

Article (refereed) - postprint

Staley, Joanna T.; Botham, Marc S.; Chapman, Roselle E.; Amy, Sam R.; Heard, Matthew S.; Hulmes, Lucy; Savage, Joanna; Pywell, Richard F. 2016.
Little and late: how reduced hedgerow cutting can benefit Lepidoptera.

© 2016 Elsevier B.V.

This manuscript version is made available under the CC-BY-NC-ND 4.0 license <http://creativecommons.org/licenses/by-nc-nd/4.0/>



This version available <http://nora.nerc.ac.uk/513314/>

NERC has developed NORA to enable users to access research outputs wholly or partially funded by NERC. Copyright and other rights for material on this site are retained by the rights owners. Users should read the terms and conditions of use of this material at <http://nora.nerc.ac.uk/policies.html#access>

NOTICE: this is the author's version of a work that was accepted for publication in *Agriculture, Ecosystems and Environment*. Changes resulting from the publishing process, such as peer review, editing, corrections, structural formatting, and other quality control mechanisms may not be reflected in this document. Changes may have been made to this work since it was submitted for publication. A definitive version was subsequently published in *Agriculture, Ecosystems and Environment* (2016), 224. 22-28.

[10.1016/j.agee.2016.03.018](https://doi.org/10.1016/j.agee.2016.03.018)

www.elsevier.com/

Contact CEH NORA team at
noraceh@ceh.ac.uk

1 **Little and late: how reduced hedgerow cutting can benefit Lepidoptera**

2

3

4

5

6 Joanna T. Staley*, Marc S. Botham, Roselle E. Chapman, Sam R. Amy, Matthew S. Heard,

7 Lucy Hulmes, Joanna Savage, Richard F. Pywell

8

9

10

11

12 NERC Centre for Ecology & Hydrology, Maclean Building, Benson Lane, Crowmarsh

13 Gifford, Wallingford, Oxfordshire OX10 8BB, UK

14

15 *Corresponding author: jnasta@ceh.ac.uk

16

17

18

19

20

21 **Highlights**

- 22 • Hedgerows provide breeding habitat, shelter and nectar for Lepidoptera
- 23 • Three management treatments were tested using a large-scale field experiment
- 24 • Management effects over three years varied with Lepidoptera life history traits
- 25 • Cutting hedges less often, less intensively and in winter benefits most Lepidoptera
- 26 • Hedgerow agri-environment schemes benefit Lepidoptera but could be improved
- 27 further

28 **Abstract**

29

30 Hedgerows are a key semi-natural habitat for biodiversity in intensive agricultural landscapes
31 across northern Europe and support a large invertebrate fauna. Management can have large
32 effects on the value of hedgerows as a wildlife habitat, thus sensitive management is
33 incentivised through agri-environment schemes (AES). We tested how current and potential
34 future AES hedge management regimes affected the diversity and abundance of Lepidoptera
35 species that utilise the hedge as a breeding resource, using a long term, multi-site,
36 manipulative field experiment. Hedgerow management in some current AES options
37 (reduced trimming frequency and cutting in winter) increased Lepidoptera abundance and the
38 diversity of components of the Lepidoptera community linked with specific lifecycle traits.
39 However, the most frequently applied hedgerow AES option currently applied in the UK
40 (cutting once every 2 years in autumn) did not benefit Lepidoptera compared to standard
41 hedgerow management outside AES (annual trimming in autumn). Decreasing the intensity
42 of hedgerow trimming improves the diversity of the whole Lepidoptera assemblage, and
43 should be considered as part of biodiversity conservation in farmed landscapes.

44

45

46 **Keywords:** Butterflies; Brown hairstreak; Entry Level Stewardship; Moths; *Thecla betulae*;

47

48

49 **1 Introduction**

50

51 Hedgerows are recognised as a priority habitat for conservation in Europe (JNCC, 2012) and
52 protected by legislation in several countries (Baudry et al., 2000). They are a key semi-
53 natural habitat in intensively farmed landscapes and provide food resources, breeding habitat
54 and shelter for a wide range of plant and animal species (Wilson, 1979; Fuller et al., 1995;
55 Dover and Sparks, 2000; Merckx and Berwaerts, 2010; Staley et al., 2013), as well as
56 supporting ecosystem services such as pollination (Morandin and Kremen, 2013; Olsson et
57 al., 2015) and pest control (Morandin et al., 2014). Hedgerows can also form part of
58 dispersal networks for some animal species (Cranmer et al., 2012; Slade et al., 2013), which
59 may become an increasingly important role in future adaptation to climate change (Lawton et
60 al., 2010).

61

62 Hedgerow management in the UK most frequently consists of annual cutting with
63 mechanised flails in early autumn, immediately after harvest, with hedgerows cut back to the
64 same height and width each year (Sparks and Croxton, 2007). This removes almost all the
65 previous season's growth, leaving limited food resources for over-wintering wildlife, few
66 young stems on which buds form for the following year's flowers and berries (Sparks and
67 Croxton, 2007; Staley et al., 2012), and little shelter or habitat for invertebrates (Maudsley et
68 al., 2000) with repercussions for insectivorous birds and mammals. Agri-environment
69 schemes (AES) incentivise more sympathetic management in the UK and elsewhere in
70 Europe (Fuentes-Montemayor et al., 2011; Merckx et al., 2012), and in England 41% of
71 hedgerow length is managed under the Entry Level Stewardship (ELS) AES (Natural
72 England, 2009). Payments are available under ELS for cutting hedges less frequently than
73 every year and in late winter rather than autumn (Natural England, 2013a), and comparable
74 schemes operate in other countries (Fuentes-Montemayor et al., 2011). Hedges managed
75 under ELS should be no less than 1.5m high after cutting (Natural England, 2013a), and in
76 2007 just over 50% of English hedges were over 2m tall, with around 45% between 1 and
77 2m, and a small minority under 1m (Carey et al. 2008). The most popular hedge management
78 option currently applied in ELS, cutting once every two years in autumn, has been shown not
79 to increase floral and berry resources for wildlife relative to hedges managed outside AES
80 (Staley et al., 2012). A new Countryside Stewardship AES to be introduced in England in
81 2016 specifies that hedgerows trimmed every two years should be cut in January or February

82 (Natural England, 2015). There is an urgent need to test the effects of the full range of AES
83 hedgerow management options on the conservation of biodiversity, in addition to developing
84 new, improved management that could form part of future AES prescriptions.

