2010, DEFRA, UK.

Pinheiro, J., Bates, D., DebRoy, S., Sarkar, S., R Core Development Team, 2011. nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-98.

R Core Development Team, 2010. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Snow, B., Snow, D., 1988. Birds and Berries. T & AD Poyser Limited, Waterhouses, UK.

Sparks, T.H., Croxton, P.J., 2007. The influence of timing and frequency of hedgerow cutting on hawthorn flowering and berry yields: preliminary results. Aspects of Applied Biology 82, 103 - 106.

Sparks, T.H., Martin, T., 1999. Yields of hawthorn Crataegus monogyna berries under different hedgerow management. Agriculture Ecosystems & Environment 72, 107-110.

Whittingham, M.J., Krebs, J.R., Swetnam, R.D., Thewlis, R.M., Wilson, J.D., Freckleton, R.P., 2009. Habitat associations of British breeding farmland birds. Bird Study 56, 43-52.

Wilson, R., 1979. The Hedgerow Book. David & Charles Ltd, Newton Abbot.

Yu, Z.R., Baudry, J., Zhao, B.P., Zhang, H., Li, S.Q., 1999. Vegetation components of a subtropical rural landscape in China. Critical Reviews in Plant Sciences 18, 381-392.

Figure legends

Figure 1

Cumulative a) number of flowers and b) fresh mass (kg) of berries per m of hedgerow length over five years (mean ± SE) on plots cut annually, biennially or every three years in autumn (= □) or winter (= ▨), together with monitored uncut (= ■) plots. Note different y axis scales for cut and uncut plots.

Figure 2

Number of hawthorn (*Crataegus monogyna*) flowers (mean ± SE) on hedgerow plots cut annually, biennially or every three years in autumn (= □) or winter (= ▨), as a percentage of the mean number of flowers on monitored uncut plots, over 5 years. Numbers of flowers were assessed in May. ● = plots that were cut the preceding autumn / winter.

Figure 3

Fresh mass of hawthorn (*Crataegus monogyna*) berries (mean ± SE) on hedgerow plots cut annually, biennially or every three years in autumn (= □) or winter (= ▨), as a percentage of mean hawthorn berry mass on monitored uncut plots, over 5 years. Berry mass was assessed in September, up to a week after autumn hedgerow cutting. ● = plots that were cut just before the berry assessment, ● = plots that were cut the preceding autumn / winter.

Figure 4

Predicted average hawthorn berry mass produced on managed hedges in England if those currently under annual cutting regimes, AES options EB1 (biennial cut on both sides of hedge) or EB2 (biennial cut on one side of hedge) were managed under AES option EB3 (cut every three years), or cut in winter rather than autumn. Hedges are assumed to be currently cut in autumn. Horizontal lines show multiples of the current biomass of berries.

