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Contact CEH NORA team at  
[noraceh@ceh.ac.uk](mailto:noraceh@ceh.ac.uk)

1 **Comparison of trends in butterfly populations between monitoring schemes**

2 Roy, D.B.<sup>1</sup>, Ploquin, E.F.<sup>1</sup>, Randle, Z.<sup>2</sup>, Risely, K.<sup>3</sup>, Botham, M.S.<sup>1</sup>, Middlebrook, I.<sup>2</sup>, Noble, D.<sup>3</sup>,  
3 Cruickshanks, K.<sup>4</sup>, Freeman, S.N.<sup>1</sup> & Brereton, T.M.<sup>2</sup>

4

5 <sup>1</sup> NERC Centre for Ecology & Hydrology, UK

6 <sup>2</sup> Butterfly Conservation, Wareham, UK

7 <sup>3</sup> British Trust for Ornithology, Thetford, UK

8 <sup>4</sup> Footprint Ecology, Wareham, UK

9

10 Corresponding author: D.B. Roy. NERC Centre for Ecology & Hydrology, Wallingford, UK

11 Email: [dbr@ceh.ac.uk](mailto:dbr@ceh.ac.uk)

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16 biodiversity indicators

17 **Abstract**

18 Butterflies are an important indicator of the impacts of environmental change. Butterfly Monitoring  
19 Schemes have provided national and Europe-wide trends in their abundance and been widely used  
20 for research. Most schemes sample sites that are self-selected by contributors and therefore tend  
21 to cover locations that are rich in butterflies. To provide a more representative assessment of  
22 butterfly populations, the Wider Countryside Butterfly Survey (WCBS) was developed with a  
23 stratified-random sample of survey sites across the UK. We compare butterfly trends from the  
24 WCBS locations against those measured from traditional butterfly transects which are typically  
25 located in areas of good quality semi-natural habitats. Across the 26 species analysed, there was a  
26 significant positive relationship between trends measured from the two schemes between 2009 and  
27 2013, the period when both schemes were operating fully. There was a tendency (17 out of 26  
28 species analysed) for these changes to be greater within WCBS compared to traditional BMS  
29 transects, although this effect was not consistent across comparisons between pairs of consecutive  
30 years. When assessing these individual year-to-year changes, there was however a significant  
31 correlation between the two schemes in all cases. Over relatively short time periods, weather  
32 patterns are likely to dominate butterfly population fluctuations and lead to comparable trends  
33 across monitoring schemes. Over longer time periods, differences in land management may affect  
34 habitat condition differently for protected areas versus the wider countryside and it is therefore  
35 important to maintain comprehensive butterfly monitoring programmes to detect and interpret  
36 such effects.

37 **Introduction**

38 Parties to the United Nations (UN) Convention on Biological Diversity (CBD) recognise the  
39 need to reduce the rate of biodiversity loss (CBD 2010). Monitoring of species' populations is one of  
40 the key biodiversity variables for measuring progress against national goals and targets for  
41 conserving biodiversity (Pereira et al. 2013), as well as providing the additional benefits of being a  
42 rich resource for fundamental research (Fisher et al. 2010), policy and conservation management  
43 (Pereira et al. 2012).

44 Monitoring by standardised counts has been successful for a limited set of taxa but remains  
45 severely geographically restricted, with most programmes operating in developed countries (Pereira  
46 et al. 2010). Insect populations pose particular problems for monitoring as they are species-rich  
47 (representing an estimated 50-60% of all known species on earth) and require specialist skills for  
48 many families (Brereton et al. 2011a; Thomas 2005). The role of insect monitoring for measuring  
49 biodiversity change is recognised by the growing body of literature about the processes driving  
50 change in insect populations (Dempster and McLean 1998) and evidence that well-studied groups of  
51 insects are representative of obscure ones (Thomas and Clarke 2004). Insects play a key role in  
52 many ecosystem functions and key links in food webs, including as a major food resource for  
53 insectivorous animals (Strong et al. 1984).

54 Butterflies are the insect group for which monitoring of trends has proved most tractable, at  
55 least in some parts of the world. Butterflies have been advocated as indicator taxa due to their rapid  
56 and sensitive responses to habitat and climate change, and their potential to represent change in  
57 other wildlife, especially insects (e.g. Thomas 2005). Several butterfly species which reach their  
58 northern range margin in Britain have expanded their range in the past four decades, in common  
59 with other insects (Chen et al. 2011; Hickling et al. 2006), linked to improved climatic conditions  
60 (Warren et al. 2001). However, butterfly species with more specialised habitat requirements have  
61 decline over a similar period through the loss of habitat. As a group, butterflies are contracting more

62 rapidly than either birds or plants in Great Britain (Thomas et al. 2004), emphasising their potential  
63 importance for assessing the status of biodiversity beyond more charismatic groups.

64 Schemes to measure relative change in the abundance of butterflies were established in the  
65 1970s (Pollard 1977) and have expanded to more than 20 countries around the world, although  
66 predominantly within Europe and North America. Sampling is predominantly undertaken by  
67 volunteer contributors, continuing the rich tradition of citizen involvement (especially by amateur  
68 experts) in monitoring (Miller-Rushing and Primack 2008). Citizen science, including participatory  
69 schemes for monitoring butterflies, is increasingly being recognised as the only practical way of  
70 gathering the biodiversity data required to identify and address large-scale, long-term changes in  
71 biodiversity (Hochachka et al. 2012).

72 One of the disadvantages of volunteer-based monitoring schemes, and citizen science more  
73 generally, is potential bias, particularly if contributors are given a free choice in where to survey,  
74 leading to geographic bias in results (Gregory et al. 2005). For most butterfly monitoring schemes,  
75 volunteer recorders undertake sampling at locations they select which leads to a tendency to  
76 monitor areas rich in butterflies. Such a bias has provided good coverage of sites with  
77 environmental protection and semi-natural habitats that support butterfly diversity, but may not  
78 provide representative trends in species that are common elsewhere. In the heavily-modified  
79 landscape of the United Kingdom, evidence suggests that declines in many butterflies away from  
80 sites protected for nature conservation were largely undetected by monitoring and mapping  
81 schemes (Cowley et al. 1999).

