# Experimental evidence for optimal hedgerow cutting regimes for Brown hairstreak butterflies

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**Running title:** Hedge management for Brown hairstreaks

**Keywords**

*Thecla betulae*; agri-environment scheme; blackthorn; Countryside Stewardship; Environmental Stewardship; *Prunus spinosa;*

**Abstract**

1. The Brown hairstreak butterfly has declined in range and abundance over the past fifty years, leading to designated conservation status in several European countries including England and Wales. The Brown hairstreak's decline has been linked to changes in hedgerow management, based on mortality of eggs over winter and female oviposition preferences.

2. We assessed Brown hairstreak egg abundance in late winter over four years in response to hedgerow management treatments to manipulate the frequency, timing and the intensity of trimming (reduced intensity resulting in an annual increase of approximately 10cm in height and width), using a field experiment with a randomized block design.

3. Hedgerow plots cut every year to a standard height and width had the lowest Brown hairstreak egg abundance; this is the most common hedgerow management outside agri-environment schemes (AES). Cutting hedgerow plots at a reduced intensity nearly doubled the number of surviving eggs in late winter. Plots cut at a reduced frequency in autumn (once every three years), which forms part of current English AES, had 1.3 times more eggs than those cut annually.

**4.** Current AES management prescriptions are likely to benefit the Brown hairstreak, but its requirements need to be balanced with those of other taxa in relation to the timing of hedgerow cutting. Cutting hedges at a reduced intensity has previously been shown to benefit the wider Lepidoptera community as well as Brown hairstreak butterflies. Reduced intensity cutting does not currently form part of AES hedgerow prescriptions, but could be considered for inclusion in future schemes.

## Introduction

The Brown hairstreak butterfly (*Thecla betula* L.) is a designated conservation priority species in the UK and is on Red Lists in several northern European countries (de Vries et al., 2011), due to reductions in its distribution and abundance over the past five decades. In the UK, there was a 49% decline in the number of 1km squares occupied by the Brown hairstreak between 1976 and 2014, and although there are some positive signs of locally increased occupancy over the last decade, the abundance of Brown hairstreak continues to decrease (Fox et al., 2015). Brown hairstreak females preferentially oviposit on young growth of *Prunus* species which protrudes from hedges, and can result in eggs being cut off during hedge trimming (Thomas, 1974; Merckx & Berwaerts, 2010). Conservation effort has largely focused on hedgerow management, as the change towards annual cutting of hedges with mechanized flails since the middle of the twentieth century is thought to be linked to the decline in Brown hairstreak range and abundance (Bourn & Warren, 1998; Butterfly Conservation, 2013).

Hedgerow management prescriptions under agri-environment schemes (AES), which provide payments to land managers in return for less frequent cutting of hedgerows, and trimming at specific times of year, have considerable potential to support Brown hairstreak conservation (Butterfly Conservation, 2013). AES hedgerow management prescriptions in England have had high uptake over the last decade; in 2009 41% (163,712 kms) of the total length of English hedgerows were managed under reduced frequency trimming regimes in the Environmental Stewardship (ES) AES (Natural England, 2009). Links between hedgerow management and Brown hairstreak conservation are based on its life cycle (Butterfly Conservation, 2013), evidence of preference for young foliage for oviposition (Fartmann & Timmerman, 2006), and high egg mortality measured following a single cutting event with a mechanised flail at a site in Surrey (Thomas, 1974). Here, we measured Brown hairstreak egg abundance on hedgerows in late winter over four years, in a replicated field experiment. The frequency, timing and intensity of hedgerow cutting were manipulated, in the context of current and potentially future AES management prescriptions. Specifically, we tested the following questions in relation to the abundance of Brown hairstreak eggs: 1) Is abundance greater on hedges that are not cut annually?; 2) Are there fewer eggs if hedges are cut in late winter rather than autumn?; 3) Does reducing the intensity of hedge trimming increase egg abundance?