Figure 1

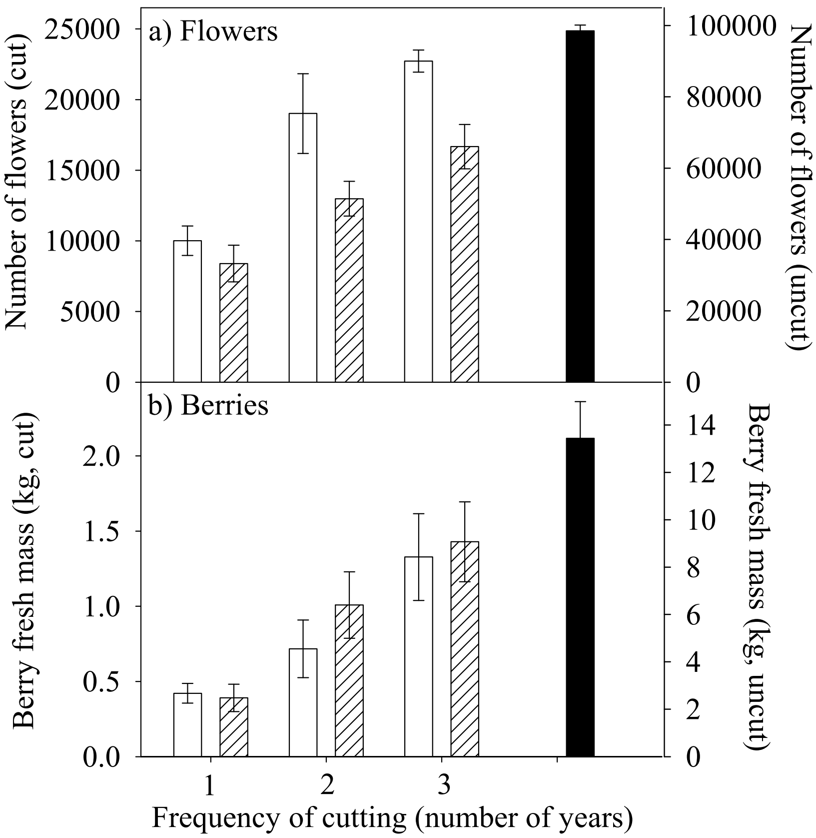

a) Flowers
Number of flowers (cut)
Number of flowers (uncut)
25000
20000
15000
10000
5000
0
100000
80000
60000
40000
20000
0
b) Berries
Berry fresh mass (kg, cut)
Berry fresh mass (kg, uncut)
2.0
1.5
1.0
0.5
0.0
14
12
10
8
6
4
2
0
1
2
3
Frequency of cutting (number of years)