82 Intensively farmed areas dominate the UK landscape yet are typically under-represented by  
83 butterfly monitoring schemes, mainly because they support a relatively depauperate butterfly fauna.  
84 Voluntary recorders are often reluctant to sample in areas where they see only a few individuals of a  
85 few common species, particularly when a high level of within-season repeat sampling is required;  
86 long-established butterfly monitoring schemes advocate weekly sampling throughout the main  
87 season of butterfly activity (26 weeks in the United Kingdom). Increasingly, the need for surveys to

88 cover all regions and habitats appropriately is being recognised by conservationists; for example the  
89 (intensive, self-selected) Common Birds Census was replaced by the less intensive, but more  
90 representative, BTO/JNCC/RSPB Breeding Bird Survey (BBS) based on randomly selected sites  
91 (Freeman et al 2007). To address the limitations of traditional butterfly monitoring schemes, a  
92 stratified-random sampling schemes with less within-year sampling has therefore been designed  
93 (Roy et al. 2007) and implemented within the United Kingdom as the Wider Countryside Butterfly  
94 Survey, WCBS (Brereton et al. 2011b). The design of the survey closely matches that of the BBS, and  
95 indeed many of the sites are common to both.

96 This paper compares year-to-year growth rates in butterfly populations between 2007 and  
97 2013 from the WCBS and traditional transects, hereafter termed traditional Butterfly Monitoring  
98 Scheme transects (also referred to as Pollard Walks). The WCBS was launched in 2009 following two  
99 pilot years and we compare year-to-year and overall population growth rates (2007-2013) for the  
100 scheme with those of the traditional BMS at the same time of the year. This comparison is  
101 undertaken to assess whether differences are apparent in butterfly trends between the two  
102 networks of sites, and to provide a basis for producing representative assessments of butterfly  
103 population trends in the UK by combining data from both surveys (Dennis et al. 2013).

104

## 105 **Methods**

### 106 ***Traditional Butterfly Monitoring Scheme (tBMS)***

107 The first national scheme to monitor butterflies was initiated in the United Kingdom in 1976.  
108 The scheme is based on a standardized method, described in detail elsewhere (Pollard & Yates  
109 1993). A fixed transect route is walked at least once a week from 1 April to 29 September, under  
110 defined weather conditions and at specified times of the day when adult butterflies are active. Every  
111 sighting of each species made in an imaginary, fixed 5-m box around the recorder is counted.  
112 Transect routes are 1.9km long on average (median) and therefore cover multiple 1km grid squares;  
113 we use the central 1km grid reference to characterise the coverage of the network. Traditional BMS

114 transect routes are established by recorders, with only general guidance provided by the scheme co-  
115 ordinators. In this paper, we label the traditional BMS transects using the acronym tBMS.

116

### 117 ***Wider Countryside Butterfly Monitoring Scheme (WCBS)***

118 The key difference between the Wider Countryside Butterfly Survey (WCBS) and traditional  
119 BMS is that volunteer surveyors are allocated a randomly selected 1 km<sup>2</sup> square within their local  
120 region (Brereton et al. 2011b). WCBS locations are selected at random, with a larger number of 1km  
121 grid squares surveyed in regions with a higher density of recorders (the strata for selection). A total  
122 of 755 grid squares were surveyed in 2009 (Figure 1), the launch year for the scheme; the scheme  
123 had two pilot years in 2007 and 2008, with reduced sampling. Within each grid square, two parallel,  
124 1 km long, fixed transects were established. Volunteers walked these transects twice within July and  
125 August (additional visits are also permitted outside these months) with most other aspects of the  
126 survey the same as for traditional transect, i.e. weather and time of day criteria and line sampling  
127 criteria (Brereton et al. 2011b). A further difference of the WCBS is the strip-width of the linear  
128 transect is 10m (5m each side of the recorder) as opposed to 5m (2.5m each side of the recorder) for  
129 the tradition BMS.

130

### 131 ***Data selection***

132 Other than selection of sites and line transect length, the two surveys of the UKBMS are  
133 equivalent and therefore the data arising are similar in form. Analysis of seasonal insect population  
134 abundance requires account to be taken of pronounced variation in numbers across the season,  
135 commonly via the estimation of a seasonal correction factor (Dennis et al. 2013; Matechou et al.  
136 2014; Rothery and Roy 2001). For this reason, and as the WCBS is nominally restricted to two visits in  
137 the months of July and August (though there are limited additional data from beyond this period),  
138 data in this analysis are restricted to these months only. The WCBS dataset therefore comprises 1 or  
139 2 visits per year whereas the traditional BMS dataset comprises between 1 and 8 weekly visits. We

140 restrict analysis to the years covered so far by the scheme (2007-2012, including ‘pilot’ years for  
141 which a reasonable amount of data are available). Due to differences in protocol (weekly visits for  
142 the traditional BMS, compared to monthly for the WCBS), more data is available for the traditional  
143 BMS although the number of sites within each species is similar (~750-1000 sites sampled each year  
144 for both schemes). We restrict analysis to species occurring in more than 25 sites in each network.

145 In order to explore regional differences in habitat coverage, we assign all UKBMS (WCBS and  
146 tBMS) 1km sites to seven Environmental Zones defined for the UK (Carey et al. 2008). In order to  
147 characterise the habitat coverage of the two schemes, we summarise the land cover of all 1km grid  
148 cells covered by the UKBMS surveys (WCBS and tBMS) using the Centre for Ecology & Hydrology  
149 Land Cover Map (Morton et al. 2011).

150

### 151 ***Statistical model***

152 We adopt a simple Poisson-based model for the data of each survey. The expected total  
153 counts of a species made in a total of  $v_{i,t}$  visits in year  $t$  to site  $i$  are defined as  $\mu_{i,t}$ . We further  
154 assume that annual proportional changes in abundance over consecutive years are identical at all  
155 sites in a survey. They are however permitted to vary over time, such that the ratio of expected  
156 counts, per visit made, in years  $t$  and  $t+1$  can be written as follows:

157

$$158 \quad \log\left(\frac{\mu_{i,t+1}/V_{i,t+1}}{\mu_{i,t}/V_{i,t}}\right) = R_t$$

159

160 We require therefore the estimates of annual growth  $R_t$ . In the form of equation (1), the  
161 model is impractical to fit; the ratios of consecutive counts observed are undefined wherever the  
162 count in year  $t$  is zero or (as is often the case) the site was not visited during that year. Merely to  
163 omit such cases from the analysis would lead to the discarding of a considerable amount of useful



164 data. However, if we further define  $\mu'_{i,t} = \mu_{i,t} / v_{i,t}$  then  $\log(\mu_{i,t}) = \log(\mu'_{i,t}) + \log(v_{i,t})$  and, after  
165 some algebra we have a more tractable expression of the same model for any  $t$  as follows:

166

$$167 \quad \log(\mu_{i,t}) = \sum_{j=1}^{t-1} R_j + \log(\mu'_{i,1}) + \log(v_{i,t})$$

168

169 Equation (2) expresses any log-transformed expected count in year  $t$  as a simple linear  
170 combination of unknown parameters, with the similarly transformed number of visits  $v_{i,t}$  (which may  
171 vary between sites and years) as a standardising offset (*cf.* Freeman and Newson, 2008). These  
172 parameters, and most usefully the annual growth rates  $R_t$ , are thus readily estimated and compared  
173 across surveys by fitting to observed counts for all sites and years via any of the many standard  
174 Generalized Linear Model (GLM) software packages. Specifically, 'unknown' counts in years lacking  
175 visits can thus be safely ignored.