## Materials and methods

*Study species*

Adult Brown hairstreak butterflies fly from late July through to early October (Bourn & Warren, 1998), and females lay eggs on the bark of Prunus species, predominantly blackthorn (*Prunus spinosa* L.) (Merckx & Berwaerts, 2010). Adult Brown hairstreaks often aggregate in Ash tree canopies, and make both short occasional flights and longer directional flights (e.g. across one or several trees; Thomas, 1974). The majority of Brown hairstreak eggs are laid on young blackthorn growth or on blackthorn suckers, in a fork or at the base of a bud, and between 50 and 170cm above ground level (Fartmann & Timmerman, 2006; Merckx & Berwaerts, 2010). Most (88%) eggs are laid singly, though groups of two, three or more can be found occasionally (Merckx & Berwaerts, 2010). Brown hairstreak overwinters in the egg stage, with larvae hatching in late April or May, in synchrony with budburst of its host plant (de Vries et al., 2011). The larvae continue to feed until late June or early July, when they pupate on the ground among leaves or in grass tussocks at the base of the hedge (Thomas & Lewington, 2010; Butterfly Conservation, 2013).

*Experimental design*

The field experiment was conducted at four hedgerows on a working farm in Yarcombe, Devon in south-west England (50°51’N, 3°03’W). The hedgerows consisted of traditional mixed woody species growing on banks, and were planted 200 – 300 years ago (Staley et al., 2016).

The four dominant plant species in the hedgerows were: Field maple (*Acer campestre*, average cover = 31.7%); Blackthorn (average cover = 25.9%); Hawthorn (*Crataegus monogyna*, average cover = 11.2%) and Hazel (*Corylus avellana*, average cover = 11.2); all other woody species were present at < 6% cover. The landscape around the experimental hedgerows consisted of a patchwork of hedges, small (mainly grassland) fields and small woodlands, with small patches of blackthorn in the hedges and woodlands.

Three experimental treatments were applied in full factorial combination: 1) frequency of cutting (once every one vs. two vs. three years); 2) timing of cutting (early autumn, September vs. late winter, January / February); and 3) intensity of cutting (standard cutting to the same hedgerow height and width each time vs. incrementally raising the cutter bar by approximately 10 cm each time the hedge is cut, resulting in a slightly wider and taller hedge).

Treatments were applied to 15 m long contiguous hedgerow plots, replicated in three randomised blocks. Two blocks each consisted of a single hedge, and the third of two parallel hedges bordering the same field. In addition, each block contained a control plot that was not cut during the experiment, the position of which was not randomized but located at the end of each block for practical reasons (Figure 1a). Hedge cutting treatments were applied to both sides and the top of each plot using tractor mounted flails, operated by the farmer who regularly cut the hedges on his farm, to ensure that the cutting was representative of typical hedgerow cutting. All experimental plots including the controls were cut prior to the start of the experiment in late winter (January / February 2010). Hedgerow cutting treatments were applied for five years from September 2010.

*Brown hairstreak egg surveys*

Egg surveys are a recognized, standardized monitoring method for Brown hairstreak butterflies, as the adults are rather difficult to locate due to their lifestyle and behaviour (they are predominantly canopy dwelling; Butterfly Conservation, 2013; Fartmann & Timmerman, 2006). Egg surveys were carried out in February or early March each year, after the 'late winter plots' had been cut but before the blackthorn was in flower or leaf, when the pale white eggs contrasted with the dark blackthorn bark (Figure 1b). All blackthorn stems and shoots in the central 10m of each experimental plot were searched intensively for Brown hairstreak eggs for 20 minutes on each side of each plot (40 minutes per plot). Once an egg was located it was checked with a magnifying glass, to verify species identity. During the verification and recording the stopwatch was paused, to ensure a consistent 40 minutes of search time per plot regardless of how many eggs were found. Trials of survey techniques during the first year of monitoring showed that extending the search time beyond 40 minutes per plot did not result in more eggs being spotted, and that a second fieldworker did not record any extra eggs in addition to those detected by one person surveying a plot over the 40 minute period. As the woody species composition of each experimental plot varied, the percentage cover of blackthorn was assessed on each side of each plot was assessed July 2013.