Figure 2

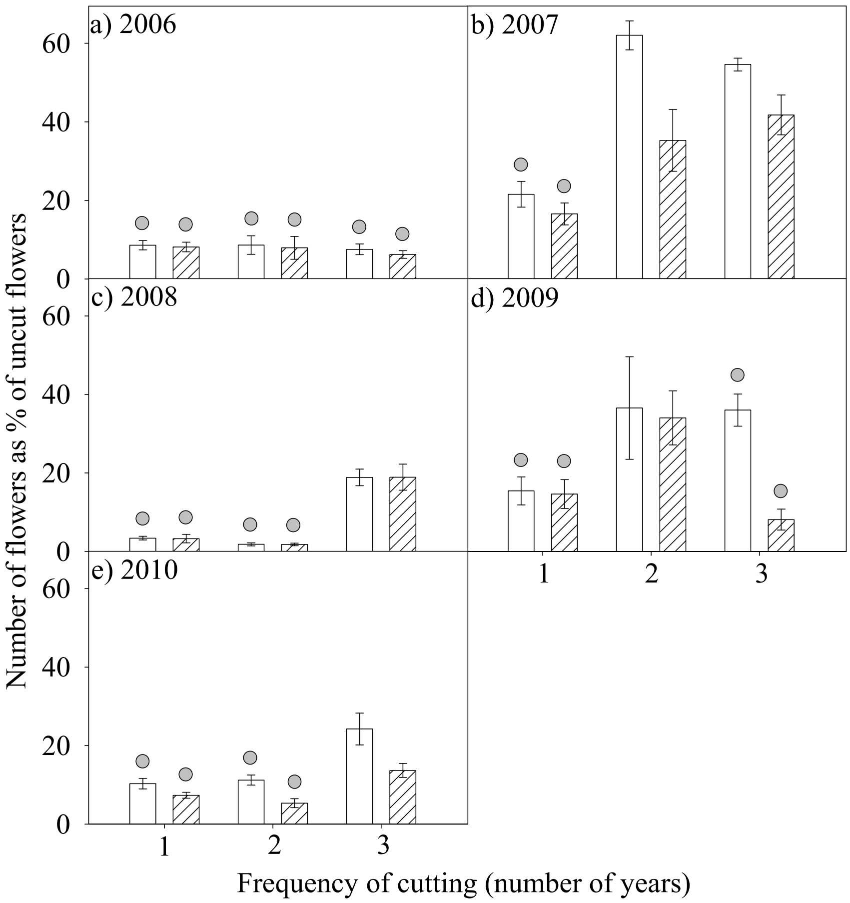
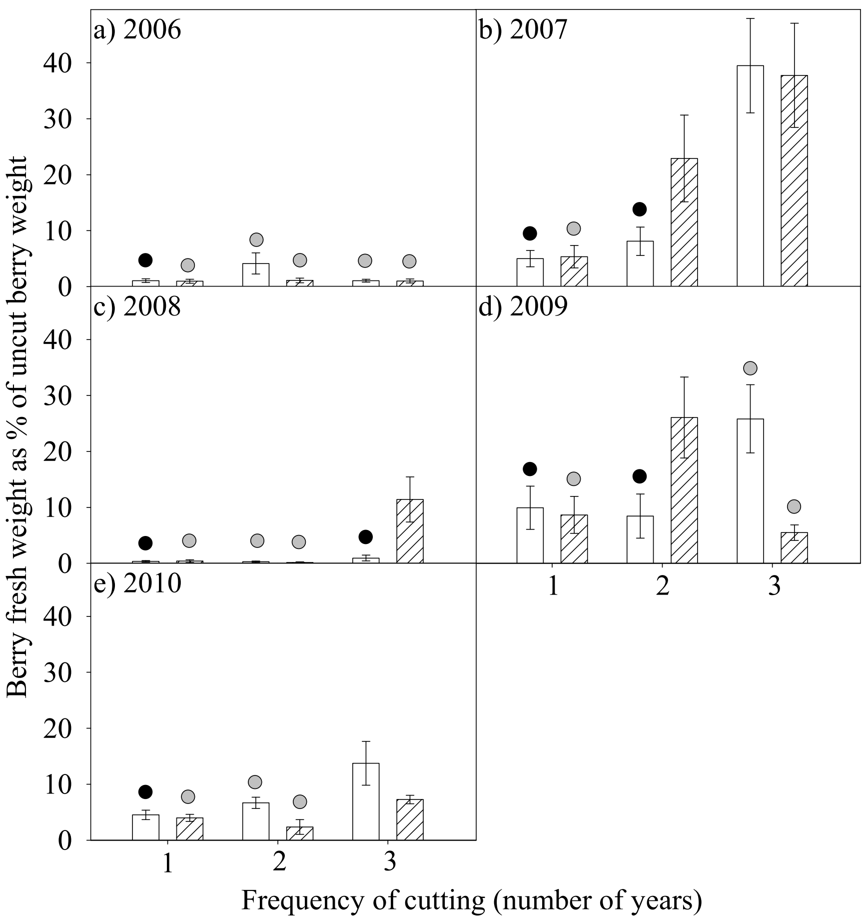
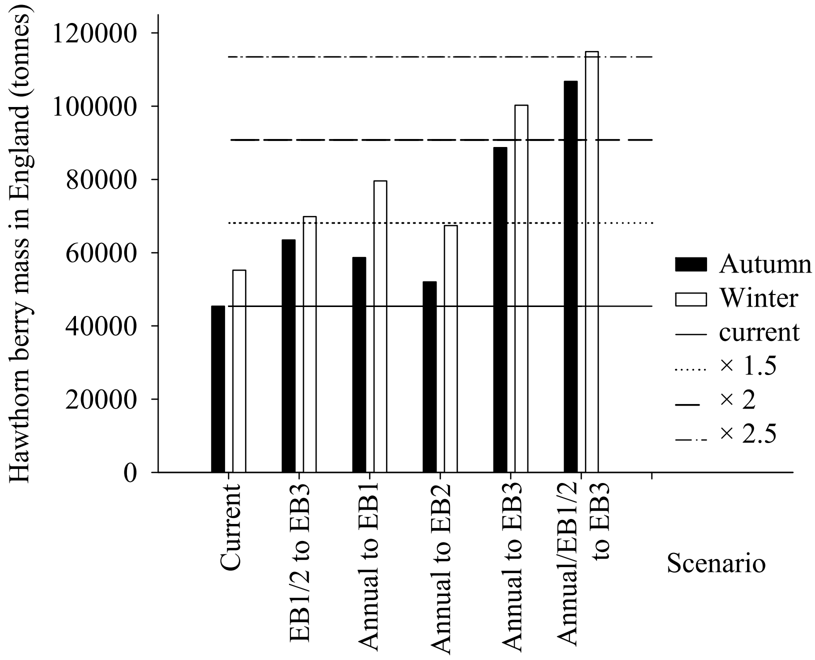

a) 2006
b) 2007
c) 2008
d) 2009
e) 2010
Number of flowers as % of uncut flowers
Frequency of cutting (number of years)
0
20
40
60
1
2
3

Figure 3



a) 2006
b) 2007
c) 2008
d) 2009
e) 2010
Berry fresh weight as % of uncut berry weight
Frequency of cutting (number of years)
0
10
20
30
40
1
2
3

Figure 4



Hawthorn berry mass in England (tonnes)
120000
100000
80000
60000
40000
20000
0
Current
EB1/2 to EB3
Annual to EB1
Annual to EB2
Annual to EB3
Annual/EB1/2 to EB3
Scenario
Autumn
Winter
current
× 1.5
× 2
× 2.5