176 Butterfly counts are highly variable in their nature and the goodness-of-fit of such models, in  
177 which annual trends are constrained to be identical at all sites, is in formal terms rarely good. We  
178 therefore adjust standard errors and hypothesis tests rescaling by the Pearson Chi-squared statistic  
179 in the standard, 'quasiPoisson' fashion, to compensate for overdispersion.

180 Maximum likelihood estimates  $\hat{R}_t$  of the growth rates under the two surveys in a given year  $t$   
181 can be compared, using confidence limits based upon their associated estimates of asymptotic  
182 standard error, also available from the standard GLM software. We use these to estimate the  
183 difference in growth between the two surveys, log-transformed, defined as  $d_t = R_t(\text{WCBS}) - R_t(\text{tBMS})$   
184 along with its 95% Confidence Limits. Where the confidence limits of the difference between the  
185 two surveys  $d_t$  include zero, we conclude that there is no significant difference between their  
186 population change estimates for the year in question.

187

188 We also have a ready comparison of the net change  $N$  over the five years 2009-2013 under  
189 the two surveys, since, for either survey:

$$190 \quad \hat{N} = \sum_{t=1}^4 \hat{R}_t ; \quad \text{var}(\hat{N}) = \sum_{t=1}^4 \text{var}(\hat{R}_t) + 2 \sum_{t=1}^4 \sum_{k=1}^{t-1} [\text{cov}(\hat{R}_t, \hat{R}_k)]$$

191 and as the annual estimates of growth are independent between surveys confidence limits for the  
192 difference in  $N$  between the two can be examined and found to include zero or otherwise, giving a  
193 test of equality between surveys as above.

194

195

## 196 **Results**

197 Within lowland England and Wales (Environmental Zones 1 & 2), traditional BMS transects are  
198 predominantly located within areas of relatively high cover of broadleaved woodland and sub-urban  
199 land cover, with typically correspondingly lower cover of arable land (Figure 1; Table 1). In contrast,  
200 WCBS samples in lowland areas are similar to the average values for the region, as would be  
201 expected from a random sample of locations. Within upland regions, 1km grid squares sampled by  
202 traditional BMS transects and the WCBS are both characterised by relatively low cover of montane  
203 habitats. Within upland regions, sampling locations for the WCBS tends to have relatively high cover  
204 of arable land and coniferous woodland (Table 1).

205 Of the butterfly species included in the analysis, there was no overall clear tendency for mean  
206 counts (per km of line transect per visit) during the survey period (July and August) to be higher on  
207 one survey versus the other, in spite of the minor difference in protocol; 14 out of 26 species had  
208 higher counts for WCBS versus traditional BMS transects. Species with notably higher mean counts  
209 within WCBS survey squares included the three *Pieris* species: *P. brassicae*, *P. napi* and *P. rapae*. In  
210 contrast, *Nymphalidae* tended to have higher counts within traditional BMS survey locations, i.e.  
211 *Maniola jurtina*, *Aphantopus hyperantus* and *Erebia aethiops* (Table 2). It should be noted, however,  
212 that abundance estimates between the two schemes may not be directly comparable. The Wider

213 Countryside Survey typically samples public rights of way due to the practical difficulties of accessing  
214 land within randomly-located 1km grid squares; traditional transect routes are likely to be more  
215 representative of habitat parcels. Difference in the visibility of butterfly species between habitats  
216 can also affect their detectability (Dennis et al. 2006) and ideally is taken into account when  
217 comparing population abundance between schemes. Analysis of differences in growth rates  
218 between the two schemes, the primary aim of this manuscript, is not affected by these factors.

219 For all but one species (*Erebia aethiops*, the only predominantly Northern species considered),  
220 the number of sites where species were recorded was markedly higher for the traditional BMS  
221 survey; mean number of sites per species of 601 for WCBS and 951 for the traditional BMS. The  
222 number of samples (visits) was approximately ten times higher for the BMS survey than the WCBS  
223 survey with mean number of samples per species of 24,485 and 2306 respectively (Table 2).

224 Over the period since the WCBS became fully operational following its full launch in 2009, 12  
225 species had a significantly positive and 5 had a significantly negative change in abundance (Table 2)  
226 for this scheme. More species had significant growth rates over this period when sampled by  
227 traditional BMS transects, suggesting higher power for this scheme for detecting trends; 15 and 8  
228 species showed a significant positive or negative change respectively over this period. For most  
229 species, change was similar between the two schemes, being negative or positive for both surveys  
230 over the 2009 to 2013 period. For only 2 species were changes significantly different from zero and  
231 in opposite directions for the two schemes. *Polyommatus icarus* declined within WCBS sites yet  
232 increased within traditional BMS transects over this period. In contrast, *Pyronia tithonus* had  
233 positive population growth within WCBS sites over the period yet negative growth rate within  
234 traditional BMS transects (Table 2).

235 There was a significant overall correlation ( $\rho = 0.75$ ,  $p < 0.001$ ) between the population change  
236 from the two sampling schemes over the period 2009-2013 (Figure 2). The confidence intervals of  
237 the growth rate estimates are larger for the WCBS compared to the traditional BMS (mean CIs:  
238 WCBS = 0.43; tBMS = 0.14), likely to be caused by fewer sampling visits per year for this scheme.

239 When assessing individual year-to-year changes, there was also a significant correlation between the  
240 two schemes (Figure 3), and similarly between 2007/2008 and 2008/2009 when the WCBS was being  
241 piloted and therefore relatively few locations were sampled. *Vanessa cardui* is a notable outlier  
242 when comparing growth rates between 2008 and 2010 (Figure 3). The significant correlation  
243 between population change from the two schemes remains when this species is excluded. *V. cardui*  
244 is migratory in the UK, arriving each spring from populations that emerge in North Africa or Southern  
245 Europe. Numbers arriving in the UK fluctuate markedly from year to year, depending on conditions  
246 in natal areas. Vast numbers arrive in some years, with recent migrant events occurring in 1996 and  
247 2009. Growth in numbers of *V. cardui* during the invasion event of 2009 was higher on traditional  
248 BMS sites than Wider Countryside Survey transects.