85

86 Lepidoptera comprises one of the largest insect orders in the UK with over 2900 species
87 (Bradley, 2000), and has the largest number of species listed as high conservation priority in
88 the UK (165 Lepidoptera species of 379 terrestrial invertebrate species listed in section 41 of
89 the Natural Environment and Rural Communities Act 2006; Webb et al., 2010). The
90 widespread declines in the abundance and ranges of many butterfly and moth species
91 (Warren and Bourn, 2011) are largely attributed to habitat loss and fragmentation as a result
92 of agricultural intensification, together with other drivers such as climate change (Fox, 2013;
93 Fox et al., 2014). Lepidoptera form a key part of many terrestrial food webs, and are a major
94 food source for insectivorous animals (Fox et al., 2014). Many species are associated with
95 hedgerows, which provide larval food plants, nectar for adults, shelter and overwintering
96 habitats (Dover et al., 1997; Merckx and Berwaerts, 2010). Previous work from one
97 experimental site has demonstrated that hedgerow management can affect the abundance of
98 immobile Lepidoptera larval feeding guilds and their trophic interactions with parasitoids
99 (Facey et al. 2014). In contrast, Fuentes-Montemayor et al. (2011) found that hedgerow
100 management under AES had no effect on populations of macro or micro-moths, but they
101 focussed only on adult moths flying in the vicinity of hedgerows. There is also increasing
102 evidence that hedges may facilitate the use of other semi-natural habitats by Lepidoptera in
103 agricultural landscapes. Slade et al. (2013) found that macro-moths moving between
104 fragmented woodlands were more abundant at isolated trees that were located along a
105 hedgerow rather than out in a field, and Merckx et al. (2009) showed that moth diversity and
106 abundance were increased by hedgerow trees when these were present in a landscape with
107 high uptake of AES options.

108

109 Here, we present the first multi-site, long term field experiment assessing the effects of both
110 current and potential future AES options for hedgerow management on Lepidoptera
111 communities that have a direct trophic link with the hedgerow, by sampling and rearing
112 larvae and pupae from within the hedge. Importantly, our focus on the juvenile stages means
113 that we are able to evaluate the management impacts on use of hedgerows as a breeding
114 habitat by Lepidoptera. This approach avoids attracting adult moths that may be utilising

115 resources in other nearby habitats and across the wider countryside (Fuentes-Montemayor et
116 al. 2011; Merckx and Slade, 2014). We experimentally tested the effects of hedgerow
117 management regimes, including options currently in the English ELS AES (reduced cutting
118 frequency and cutting in winter), standard practice outside AES (annual cutting in autumn)
119 and a reduced cutting intensity treatment that could form part of future hedgerow
120 management prescriptions, on the abundance and diversity of Lepidoptera caterpillars and
121 pupae across five geographically separated sites over three years. We tested the following
122 hypotheses: H1) Lepidoptera diversity and abundance will be greater on hedgerows that are
123 cut less frequently than annually and those that are cut in winter; H2) cutting hedgerows at a
124 reduced intensity to retain recent growth will increase Lepidoptera abundance and diversity,
125 compared to hedges cut back to a standard height and width.

126

127 **2 Methods**

128

129 *2.1 Field sites and experimental design*

130

131 Experimental hedgerows on five field sites were located across southern UK, all on working
132 farms. Two of these sites contained mature hedgerows dominated by hawthorn
133 (*Crataegus monogyna*): Marsh Gibbon, Oxfordshire (planted in 1840: 51°53'N, 1°03'W);
134 and Woburn, Buckinghamshire (planted between 1793 and 1799: 51°58'N, 0°37'W). The
135 other three sites consisted of one blackthorn (*Prunus spinosa*) dominated site at Waddesdon
136 Estate, Oxfordshire (Waddesdon blackthorn: 51°50'N, 0°53'W); a mixed species hedgerow
137 site planted under the Countryside Stewardship AES in the mid-1990s at Waddesdon Estate,
138 Oxfordshire (Waddesdon mixed: 51°50'N, 0°56'W) and a traditional mixed species hedge
139 growing on a bank in Yarcombe, Devon (planted 200 – 300 years ago: 50°51'N, 3°03'W).

140

141 Three experimental treatments were applied in full factorial combination: 1) frequency of
142 cutting (once every 1 vs. 2 vs. 3 years); 2) timing of cutting (early autumn, September vs. late
143 winter, January / February); and 3) intensity of cutting (standard cutting to the same height
144 and width each time vs. incrementally raising the cutter bar by approximately 10 cm each
145 time the hedge is cut, resulting in a slightly wider and taller hedge). Treatments were applied
146 to 20 m long contiguous hedgerow plots, replicated in three randomised blocks at each of the
147 five sites. In addition, each block contained a control plot that was not cut during the

148 experiment (Figure 1). All experimental plots within a site contained the same woody tree
149 and shrub species. .

150

151 Hedge cutting treatments were applied using tractor mounted flails, operated by local
152 contractors who regularly cut the hedges on each farm, to ensure that the cutting was
153 representative of hedgerow cutting in the wider countryside. All experimental plots including
154 the controls were cut prior to the start of the experiment in late winter (January / February
155 2010). Hedgerow cutting treatments were applied for 3 years from September 2010. The
156 winter cutting treatments were not applied at the Waddesdon blackthorn field site, due to a
157 shortage of suitable hedgerow. Total replication of each factorial combination of the three
158 cutting treatments was thus 15 (for autumn cutting treatments) or 12 (for winter cutting
159 treatments as these were not applied at the Waddesdon blackthorn site) across the five field
160 sites.

161

162 *2.2 Lepidoptera collection and identification*

163

164 Lepidoptera larvae and pupae were collected in May from experimental plots for each of 3
165 years (2011 – 2013), using a modified beating method (Maudsley et al., 2002; Amy et al.,
166 2015). A 2 m long × 11.2 cm wide section of guttering was inserted through the width of
167 each hedgerow plot approximately 80 cm above the ground. The hedgerow was beaten five
168 times with a 2 m long × 27 mm diameter steel range pole, approximately 1 m above the
169 inserted length of guttering. Invertebrates which were knocked into the guttering were swept
170 gently using a soft paint brush into a plastic bag, which was sealed, stored in a cool box and
171 then at 4 °C in a refrigerator for up to 48 h. Each hedgerow plot was sampled in three places
172 on each occasion, spaced at 5 m, 10 m and 15 m along its length. The invertebrate samples
173 from these three positions on each plot were then combined.