*Statistical analyses*

The effects of cutting frequency, timing, intensity and the interactions between them on cumulative Brown hairstreak egg counts over four years was tested using Generalised Linear Models (GLMs) with a Poisson distribution. Percentage cover of blackthorn was included as a covariate in all analyses. Interactions and factors that did not contribute significantly to GLMs were removed one at a time, and changes in the explanatory power of the models were tested using likelihood ratio tests in a backwards selection procedure (LRT, Faraway, 2015). All analyses were carried out in R version 3.0.3 (R Core Development Team, 2014) using package lme4 (Pinheiro et al., 2014). Final model output is given in the Electronic Supplementary Information.

**Results and Discussion**

Two hundred and thirty eggs were recorded during this study, with the number varying between years (total located across experimental plots, minimum = 25 in 2013, maximum = 91 in 2015), in line with numbers of eggs found at a single site in previous studies on Brown hairstreak eggs (e.g. Thomas, 1974). Assessing cumulative egg abundance per plot over all four years of the survey, hedges cut to allow incremental growth had on average 2.3 times more Brown hairstreak eggs on average than those cut back to a standard height and width (LRT $\chi^2_2$=35.0, $P$<0.001; Figure 2). There was an interaction between the frequency and timing of hedgerow cutting on cumulative Brown hairstreak egg abundance (LRT $\chi^2_2$=16.7, $P$<0.05); on hedgerow plots cut in autumn, there were on average 1.3 times more Brown hairstreak eggs if plots were cut once every three years compared to those cut every year (for GLM final model output see electronic supplementary material)..Hedges cut in autumn also had nearly twice as many eggs as those cut in winter, for those plots cut less frequently than every year (1.96 times more eggs when cut in autumn vs. winter for plots cut once every three years; 1.83 times if cut once every two years). More eggs were found on block 3 of the experiment than blocks 1 and 2.

Reductions in Brown hairstreak butterfly distributions have previously been linked to changes in hedgerow management regimes, largely based on anecdotal observations and autecology. The current multi-year study provides the first empirical evidence demonstrating that Brown hairstreak egg abundance in late winter varies with the frequency, timing and intensity of hedgerow cutting. These differences in abundance could be due to egg mortality as a direct result of trimming blackthorn branches containing eggs, resulting in eggs being damaged and not hatching, or hatching at the base of hedges in the mulch that is left by trimming with mechanical flails, without open buds and leaves to provide a food source. Alternatively, the reduced abundance could be caused by female oviposition choice, or by a combination of egg mortality and oviposition choice. Previous studies on Brown hairstreak oviposition preference and the position of eggs suggest that the differences in abundance are largely due to egg mortality. The tendency for female Brown hairstreak butterflies to lay the majority of eggs on recent blackthorn growth (de Vries et al., 2011; Merckx & Berwaerts, 2010; Fartmann & Timmerman, 2006) probably results in high egg mortality as a result of hedgerow trimming, as young growth often protrudes the furthest and is hence most likely to be trimmed. In a study where eggs were marked and counted before and after a single hedgerow cutting event, egg mortality was found to be around 80% (Thomas, 1974). Moreover, Thomas (1974) showed no effect of past management on Brown hairstreak oviposition preference between blackthorn branches and stems in hedges that had last been cut one vs. between one and two vs. more than two years previously.