249 For the period 2009-2013, there was a slight tendency for change to be greater within WCBS  
250 than for traditional BMS transects with for 17 (65%) of the 26 species analysed showing this  
251 difference (Table 3). Of the 15 species with a significant difference between the two surveys, 12 had  
252 a significantly higher growth rate within WCBS survey locations. However, there was no species  
253 where the difference in growth rates was in the same direction for all individual year-to-year  
254 comparisons (Table 3) showing a lack of consistency in this result. When restricted to significant  
255 growth rates, there was some consistency in effects with *Polyommatus icarus* and *Celestrina argiolus*  
256 having significantly lower growth rates for the WCBS. The three species with a significantly higher  
257 growth rates 2009-2013 within traditional BMS transects over 2009-2013 were *Pieris rapae*,  
258 *Polyommatus icarus* and *Erebia aethiops* (Table 3).

259 When assessing year-to-year growth, for most years there is a relatively even split between  
260 higher growth rates for species on one scheme or the other (Table 3). For three year-to-year  
261 comparisons (2009/10, 2010/11 and 2011/12), the majority of species had higher growth rates  
262 greater on WCBS sites compared to traditional BMS transects. Notably, between 2011 and 2012,  
263 growth rate was higher on WCBS transects for 17 out of the 26 species analyses, 11 significantly so.

264 In contrast, growth rates were higher on traditional BMS transect sites between 2008 and 2009 for  
265 19 out of 26 species, with this difference statistically significant for 8 species.

266

267

## 268 **Discussion**

269 There is no strong evidence from this analysis that there is a systematic difference in butterfly  
270 population trends between locations sampled by the two UKBMS schemes – the Wider Countryside  
271 Butterfly Survey and traditional BMS transects. Comparing species' trends over the main period for  
272 comparison (2009-2013), when both schemes were operating fully, there was a strong positive  
273 relationship in butterfly population trends between the two schemes. There were only two (out of  
274 26) species where significant trends 2009-2013 for the two schemes were in opposite directions, i.e.  
275 a significant decline for one scheme and a significant increase for the other. However, there were  
276 no species for which growth rates differences were consistent for all comparisons over consecutive  
277 years; all species performed better on either scheme at some time during the period of analysis.

278 The relative consistency in trends between the two UKBMS schemes suggests that previous  
279 results based solely on analysis of the traditional BMS sites are likely to be validated (for most  
280 species) by the Wider Countryside Butterfly Survey. Monitoring data has been a rich resource for  
281 assessing the impacts of climate change (e.g. Oliver et al. 2013; Roy and Thomas 2003), habitat  
282 management (Woodcock et al. 2012) and conservation policies (Brereton et al. 2008) for example.  
283 However, there is considerable scope for using the combined UKBMS surveys to understand further  
284 the impact of environmental change on butterfly populations using a more representative sample of  
285 the UK. A particular advantage of the combined UKBMS datasets is good coverage of both protected  
286 areas and the wider countryside. Although protected areas have been shown to facilitate range  
287 expansion (Thomas et al. 2012) and support higher population sizes than non-protected areas  
288 (Gillingham et al. 2014), there is a lack of evidence of the influence of site protection on population  
289 dynamics (i.e. improved population trends or stability of populations). Similarly, data from the

290 combined datasets enables future studies to investigate the effects of habitat composition and  
291 configuration (i.e. fragmentation) and land management on butterfly population trends; previous  
292 studies addressing these questions have been limited to the traditional UKBMS sites which  
293 predominantly sample semi-natural habitats.

294 Although trends between the two surveys are broadly similar, it should be noted that the  
295 traditional BMS enables trends to be reported for a wider set of species, particularly those with  
296 smaller ranges and/or tending to occur in rarer habitats which are not sampled sufficiently by the  
297 stratified-random set of WCBS locations. The traditional BMS enables trends to be estimated for 56  
298 species for example, compared to the 26 species reported in this paper. The WCBS also has lower  
299 power for detecting trends in populations due to fewer visits within the season and therefore  
300 greater error in estimates of annual growth rates (Roy et al. 2007). Therefore, a comprehensive  
301 UKBMS is ideally composed of both surveys, realising the beneficial features of each. Combined data  
302 from the two schemes is also invaluable for assessing the spatial distribution and abundance of  
303 butterfly populations (Oliver et al. 2012a), particularly when combined with opportunistic recording  
304 data (Pagel et al. 2014). The improved coverage of habitats achieved by combining the WCBS and  
305 the traditional BMS transect scheme offers potential for estimation of population abundance on a  
306 regional basis. However, although the WCBS improves sampling of previously under-represented  
307 habitats such as arable farmland and urban areas, the transect route typically follows public rights of  
308 way through sample 1km grid squares. Random location of transect routes within a larger 1km grid  
309 square was shown to not impractical during the design of the scheme (Brereton et al. 2011b).  
310 Models to upscale UKBMS data for population estimates therefore need to account for habitat  
311 coverage, as well as differences in the detectability of species (Dennis et al. 2006).

312 Butterflies population size and annual fluctuations are known to be strongly affected by  
313 climate and weather (Oliver et al. 2012b; Powney et al. 2010; Roy et al. 2001); over the relatively  
314 short time periods available for comparison here, weather effects are therefore likely to dominate  
315 year-to-year population changes. Given summer temperatures typically show a high degree of

316 similarity between locations (i.e. high spatial autocorrelation), we expect UKBMS sites for both  
317 schemes (WCBS and traditional BMS) to experience similar conditions within a year. Annual changes  
318 in butterfly population size are therefore likely to be broadly similar between the two schemes over  
319 short time-periods, as demonstrated here. Such a result is particularly likely for relatively mobile  
320 species which can disperse across the UK landscape. Such 'wider countryside' species are those  
321 predominantly sampled by the WCBS (Brereton et al. 2011b) and therefore form the basis of the  
322 analyses presented here.

323 Habitat availability and quality are also known to strongly affect butterfly populations (Warren  
324 et al. 2001). Habitat associations of butterflies have been shown to vary across geographic ranges  
325 (Oliver et al. 2009) with several species restricted to a narrower set of habitats towards the northern  
326 edge of their distribution in Britain. Monitoring data have also shown that the range of habitats  
327 used by butterflies in Britain has reduced over the last 40 years, despite predicted expansions in  
328 associations through recent climate warming (Oliver et al. 2012c).