174

175 Lepidoptera larvae and pupae were separated from other invertebrates in the laboratory.

176 Where possible, Lepidoptera larvae were identified to species (later instars of many macro-
177 moth species, e.g. The Magpie *Abraxas glossulariata*, Yellow-tail *Euproctis similis*) using
178 Porter (2010), Sterling and Parsons (2012) and online resources (ukmoths.org.uk). Pupae and
179 larvae that could not be identified were reared individually on hawthorn foliage in glass tubes
180 with small air holes in plastic lids. Fresh hawthorn foliage was provided every 2-3 days and

181 frass removed from the tubes. Larvae were reared in an open-sided insectary, to ensure
182 external temperature and day-length cues for pupation and adult emergence. Emerging adults
183 were identified to species.

184

185 The height of the woody vegetation in each hedgerow plot was measured to the nearest 10 cm
186 using graduated poles. Heights were measured each year at five evenly spaced positions
187 along each plot.

188

189 *2.3 Statistical analysis*

190

191 The beating method sampled Lepidoptera from a fixed height above the guttering as it was
192 not possible to beat the full height of each plot consistently, because plot height varied
193 depending on whether each plot had been cut recently. Abundance of Lepidoptera larvae and
194 pupae were scaled for plot height each year, by multiplying abundance by average height for
195 each plot. The converted Lepidoptera data were combined to give cumulative data across the
196 three years of sampling.

197

198 Shannon-Wiener diversity indices and species richness were calculated for each plot. In
199 addition, we divided species into two groups based on their susceptibility to cutting regimes
200 using life cycle information in Emmet and Heather (1991). We defined species as likely to be
201 ‘vulnerable’ to autumn cutting if they occurred as eggs, larvae or pupae on woody hedgerow
202 plants in September, and as ‘robust’ if they occurred as adults, or as larvae or pupae within
203 the soil or detritus in September.

204

205 The effects of cutting frequency, cutting timing, cutting intensity and the interactions between
206 them on Lepidoptera abundance and Shannon-Wiener diversity indices were tested using
207 linear mixed effect models (LMEs), and the effects on species richness were tested using
208 generalised linear mixed effects models (GLMMs) with a Poisson distribution. Site was
209 included as a random variable in all mixed effect models (Faraway, 2005). Lepidoptera
210 abundance could not be analysed as count data using GLMMs, as following scaling by plot
211 height (above) these data no longer consisted of integers, a requirement for a Poisson
212 distribution. Lepidoptera abundance and Shannon-Wiener diversity were log transformed
213 prior to analysis, and model diagnostics showed this was an appropriate transformation.

214 Interactions and factors that did not contribute significantly to LME or GLMM models were
215 removed one at a time, and changes in the explanatory power of the model were tested using
216 likelihood ratio tests (LRT, Faraway, 2005). All analyses were carried out in R version 3.0.3
217 (R Core Development Team, 2014) using packages lme4 (Bates et al., 2015) and vegan
218 (Oksanen et al., 2013).

219

220 **3 Results**

221

222 Over 3 years 1100 Lepidoptera pupae and larvae were collected, 789 of which were identified
223 to 61 species. A number of specimens could not be identified because they died during the
224 rearing process, or parasitoids hatched out instead of adult Lepidoptera. Emergence rate was
225 74% on average, and differed slightly between sites (average maximum 83% at the
226 Waddesdon mixed species site, minimum average emergence rate 71% at Yarcombe,
227 emergence rate differed significantly only between Waddesdon mixed species and Yarcombe,
228 $t_{152} = 2.15$, $P < 0.05$). All but one species were moths; the only butterfly species collected
229 was brown hairstreak (*Thecla betulae*).

230

231 *3.1 Lepidoptera abundance*

232

233 There were significantly more (16%) larvae and pupae on hedges cut in winter compared
234 with those cut in autumn ($t_{152} = 2.02$, $P < 0.05$; Figure 2). Hedgerow plots cut every 3 years
235 also had a significantly higher abundance (4%) than those cut annually ($t_{152} = 2.7$, $P < 0.01$)
236 while plots cut once every 2 years did not differ from those cut annually. There was a nearly
237 significant interaction between the timing and frequency of hedgerow trimming (LRT $\chi^2_2 =$
238 5.9 , $P = 0.052$), which indicated that the increased abundance due to winter trimming may be
239 limited to hedgerow plots cut once every 1 or 2 years. There was no significant effect of
240 trimming intensity, or any interaction involving trimming intensity and the other cutting
241 treatments, on abundance.

242

243 *3.2 Species richness and Shannon-Wiener diversity of Lepidoptera*

244

245 Lepidoptera species richness was greater (18%) on plots cut for incremental growth
246 compared with standard cutting, though the difference between incremental growth and

247 standard plots was not quite statistically significant (LRT $\chi^2_1 = 3.7$, $P = 0.054$; Figure 3).
248 Shannon-Wiener diversity of the whole community was significantly greater (15%) on
249 hedgerow plots cut for incremental growth compared with those cut to a standard height and
250 width each time (LRT $\chi^2_1 = 3.9$, $P < 0.05$; Figure 4). There was also a non-significant trend
251 towards an interaction between the frequency, timing and intensity of cutting (LRT $\chi^2_2 = 4.7$,
252 $P = 0.096$), as plots cut incrementally every two years in winter had reduced Shannon-Wiener
253 diversity.

254

255 Species richness of the ‘vulnerable’ species group was significantly affected by an interaction
256 between the frequency and timing of cutting (LRT $\chi^2_2 = 6.9$, $P < 0.05$), as plots cut in autumn
257 had a greater species richness (54%) if they were cut once in 3 years compared with every
258 year ($z_{151} = 2.6$, $P < 0.05$). Species richness of the ‘robust’ species group was not affected by
259 the frequency, timing or intensity of hedgerow cutting.

260

261 Shannon-Wiener diversity of the ‘robust’ species group was significantly greater (15%) on
262 hedgerow plots cut for incremental growth compared with standard plots ($t_{117} = 2.3$, $P < 0.05$;
263 Figure 5) as was found for the whole Lepidoptera community. In addition, there was a nearly
264 significant interaction between the intensity and timing of cutting, indicating that for this
265 ‘robust’ species group, the effect of cutting intensity was stronger for plots cut in autumn
266 (LRT $\chi^2_1 = 3.83$, $P = 0.0504$). Shannon-Wiener diversity of the ‘vulnerable’ species group
267 was not significantly affected by any of the cutting treatments.