Cutting at a standard intensity every year in autumn is the most common hedge management outside AES (Sparks & Croxton, 2007; Staley et al., 2012). Current AES in England (ES and the recently launched Countryside Stewardship) include guidance/prescriptions to cut hedgerows either once every two years between September and February, or for a higher payment either once every two years in January/February or once every three years between September – February (Natural England, 2013, 2015). Within the ES AES the most common prescription is cutting once every two years in autumn, to the same height and width on each occasion (Natural England, 2009). The lower payments associated with autumn cutting once every two years within ES are based on evidence that this cutting regime provides less benefit for wildlife, for example in provision of berries for overwintering birds and mammals (Staley et al., 2012) or in increasing Lepidoptera abundance and diversity (Facey et al., 2014; Staley et al., 2016). In contrast to the benefits of winter cutting for other taxa, here we demonstrate that cutting in September results in nearly twice the number of Brown hairstreak eggs compared with cutting hedgerows in February. Brown hairstreak adults often persist until late September and in some years early October, and therefore may have laid eggs after the autumn plots were cut in September. Over the four years of this study, autumn plots were cut between 17$^{th}$ and 29$^{th}$ September. Cutting dates were compared with the last date on which Brown hairstreak adults were recorded in the three counties surrounding the Yarcombe experimental site (Devon, Dorset and Somerset) for each of the four years, using data from the UK Butterfly Monitoring Scheme (http://www.ukbms.org/). Brown hairstreak adults were recorded on the wing at nearby UKBMS sites on or after the autumn cutting date in three of the four years of egg monitoring. The Brown hairstreak species action plan states that cutting hedges in August may be beneficial for Brown hairstreak egg survival (Bourn & Warren, 1998), but here we show that cutting hedges within AES in mid to late September every two to three years can also nearly double the number of eggs, compared with late winter. Clearly, there is a need to balance the benefits of earlier cutting in relation to Brown hairstreak against the conservation of other taxa which are likely to do better under late winter cutting regimes, including the broader Lepidoptera community in hedgerows (Facey et al., 2014; Staley et al., 2016).

Cutting to allow incremental growth forms part of the discretionary management advice for hedgerows within the new Countryside Stewardship AES in England (Natural England, 2015). The prevalence of this form of management within AES cannot be estimated as it is not part of the prescribed management for any AES option. The increase in Brown hairstreak egg abundance under trimming for incremental growth shown here, together with the increased Lepidoptera diversity and abundance found previously (Staley et al., 2016), demonstrate that this form of reduced cutting intensity has benefits across the broader Lepidoptera community that utilizes hedges, and could hence be considered as part of prescribed management under future AES. Butterflies are sometimes considered indicators for invertebrate diversity more broadly, leading to the adoption of butterfly population data as biodiversity indicators (e.g. Fox et al., 2015; Merckx et al., 2013). Trimming for incremental growth thus has the potential to benefit broader invertebrate assemblages.

Over the long term, cutting to allow incremental growth would result in hedges that are taller and wider. However, if landowners do not want hedgerows that are larger eventually, they have the option of cutting hedgerows back to their original height and width periodically, or of rejuvenating hedgerows to encourage regrowth from the base using techniques such as coppicing or hedge-laying (Amy et al., 2015; Staley et al., 2015), following a period of incremental cutting intensity. As well as providing food resources for Lepidoptera larvae and other invertebrates, hedges benefit invertebrates in other ways, such as through the provision of shelter against convective cooling for (ectothermic) species in otherwise often exposed agricultural landscapes (Merckx et al., 2008). The use of a range of hedgerow management regimes to create a heterogenous landscape, including supporting a range of microclimates, may also balance the conservation requirements of a range of taxa (Merckx et al., 2008; Merckx et al. 2010; Oliver et al., 2010).

In conclusion, here we show using a four-year study that the abundance of Brown hairstreak butterfly eggs is greater on hedgerow plots that are cut less frequently, in mid to late September, or at a reduced cutting intensity, compared to the standard practice of cutting hedgerows back to a standard height and width every year. Hedgerow management under AES has clear potential to contribute to Brown hairstreak conservation, but the potentially conflicting needs of other taxa in relation to the timing of hedgerow cutting need to be considered. One possible solution for this would be the inclusion of reduced intensity cutting, shown to benefit both Brown hairstreak butterflies and the wider Lepidoptera community.