329 Effects of habitat change and associated interactions with climate (Oliver and Morecroft 2014)  
330 are typically subtle and have the greatest effects on species which are specialised to localised habitat  
331 conditions – species that were not analysed here as they do not occur frequently within WCBS  
332 samples. For widespread butterfly species, populations are likely to be sensitive to management of  
333 habitats that are common in the landscape, such as farmland. Within the European Union,  
334 considerable financial resource is allocated to enhancement of the farmed environment through the  
335 Common Agricultural Policy, although the effectiveness of these measures for biodiversity have  
336 come into question (Pe'er et al. 2014) unless they are well-designed and implemented effectively  
337 (Pywell et al. 2012). Evidence is lacking as to whether such schemes are having a positive effect on  
338 butterfly populations. If effective, we would predict butterfly population trends in the wider  
339 countryside (where agri-environment schemes are implemented) to be better than within other  
340 habitats. Although from this initial assessment we find no evidence of improved trends in the wider  
341 countryside versus semi-natural habitats that might be evident if management of the farmed

342 environment agri-environment was effective, it is important that monitoring schemes are in place to  
343 undertake robust assessments.

344 Butterfly populations have declined in the UK, markedly since the turn of the 20th Century but  
345 also within the more recent period since standardised monitoring began in 1976 (Fox et al. 2006).  
346 The decline in the distribution of butterflies has been more marked than for other well monitored  
347 taxa, birds and vascular plants (Thomas et al. 2004), stressing the importance of effective monitoring  
348 of insects to provide a more representative assessment of the status of biodiversity. The two  
349 component sampling schemes of the UKBMS estimate similar population trends for relatively  
350 common and widespread species. Together, these schemes provide a strong framework for future  
351 assessments of butterfly populations.

352

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360

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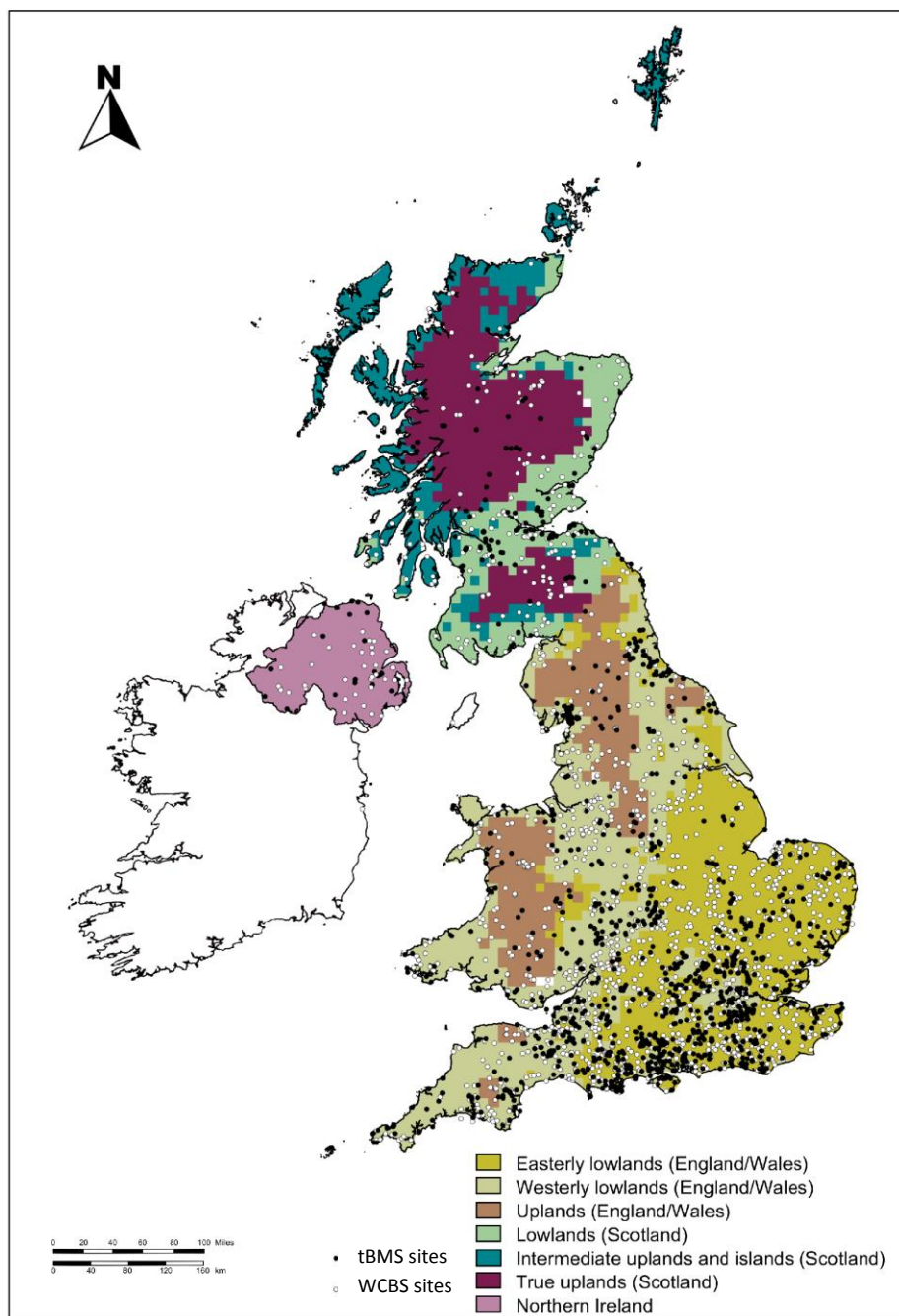
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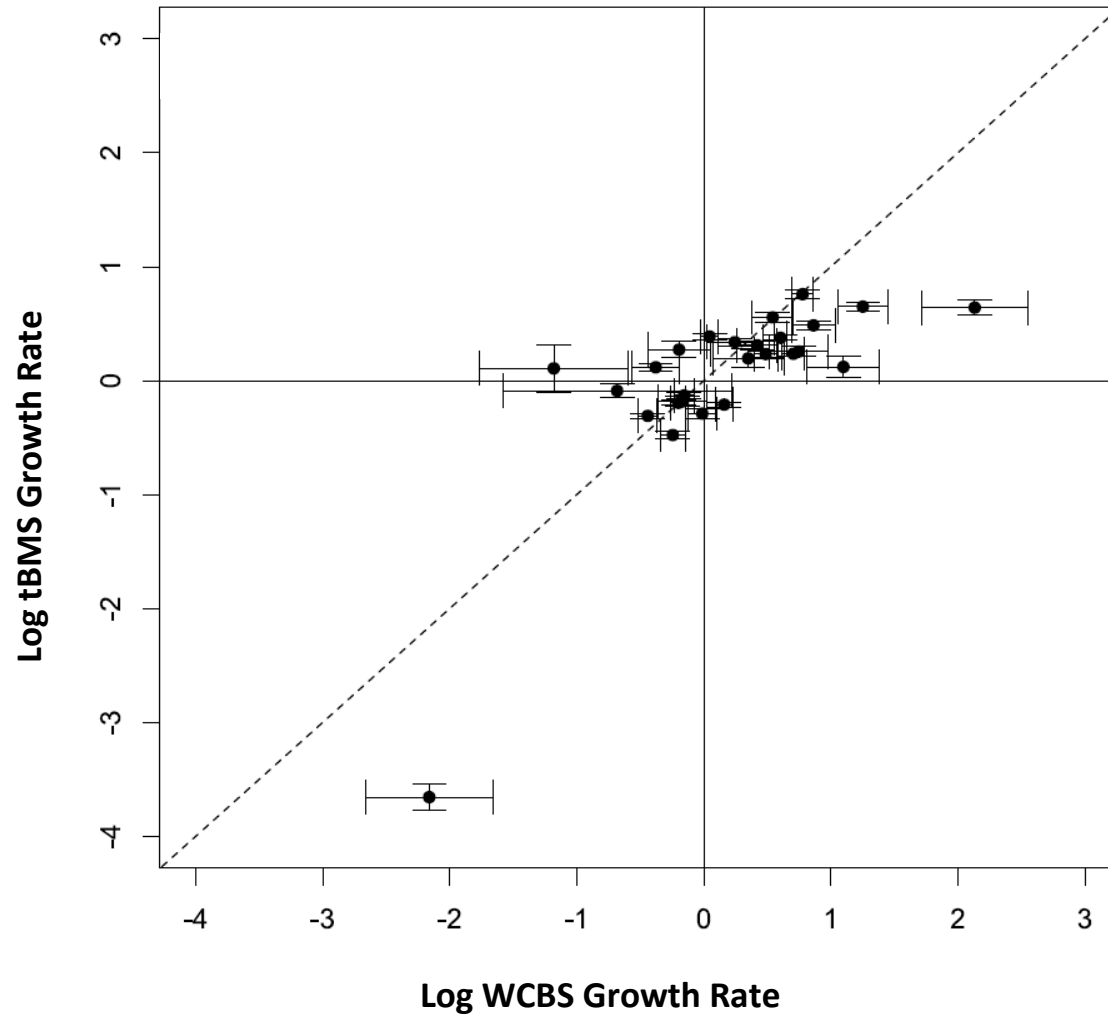
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471 **Figure 1.** Location of UKBMS survey squares for two surveys in 2009. Environmental Zones as  
472 defined in Carey *et al.* (2008). Solid symbols represent locations of traditional BMS sites; open  
473 circles are locations of Wider Countryside Butterfly Survey sites.