268

269

270 **4 Discussion**

271

272 This is the first long-term, multi-site field experiment assessing the effects on Lepidoptera of
273 both current and potential future AES options for hedgerow management. Lepidoptera
274 abundance was most strongly affected by the timing of trimming, and was increased by 16%
275 on hedgerow plots cut in late winter, as well as being 4% greater on hedges cut once every 3
276 years. The majority of hedges not in AES (approximately 237 000 km; Natural England,
277 2009) are cut every year in early autumn after crops are harvested (Sparks and Croxton,
278 2007), so the current most common hedgerow management practice outside AES results in a
279 lower abundance of Lepidoptera larvae and pupae than could be achieved under some AES

280 management options. While our experimental work was conducted in southern England,
281 other European countries have AES that specify reduced cutting frequencies and cutting at a
282 particular time of year (e.g. Fuentes-Montemayor et al., 2011), so the findings of our study
283 have broad geographical relevance.

284

285 The Shannon-Wiener diversity of hedgerow Lepidoptera assemblages was more strongly
286 affected by the intensity of cutting than by frequency or timing, with a large increase (15%)
287 in diversity on plots that were cut less intensely, relative to those cut back to a standard height
288 and width. Lepidoptera species richness was also greater on plots cut for incremental growth.
289 Cutting intensity does not form part of current hedgerow English AES prescriptions (Natural
290 England, 2013a, b, 2015), so this shows a strong potential benefit of introducing a reduced
291 cutting intensity option in the future. Current AES that promote cutting of hedges once every
292 3 years and cutting in winter thus benefit Lepidoptera by increasing their abundance, as well
293 as the diversity of part of the Lepidoptera assemblage. However, our results show no benefit
294 to Lepidoptera of cutting in autumn once every 2 years, currently the most popular hedgerow
295 option in England within the ELS AES (Table 1). There has been a shift away from this
296 option of cutting once every 2 years in autumn due to a reduction in the incentives (number
297 of points awarded) offered under ELS for this option in 2013 (Table 1), and this option does
298 not form part of new Countryside Stewardship AES which has just started in 2016 (Natural
299 England, 2015).

300

301 Uptake of AES hedgerow options that specify trimming in January or February may be
302 limited by poor access for hedgerow management in wet conditions in late winter, and
303 dependant on the timing of agricultural activities. Many landowners choose to cut hedges
304 immediately after harvest when no crops are present to restrict access, prior to sowing winter
305 crops. Incremental trimming could be a useful addition to AES hedgerow options where late
306 winter cutting is not an option. In addition to increasing Lepidoptera diversity as shown here,
307 incremental trimming may result in some hedgerow berries being retained for overwintering
308 wildlife compared with cutting back to the same height and width each year which removes
309 all recent growth. Over the long term, incremental trimming would result in hedges that are
310 taller and wider (on a two year incremental trimming cycle, hedge height would increase
311 approximately one metre over 20 years). If landowners do not want larger hedgerows they
312 have two options following a period of incremental trimming; cutting hedgerows back to

313 their original height and width periodically, or rejuvenating hedgerows to encourage regrowth
314 from the base using a technique such as coppicing or hedge-laying. The pros and cons of
315 different rejuvenation methods, including the use of a circular saw to cut several years of
316 thick, woody growth from a large hedgerow, has been the subject of another large-scale
317 manipulative field experiment and are discussed elsewhere (Amy et al., 2015, Staley et al.,
318 2015).

319

320 Facey et al. (2014) found that Lepidoptera with concealed larvae (e.g. leaf miners, case
321 bearers) were more abundant on hedges cut once every 2 or 3 years compared with those cut
322 annually, and had greater species richness on hedges cut in winter rather than autumn. Their
323 findings for concealed Lepidoptera are broadly similar to those of the current study, but in
324 contrast Facey et al. (2014) found no effect of timing or frequency of cutting on free-living
325 larvae, which form the majority of the Lepidoptera assemblage in the current study. Facey et
326 al. (2014) focussed on Lepidoptera at a single field site in one year, so the data were less
327 comprehensive and more affected by annual variation in insect populations than those
328 analysed above, which were collected from five field sites over three years. Fuentes-
329 Montemayor et al. (2011) surveyed adult moths using heath light traps next to hedges that
330 were in AES (cut once every three years) vs. those that were not in AES (for which the most
331 common management is annual trimming), but in contrast to our study found no effects of
332 hedge management. Heath light traps attract moths over fairly short distances (averages of
333 10-27m in woodlands depending on moth family, Merckx and Slade, 2014), but as hedges are
334 narrow, linear habitats they are likely to attract and sample adult moths from neighbouring
335 habitats such as field margins and crops, in addition to those using the hedgerow. This may
336 reduce the likelihood of detecting hedgerow management treatment effects. Neither Fuentes-
337 Montemayor et al., (2011) nor Facey et al. (2014) tested trimming intensity, shown here to be
338 the strongest driver of Lepidoptera diversity.

339

340 The response of Lepidoptera species richness and diversity to the frequency and timing of
341 hedgerow cutting varied with life cycle traits in the current study. More Lepidoptera species
342 are likely to be in larval diapause or pupating in soil or detritus in late winter than in early
343 autumn, when leaves are still present on hedgerow plants (Emmet and Heather, 1991). We
344 split Lepidoptera species using temporally sensitive classes into ‘vulnerable’ species using
345 foliage in early autumn vs. ‘robust’ species. Frequency and timing of cutting was important

346 for 'vulnerable' species, since species richness for this group was maximised by cutting
347 hedges in winter or once in three years, while in contrast diversity of the 'robust' group of
348 Lepidoptera species was most strongly increased by reducing cutting intensity. Over half of
349 the Lepidoptera species sampled in this study were in the 'vulnerable' group (39 out of 61
350 species) so late winter cutting would be generally beneficial for hedgerow Lepidoptera,
351 though individual species may be disadvantaged by this (e.g. Brown hairstreak butterfly
352 discussed below). The effects of cutting timing may also be modified under other
353 environmental drivers such as future climate change, which many moth and butterfly species
354 are highly sensitive to (Fox et al., 2014). A mixed regime of cutting timing might be most
355 beneficial for maximising Lepidoptera diversity. The complexity of enforcing this
356 prescription is likely to make it untenable at a national level within AES, but it could be
357 achieved in schemes where AES management is more specifically tailored to individual
358 farms (e.g. in the higher tier of the new Countryside Stewardship scheme in England; Natural
359 England, 2015) or on a regional basis.