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**Figure legends**

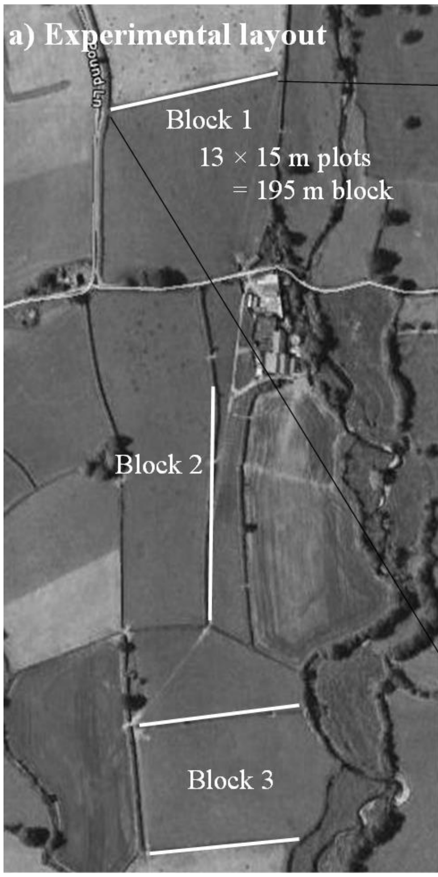
Figure 1

a) Layout of experimental hedgerow blocks and factorial combinations of treatments manipulating the frequency (once every 1 vs. 2 vs. 3 years), timing (A = autumn, September vs. W = winter, January or February) and intensity (S = cut back to standard height and width vs. I = incremental growth, cut to allow 10 cm of recent growth to remain on sides and top) of hedgerow cutting, and a control treatment that was not cut for the duration of the experiment. B) Brown hairstreak butterfly eggs at the experimental plots at Yarcombe, Devon. © Lucy Hulmes, CEH

Figure 2

Cumulative abundance (mean ± SE) of Brown hairstreak eggs over four years (2012 – 2015) on blackthorn in 15m long hedgerow plots subject to cutting frequency (every 1 vs. 2 vs. 3 years), timing (autumn (unfilled) vs. winter (striped)) and intensity (standard (a) vs. incremental growth (b)) experimental treatments since 2010. A control treatment was not cut for the duration of the experiment.

**Figure 1**




| Plot number | Treatment number | Hedgerow cutting treatment frequency, timing, intensity |
|---|---|---|
| 1 | 4 | 1, A, I |
| 2 | 2 | 2, A, S |
| 3 | 3 | 3, A, S |
| 4 | 12 | 3, W, I |
| 5 | 7 | 1, W, S |
| 6 | 5 | 2, A, I |
| 7 | 11 | 2, W, I |
| 8 | 1 | 1, A, S |
| 9 | 9 | 3, W, S |
| 10 | 10 | 1, W, I |
| 11 | 8 | 2, W, S |
| 12 | 6 | 3, A, I |
| 13 | 13 | Control |