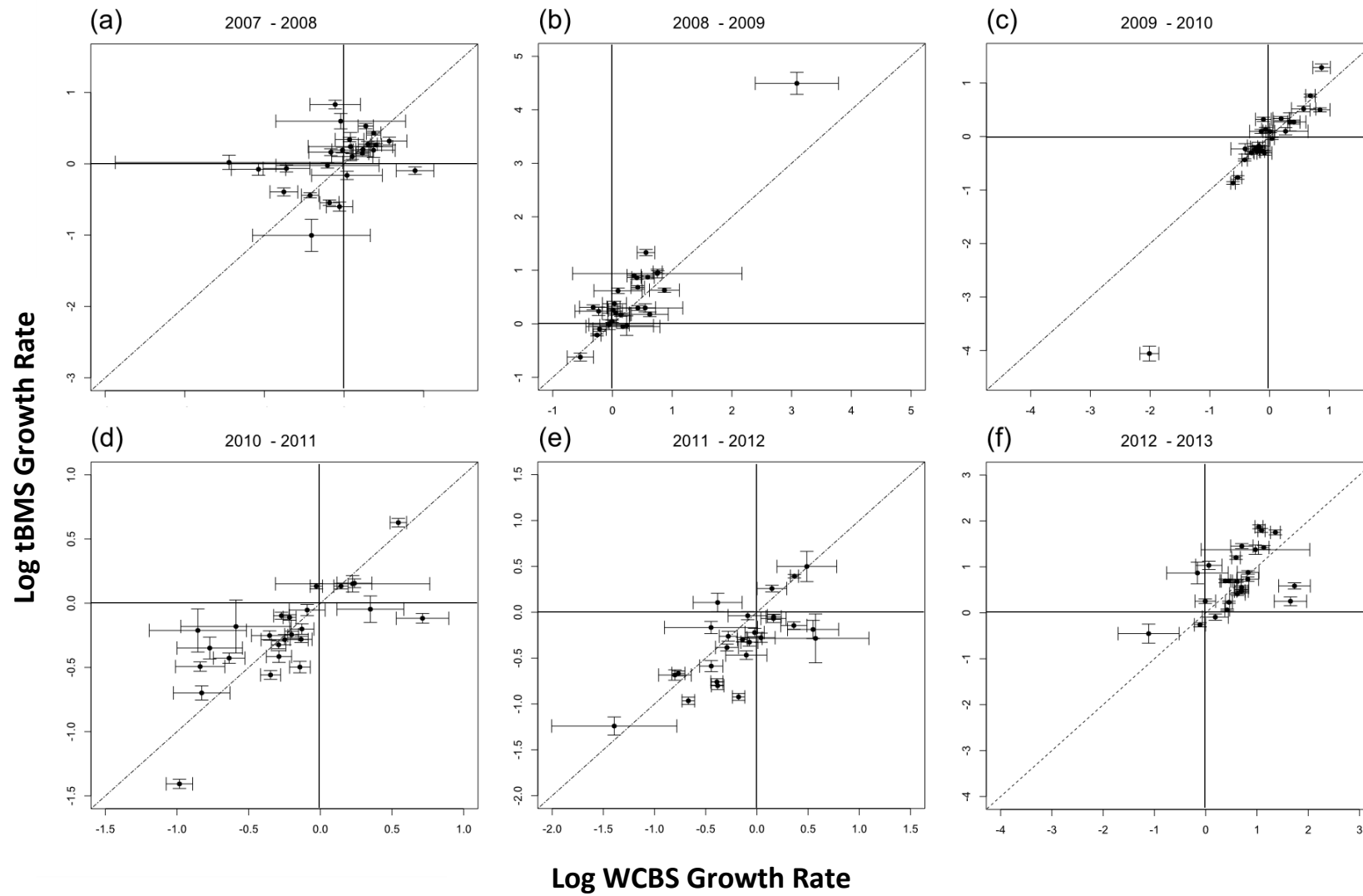


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**Figure 2.** Comparison of log (growth rates) from 2009 to 2013 of the two surveys for 26 species analysed. Solid lines to indicate zero growth for the WCBS (vertical) and tBMS (horizontal) are shown; the dashed line indicates the line of unity where growth rates are equal for the two schemes. Bars represent 1 standard error.