360

361 Brown hairstreak (*T. betulae*) was the only Lepidoptera species found in this study that is
362 classified of high conservation priority in the UK (listed in section 41 of the Natural
363 Environment and Rural Communities Act 2006; Webb et al., 2010). It flies from late June to
364 September and larvae feed on *Prunus* species, mainly blackthorn (*P. spinosa*). Female brown
365 hairstreak butterflies lay eggs on young blackthorn stems close to a bud or base of a spine
366 which remain over winter (Merckx and Berwaerts, 2010), and are thus vulnerable to
367 mechanised hedge trimming. If hedges are cut in early September, female brown hairstreaks
368 may lay eggs later in September after trimming, but eggs laid on hedges prior to winter hedge
369 management are likely to be cut off or destroyed during flailing. Too few brown hairstreak
370 caterpillars were found in the current study to detect effects of hedgerow management on this
371 one species, so ongoing brown hairstreak winter egg surveys are being conducted. In areas
372 where brown hairstreak are known to be present, early autumn trimming of hedges containing
373 blackthorn may be better for this species than cutting in late winter. In the majority of the
374 UK, where brown hairstreak is absent, the majority of Lepidoptera species are likely to
375 benefit from winter trimming. As discussed above, it may be possible to tailor hedgerow
376 management to benefit brown hairstreak in specific areas, using a scheme such as the higher
377 tier of the new Countryside Stewardship scheme, where management can be targeted using
378 regional and local objectives (Natural England, 2015).

379

380 4.1 *Conclusions*

381 This study shows that current AES which promote a reduced hedgerow cutting frequency
382 (once in 3 years) and cutting in winter may benefit Lepidoptera through increased abundance
383 and greater diversity of part of the Lepidoptera assemblage. The most frequent AES
384 hedgerow option currently applied under ELS in England, cutting in autumn once every 2
385 years, does not benefit Lepidoptera and has previously been shown not to increase hedgerow
386 resources for other wildlife groups (Staley et al., 2012), compared to standard non-AES
387 hedge management. Reducing the intensity of hedgerow trimming could increase diversity
388 across the whole Lepidoptera assemblage, and should be considered as a potential addition
389 both to future AES prescriptions and more broadly within landscape management.

390

391

392 **Acknowledgements**

393 This project was funded by Defra grant BD2114. Thanks to Emily Ledger of Natural England
394 for providing the data on ELS hedgerow option uptake. We thank Sarah Hulmes, Jodey
395 Peyton, Pete Nuttall, Rachel MacDonald and Gemma Baron for their assistance collecting
396 data, Hannah Dean for database assistance and members of the hedgerow project advisory
397 group for their input.

398

399 **References**

- 400 Amy, S.R., Heard, M.S., Hartley, S.E., George, C.T., Pywell, R.F., Staley, J.T., 2015.
401 Hedgerow rejuvenation management affects invertebrate communities through changes
402 to habitat structure. *Basic and Applied Ecology* 16, 443-451.
- 403 Bates, D., Maechler, M., Bolker, B., Walker, S., 2015. Fitting Linear Mixed-Effects Models
404 Using lme4. *Journal of Statistical Software* 67, 1-48.
- 405 Baudry, J., Bunce, R.G.H., Burel, F., 2000. Hedgerows: An international perspective on their
406 origin, function and management. *Journal of Environmental Management* 60, 7-22.
- 407 Bradley, J.D., 2000. Checklist of Lepidoptera Recorded from the British Isles. Bradley &
408 Bradley, Fording-bridge, UK.
- 409 Carey, P.D., Wallis, S., Chamberlain, P.M., Cooper, A., Emmett, B.A., Maskell, L.C.,
410 McCann, T., Murphy, J., Norton, L.R., Reynolds, B., Scott, W.A., Simpson, I.C.,
411 Smart, S.M., Ulyett, J.M., 2008. Boundary and linear features, chapter 5 in
412 Countryside Survey: UK Results from 2007. eds P.D. Carey, S. Wallis, P.M.
413 Chamberlain, A. Cooper, B.A. Emmett, L.C. Maskell, T. McCann, J. Murphy, L.R.
414 Norton, B. Reynolds, W.A. Scott, I.C. Simpson, S.M. Smart, J.M. Ulyett. Centre for
415 Ecology and Hydrology.
- 416 Cranmer, L., McCollin, D., Ollerton, J., 2012. Landscape structure influences pollinator
417 movements and directly affects plant reproductive success. *Oikos* 121, 562-568.
- 418 Dover, J., Sparks, T., 2000. A review of the ecology of butterflies in British hedgerows.
419 *Journal of Environmental Management* 60, 51-63.
- 420 Dover, J.W., Sparks, T.H., Greatorex-Davies, J.N., 1997. The importance of shelter for
421 butterflies in open landscapes. *Journal of Insect Conservation* 1, 89-97.
- 422 Emmet, A.M., Heather, J., 1991. Moths and Butterflies of Great Britain and Ireland:
423 Lasiocampidae to Thyatiridae with Life History Chart of the British
424 Lepidoptera. Volume 7(2). Harley Books, Colchester, Essex, UK.
- 425 Facey, S.L., Botham, M.S., Heard, M.S., Pywell, R.F., Staley, J.T., 2014. Lepidoptera
426 communities and agri-environment schemes; examining the effects of hedgerow cutting
427 regime on Lepidoptera diversity, abundance and parasitism. *Insect Conservation and*
428 *Diversity* 7, 543-552.
- 429 Faraway, J.J., 2005. *Extending the Linear Model with R: Generalised Linear, Mixed Effects*
430 *and Nonparametric Regression Models*. Chapman and Hall, Florida, USA.

431 Fox, R., 2013. The decline of moths in Great Britain: a review of possible causes. *Insect*
432 *Conservation and Diversity* 6, 5-19.

433 Fox, R., Oliver, T.H., Harrower, C., Parsons, M.S., Thomas, C.D., Roy, D.B., 2014. Long-
434 term changes to the frequency of occurrence of British moths are consistent with
435 opposing and synergistic effects of climate and land-use changes. *Journal of Applied*
436 *Ecology* 51, 949-957.

437 Fuentes-Montemayor, E., Goulson, D., Park, K.J., 2011. The effectiveness of agri-
438 environment schemes for the conservation of farmland moths: assessing the importance
439 of a landscape-scale management approach. *Journal of Applied Ecology* 48, 532-542.

440 Fuller, R.J., Gregory, R.D., Gibbons, D.W., Marchant, J.H., Wilson, J.D., Baillie, S.R.,
441 Carter, N., 1995. Population declines and range contractions among lowland farmland
442 birds in Britain. *Conservation Biology* 9, 1425-1441.