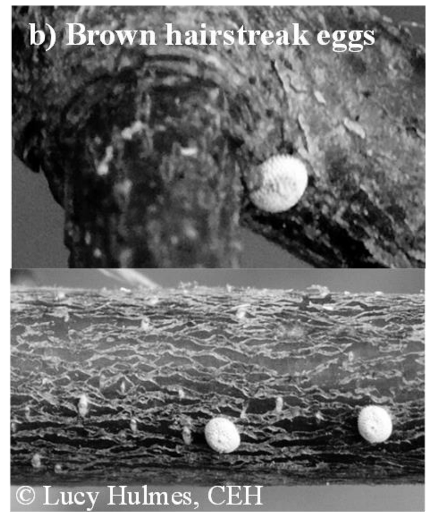
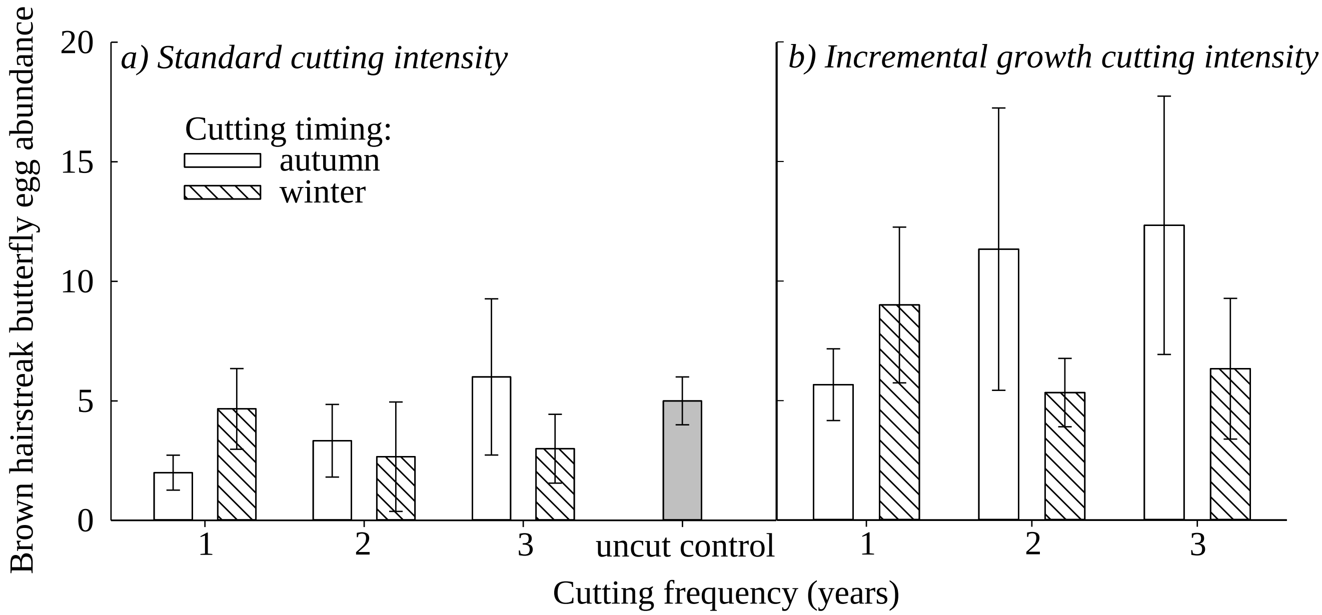


**Figure 2**


a) Standard cutting intensity
b) Incremental growth cutting intensity
Cutting timing:
autumn
winter
Brown hairstreak butterfly egg abundance
0
5
10
15
20
1
2
3
uncut control
1
2
3
Cutting frequency (years)

**Electronic Supplementary Information ICDIV-16-0232 R1: Statistical output for Generalised Linear Model analysis of cumulative number of Brown hairstreak eggs**

> summary(m10a)

Call:
glm(formula = Lep_Thecla_betulae_eggs ~ blockBHcumNC +
cutfreqBHcumNC +
   cuttimeBHcumNC + cutintBHcumNC +
cutfreqBHcumNC:cuttimeBHcumNC,
   family = quasipoisson)

Deviance Residuals:

| Min | 1Q | Median | 3Q | Max |
|---|---|---|---|---|
| -2.561 | -1.428 | -0.055 | 0.607 | 3.048 |

Coefficients:

| | Estimate | Std. Error | t value | Pr(>\|t\|) | |
|---|---|---|---|---|---|
| (Intercept) | 1.317 | 0.380 | 3.468 | 0.002 | ** |
| blockBHcumNC2 | 0.058 | 0.304 | 0.192 | 0.849 | |
| blockBHcumNC3 | 0.806 | 0.262 | 3.080 | 0.005 | ** |
| cutfreqBHcumNC2 | 0.649 | 0.396 | 1.638 | 0.113 | |
| cutfreqBHcumNC3 | 0.872 | 0.382 | 2.280 | 0.031 | * |
| cuttimeBHcumNCw | 0.578 | 0.401 | 1.441 | 0.161 | |
| cutintBHcumNCs | -0.836 | 0.229 | -3.658 | 0.001 | ** |
| cutfreqBHcumNC2:cuttimeBHcumNCw | -1.184 | 0.560 | -2.115 | 0.044 | * |
| cutfreqBHcumNC3:cuttimeBHcumNCw | -1.253 | 0.537 | -2.333 | 0.027 | * |

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Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for quasipoisson family taken to be 2.370382)

   Null deviance: 155.504  on 35  degrees of freedom
Residual deviance:  66.145  on 27  degrees of freedom
AIC: NA