**Figure 3.** Comparison of year-to-year growth rates from 2007 and 2013 of the two surveys for 26 species analysed. ; the dashed line indicates the line of unity where growth rates are equal for the two schemes. Bars represent 1 standard error.



**Table 1.** Mean (SE) cover of habitat types (%) for 1km squares sampled by the traditional BMS transects (n=1220) and WCBS survey squares (n=1408) during the period 2007-2013. Mean cover for all 1km squares in the UK are included for comparison (n=264002). Habitat data from the CEH Land Cover Map 2007 (Morton et al. 2011).

(table overleaf to fit on a single page)

<sup>a</sup> Fen, Marsh and Swamp & Bogs

<sup>b</sup> Salt water and freshwater

<sup>c</sup> Littoral and supra-littoral rocks and sediments (sand dunes, saltmarsh)

<b>Zone Scheme</b>	<b>Broadleaved woodland</b>	<b>Coniferous woodland</b>	<b>Arable and horticulture</b>	<b>Improved grassland</b>	<b>Natural grassland</b>	<b>Wetland<sup>b</sup></b>	<b>Heath</b>	<b>Montane habitats</b>	<b>Inland rock</b>	<b>Water<sup>c</sup></b>	<b>Coastal habitats<sup>d</sup></b>	<b>Urban Suburban</b>
<b>Zone 1. Easterly lowlands (England/Wales)</b>												
tBMS	20.16 (0.86)	3.30 (0.41)	28.82 (1.06)	26.21 (0.87)	7.00 (0.40)	0.78 (0.30)	2.01 (0.37)	0.00 (0.00)	0.43 (0.09)	1.33 (0.25)	0.31 (0.14)	9.52 (0.70)
WCBS	10.02 (0.56)	2.93 (0.45)	48.95 (1.20)	26.35 (0.82)	4.23 (0.29)	0.03 (0.01)	0.54 (0.16)	0.00 (0.00)	0.37 (0.09)	0.58 (0.12)	0.18 (0.10)	5.92 (0.54)
all zone	7.87	1.68	53.37	24.06	4.90	0.13	0.56	0.00	0.26	0.75	0.37	5.94
<b>Zone 2. Westerly lowlands (England/Wales)</b>												
tBMS	18.27 (0.88)	3.48 (0.43)	21.34 (0.96)	28.50 (0.96)	7.08 (0.47)	0.98 (0.32)	1.52 (0.27)	0.00 (0.00)	0.62 (0.14)	1.78 (0.26)	4.62 (0.67)	9.22 (0.76)
WCBS	9.01 (0.63)	2.35 (0.32)	33.44 (1.27)	34.82 (1.10)	7.55 (0.43)	0.19 (0.16)	0.74 (0.20)	0.00 (0.00)	0.35 (0.11)	1.20 (0.24)	1.52 (0.36)	7.97 (0.84)
all zone	7.24	2.09	33.2	35.33	7.18	0.17	0.90	0.00	0.33	1.36	2.43	7.56
<b>Zone 3. Uplands (England/Wales)</b>												
BMS	9.88 (1.53)	7.37 (2.33)	8.43 (2.06)	31.22 (3.91)	24.24 (2.78)	3.45 (2.31)	8.96 (1.77)	0.00 (0.00)	2.39 (1.58)	1.29 (0.71)	0.00 (0.00)	3.06 (1.38)
WCBS	4.86 (0.70)	8.80 (1.61)	3.91 (0.73)	31.53 (2.65)	28.16 (2.24)	9.19 (2.23)	10.52 (1.68)	0.00 (0.00)	0.15 (0.06)	0.93 (0.42)	0.00 (0.00)	2.02 (0.63)
all zone	4.27	8.27	4.17	27.56	28.30	8.77	14.82	1.48	0.58	0.67	0.00	1.30
<b>Zone 4. Lowlands (Scotland)</b>												
BMS	13.42 (1.54)	13.29 (2.31)	11.28 (2.06)	21.25 (2.38)	9.88 (1.43)	1.07 (0.74)	3.08 (0.87)	0.00 (0.00)	0.76 (0.35)	5.97 (1.69)	5.60 (2.05)	13.07 (2.41)
WCBS	7.10 (0.97)	8.23 (1.68)	30.58 (3.28)	31.27 (2.46)	9.77 (1.19)	3.63 (1.59)	2.29 (0.53)	0.00 (0.00)	0.33 (0.12)	1.18 (0.46)	0.20 (0.11)	4.73 (1.49)
all zone	5.82	10.85	26.13	30.04	10.79	2.72	4.56	0.00	0.48	1.96	1.16	3.90
<b>Zone 5. Intermediate uplands and islands (Scotland)</b>												
BMS	9.68 (3.02)	13.88 (4.34)	2.36 (0.97)	16.68 (3.96)	16.12 (4.41)	1.12 (1.00)	9.60 (2.95)	0.00 (0.00)	0.48 (0.25)	7.28 (3.26)	6.64 (2.42)	4.16 (1.79)
WCBS	4.38 (1.30)	20.83 (4.79)	5.29 (1.79)	14.69 (2.93)	17.85 (2.75)	6.75 (2.81)	22.00 (4.22)	0.00 (0.00)	0.44 (0.20)	1.73 (0.76)	2.23 (1.70)	1.48 (0.89)
all zone	2.62	11.22	2.91	10.67	17.20	14.24	18.91	0.15	0.91	3.52	2.67	0.59
<b>Zone 6. True Uplands (Scotland)</b>												
BMS	1.32 (0.45)	17.89 (6.73)	1.11 (0.67)	4.11 (1.93)	34.05 (6.77)	5.32 (3.15)	25.74 (5.78)	6.47 (4.99)	0.26 (0.21)	3.68 (2.35)	0.00 (0.00)	0.16 (0.12)
WCBS	2.29 (0.70)	32.92 (4.92)	2.94 (1.65)	4.54 (1.60)	21.02 (3.85)	3.63 (1.14)	27.67 (4.54)	2.29 (2.09)	0.54 (0.28)	2.15 (1.36)	0.00 (0.00)	0.21 (0.11)
all zone	1.69	13.04	0.84	3.66	26.51	9.04	28.29	14.00	1.03	1.91	0.01	0.09
<b>Zone 7. Northern Ireland</b>												
BMS	8.81 (1.83)	9.28 (2.77)	3.47 (1.00)	24.76 (4.79)	14.77 (3.53)	3.74 (2.94)	5.79 (1.92)	0.00 (0.00)	0.16 (0.11)	7.16 (3.03)	7.98 (3.97)	8.92 (3.05)
WCBS	3.01 (0.90)	2.42 (0.99)	6.49 (1.02)	58.18 (4.26)	13.50 (2.03)	1.83 (1.46)	5.59 (2.78)	0.00 (0.00)	0.90 (0.26)	1.96 (1.41)	0.12 (0.12)	5.96 (2.00)
all zone	1.79	2.16	2.87	23.47	6.52	3.06	2.42	0.02	0.32	2.50	0.30	2.13
<b>UK (all zones)</b>												
BMS	17.84 (0.55)	4.73 (0.35)	22.51 (0.67)	26.41 (0.61)	8.71 (0.36)	1.13 (0.23)	2.79 (0.27)	0.10 (0.08)	0.60 (0.10)	2.07 (0.21)	2.56 (0.31)	9.08 (0.47)
WCBS	8.45 (0.34)	5.25 (0.41)	35.09 (0.83)	29.27 (0.63)	8.92 (0.38)	1.49 (0.26)	3.40 (0.34)	0.08 (0.07)	0.36 (0.05)	0.96 (0.12)	0.63 (0.13)	5.76 (0.38)
all UK	5.17	5.71	23.84	23.43	12.41	4.20	8.01	1.86	0.50	1.64	1.07	3.93