443 JNCC, DEFRA (on behalf of the Four Countries Biodiversity Group), 2012. UK Post-2010
444 Biodiversity Framework. JNCC, Peterborough, UK.

445 Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J.,
446 Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland,
447 W.J., Tew, T.E., Varley, J., Wynne, G.R., 2010. Making Space for Nature: a review of
448 England's wildlife sites and ecological network. DEFRA, London, UK.

449 Maudsley, M., Seeley, B., Lewis, O., 2002. Spatial distribution patterns of predatory
450 arthropods within an English hedgerow in early winter in relation to habitat variables.
451 *Agriculture Ecosystems & Environment* 89, 77-89.

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

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

458 Merckx, T., Feber, R.E., Dulieu, R.L., Townsend, M.C., Parsons, M.S., Bourn, N.A.D.,
459 Riordan, P., MacDonald, D.W., 2009. Effect of field margins on moths depends on
460 species mobility: Field-based evidence for landscape-scale conservation. *Agriculture*
461 *Ecosystems & Environment* 129, 302-309.

462 Merckx, T., Marini, L., Feber, R.E., Macdonald, D.W., 2012. Hedgerow trees and extended-
463 width field margins enhance macro-moth diversity: implications for management.
464 Journal of Applied Ecology 49, 1396-1404.

465 Merckx, T., Slade, E.M., 2014. Macro-moth families differ in their attraction to light:
466 implications for light-trap monitoring programmes. Insect Conservation and Diversity
467 7, 453-461.

468 Morandin, L.A., Kremen, C., 2013. Bee Preference for Native versus Exotic Plants in
469 Restored Agricultural Hedgerows. Restoration Ecology 21, 26-32.

470 Morandin, L.A., Long, R.F., Kremen, C., 2014. Hedgerows enhance beneficial insects on
471 adjacent tomato fields in an intensive agricultural landscape. Agriculture, Ecosystems
472 and Environment 189, 164-170.

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

475 Natural England, 2013a. Entry Level Stewardship - Environmental Stewardship Handbook,
476 fourth edition. DEFRA, UK

477 Natural England, 2013b. Higher Level Stewardship - Environmental Stewardship Handbook.
478 DEFRA, UK

479 Natural England, 2015. Countryside Stewardship - Options and Supplements, DEFRA, UK.
480 [https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/447651/
481 cs-options-supplements.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/447651/cs-options-supplements.pdf), accessed 02/09/2015

482 Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., Simpson,
483 G.L., Solymos, P., Stevens, M.H.M., Wagner, H., 2013. vegan: Community Ecology
484 Package. R package version 2.0-10. <http://CRAN.R-project.org/package=vegan>.

485 Olsson, O., Bolin, A., Smith, H.G., Lonsdorf, E.V., 2015. Modeling pollinating bee visitation
486 rates in heterogeneous landscapes from foraging theory. Ecological Modelling 316,
487 133-143.

488 Porter, J., 2010. Colour Identification Guide to Caterpillars of the British Isles
489 (Mecoptera). Apollo Books, Stenstrup, Denmark.

490 R Core Development Team, 2014. R: A Language and Environment for Statistical
491 Computing URL <http://www.R-project.org/>. R Foundation for Statistical Computing,
492 Vienna, Austria.

493 Slade, E.M., Merckx, T., Riutta, T., Bebbber, D.P., Redhead, D., Riordan, P., Macdonald,
494 D.W., 2013. Life-history traits and landscape characteristics predict macro-moth
495 responses to forest fragmentation. *Ecology* 94, 1519-1530.

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

499 Staley, J.T., Amy, S.R., Adams, N.P., Chapman, R.E., Peyton, J.M., Pywell, R.F., 2015. Re-
500 structuring hedges: rejuvenation management can improve the long term quality of
501 hedgerow habitats for wildlife. *Biological Conservation* 186, 187-196.

502 Staley, J.T., Bullock, J.M., Baldock, K.C.R., Redhead, J.W., Hooftman, D.A.P., Button, N.,
503 Pywell, R.F., 2013. Changes in hedgerow floral diversity over 70 years in an English
504 rural landscape, and the impacts of management. *Biological Conservation* 167, 97-105.

505 Staley, J.T., Sparks, T.H., Croxton, P.J., Baldock, K.C.R., Heard, M.S., Hulmes, S., Hulmes,
506 L., Peyton, J., Amy, S.R., Pywell, R.F., 2012. Long-term effects of hedgerow
507 management policies on resource provision for wildlife. *Biological Conservation* 145,
508 24-29.

509 Sterling, P., Parsons, M., 2012. *Field Guide to the Micromoths of Great Britain and Ireland.*
510 *British Wildlife Publishing Ltd, Gillingham, UK.*

511 Warren, M.S., Bourn, N.A.D., 2011. Ten challenges for 2010 and beyond to conserve
512 Lepidoptera in Europe. *Journal of Insect Conservation* 15, 321-326.

513 Webb, J.R., Drewitt, A.L., Measures, G.H., 2010. *Managing for species: Integrating the needs*
514 *of England's priority species into habitat management. Part 1 Report Natural England*
515 *Research Report NERR024.*

516 Wilson, R., 1979. *The Hedgerow Book.* David & Charles Ltd, Newton Abbot.
517

518 **Table and figure legends**

519

520 **Table 1**

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

528

529 **Figure 1**

530 Layout of experimental hedgerow blocks at Woburn field site and factorial combinations of
531 treatments manipulating the frequency (once every 1, 2 or 3 years), timing (A = autumn,
532 September, W = winter, January or February) and intensity (S = cut back to standard height
533 and width, I = incremental growth, cut to allow 10 cm of recent growth to remain on sides
534 and top) of hedgerow cutting, and a control treatment that was not cut for the duration of the
535 experiment. Each treatment was replicated once at each of three blocks, and applied to 20 m
536 long contiguous hedgerow plots. Control plots were not cut during the experiment.

537

538 **Figure 2**

539 Cumulative abundance (mean \pm SE) of Lepidoptera larvae and pupae in hedgerow plots
540 subject to cutting frequency, timing and intensity treatments over three years (2011 – 2013).

541

542 **Figure 3**

543 Species richness (mean \pm SE) of the Lepidoptera larvae and pupae in hedgerow plots subject
544 to cutting frequency, timing and intensity treatments over three years (2011 – 2013).

545

546 **Figure 4**

547 Diversity (Shannon-Wiener index, mean \pm SE) of the Lepidoptera community in hedgerow
548 plots subject to cutting frequency, timing and intensity treatments over three years (2011 –
549 2013).

550

551 **Figure 5**

552 The response of Lepidoptera to the frequency, timing and intensity of hedgerow cutting of
553 hedgerow, divided by life cycle stage and location in September: *left*) Lepidoptera species
554 that are not likely to be present on the hedgerow as they are pupae or larvae within soil or
555 detritus in September, or adults that can fly away in response to the disturbance of hedge
556 trimming; and *right*) species that are likely to be on the hedgerow in September, as they are
557 present in leaves as larvae or pupae, or are eggs on hedgerow plants.

Table 1

ELS options	ELS agreements starting 2009 – 2012			ELS agreements starting 2013 – 2014		
	Option hedgerow cutting regime	Points per 100m*	Length of hedgerow (km)	Option hedgerow cutting regime	Points per 100m*	Length of hedgerow (km)
EB1 / EB8	Cut both sides of each hedgerow not more often than once in 2 years	22 / 38	60,811.33	Hedgerow management for landscape: Cut both sides of each hedgerow not more often than once in 2 years	16 / 38	6,505.09
EB3 / EB10	Cut both sides of each hedgerow not more often than once in 3 years	42 / 56	28,409.58	Hedgerow management for landscape and wildlife: Cut both sides of each hedgerow not more often than once every 3 years or cut each hedgerow no more than once every 2 years between 1 January and 28 February.	42 / 56	5,083.14

Figure 1

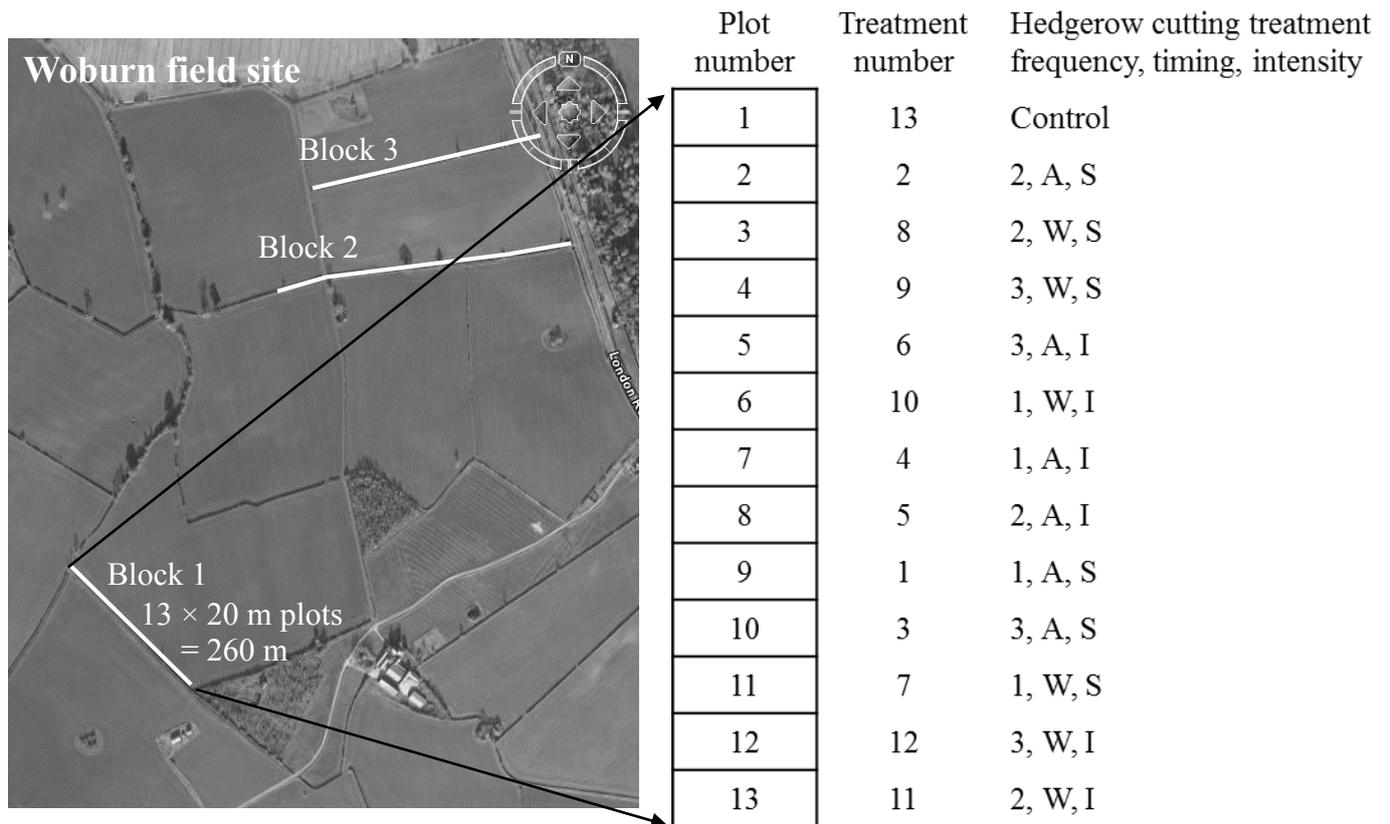


Figure 2

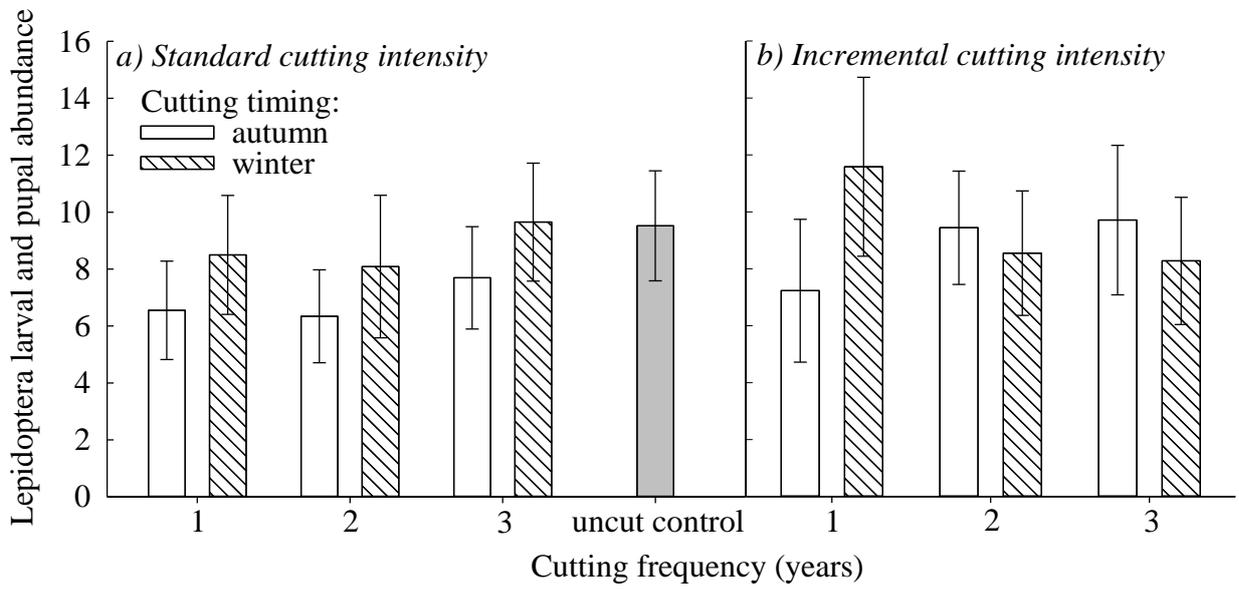


Figure 3

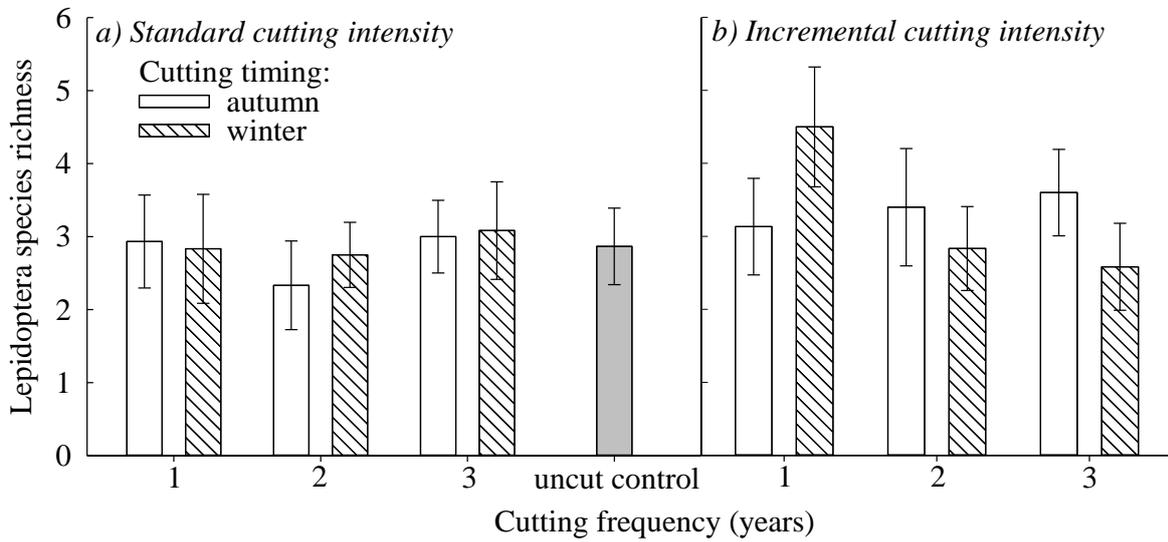


Figure 4

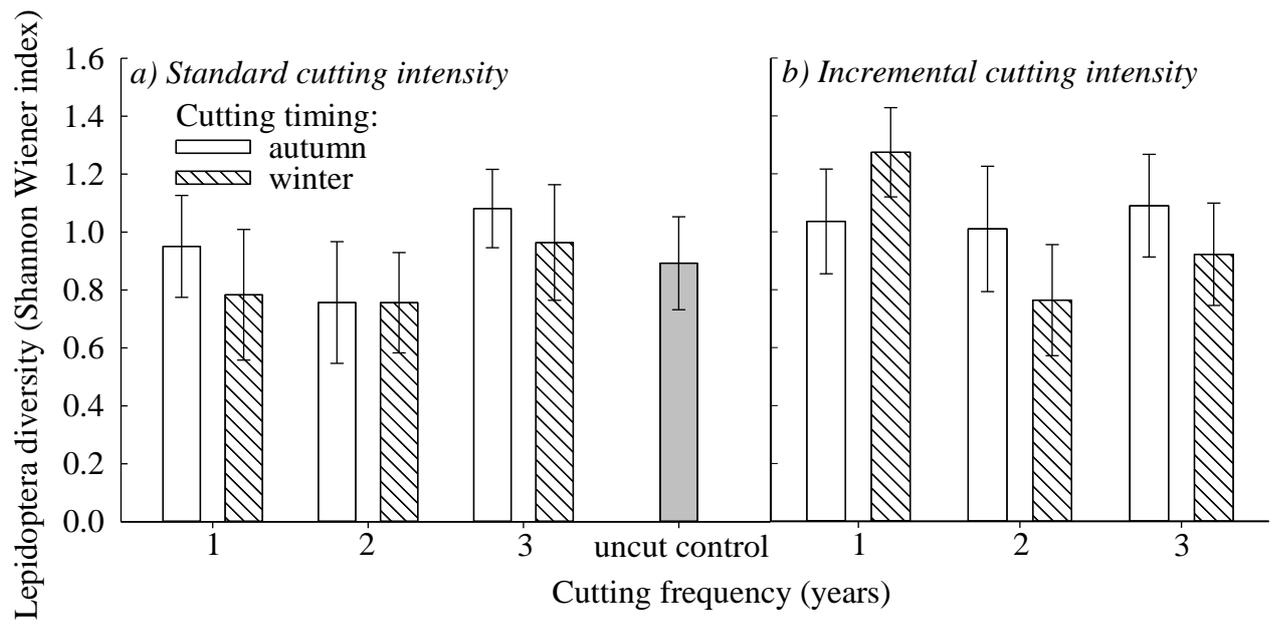


Figure 5

Species divided by their stage and location in September

Larva or pupa in soil / detritus or adults



E.g. *The Chestnut* (*Conistra vacinii*), adults in September

- Diversity (Shannon-Weiner) 15% greater on incremental growth hedgerow plots compared with standard cutting intensity

Larva or pupa on hedgerow foliage, or eggs on hedge plants



E.g. *Hedyia nubiferana*, larvae present in foliage that is silked together (spinnings) in September

- For hedges cut in autumn, species richness was 54% greater if cut once every 3 years compared with every year.