**Table 2.** Sample size, mean count and estimated population change 2009-2013 for the two schemes. The number of sites for the two schemes are: WCBS – 1366 sites; tBMS – 1446 sites. Mean counts are standardised to number of individuals per 1km linear transect during July and August. A log (growth rate) of zero is a stable population, i.e. no change.

Species	Common name	WCBS			BMS		
		Sites (visits)	Mean Count (se)	Log (growth rate)	Sites (visits)	Mean Count (se)	Log (growth rate)
<i>Thymelicus sylvestris</i>	Small Skipper	415 (1490)	2.05 (0.32)	0.42**	891 (20717)	1.87 (0.04)	0.31***
<i>Thymelicus lineola</i>	Essex Skipper	168 (550)	1.06 (0.10)	1.10***	376 (6893)	0.71 (0.06)	0.12
<i>Ochlodes sylvanus</i>	Large Skipper	390 (1404)	0.88 (0.04)	0.86***	1056 (28583)	0.77 (0.02)	0.49***
<i>Gonepteryx rhamni</i>	Brimstone	319 (982)	0.55 (0.04)	0.24	952 (26728)	0.58 (0.01)	0.34***
<i>Pieris brassicae</i>	Large White	1140 (5020)	3.91 (0.10)	-0.20***	1305 (36332)	2.21 (0.04)	-0.19***
<i>Pieris napi</i>	Green-veined White	1061 (4373)	3.63 (0.10)	-0.15	1281 (34479)	2.28 (0.03)	-0.13***
<i>Pieris rapae</i>	Small White	1134 (4995)	5.18 (0.13)	0.05	1292 (36107)	2.62 (0.05)	0.39***
<i>Lycaena phlaeas</i>	Small Copper	482 (1449)	0.70 (0.03)	-0.16	1105 (26436)	0.59 (0.01)	-0.18***
<i>Aricia agestis</i>	Brown Argus	174 (504)	1.00 (0.10)	-0.68	576 (13304)	0.94 (0.03)	-0.09
<i>Polyommatus icarus</i>	Common Blue	643 (2192)	1.78 (0.08)	-0.38*	1192 (31653)	3.16 (0.06)	0.12***
<i>Celastrina argiolus</i>	Holly Blue	442 (1412)	0.60 (0.03)	0.35	982 (22790)	0.25 (0.01)	0.20*
<i>Aglais urticae</i>	Small Tortoiseshell	931 (3423)	1.60 (0.06)	0.78***	1221 (29640)	0.58 (0.02)	0.76***
<i>Aglais io</i>	Peacock	968 (3587)	1.33 (0.05)	0.49***	1306 (36509)	1.35 (0.04)	0.23***
<i>Polygonia c-album</i>	Comma	700 (2631)	0.66 (0.02)	-0.24*	1114 (30120)	0.49 (0.01)	-0.48***
<i>Argynnis aglaja</i>	Dark Green Fritillary	74 (185)	0.84 (0.11)	2.13***	383 (8205)	1.52 (0.06)	0.64***
<i>Argynnis paphia</i>	Silver-washed	126 (479)	1.26 (0.13)	0.75**	485 (11344)	1.98 (0.05)	0.26***
<i>Pararge aegeria</i>	Speckled Wood	955 (4079)	1.99 (0.05)	-0.44***	1196 (34147)	2.32 (0.03)	-0.31***
<i>Lasiommata megera</i>	Wall Brown	174 (530)	1.21 (0.13)	-0.19	418 (7978)	0.51 (0.02)	0.27***
<i>Melanargia galathea</i>	Marbled White	222 (743)	2.07 (0.20)	1.25***	657 (18392)	4.81 (0.11)	0.65***
<i>Pyronia tithonus</i>	Gatekeeper	991 (4656)	5.17 (0.13)	0.16*	1092 (32166)	8.02 (0.09)	-0.21***
<i>Maniola jurtina</i>	Meadow Brown	1213 (5462)	7.55 (0.17)	0.60***	1332 (37969)	17.42 (0.17)	0.38***
<i>Aphantopus hyperantus</i>	Ringlet	853 (3413)	5.06 (0.20)	0.71***	1164 (31277)	8.05 (0.14)	0.24***
<i>Coenonympha</i>	Small Heath	363 (1116)	1.60 (0.10)	0.54***	914 (21016)	1.92 (0.04)	0.56***
<i>Erebia aethiops</i>	Scotch Argus	63 (182)	10.88 (1.54)	-1.18	28 (674)	16.56 (1.39)	0.11
<i>Vanessa atalanta</i>	Red Admiral	944 (3490)	0.88 (0.02)	-0.01	1288 (34259)	0.57 (0.01)	-0.29***
<i>Vanessa cardui</i>	Painted Lady	675 (1607)	2.76 (0.24)	-2.16***	1121 (18887)	1.70 (0.09)	-3.66***



**Table 3.** Differences in (log) annual growth rates per year,  $R_t(\text{WCBS}) - R_t(\text{tBMS})$ , and in (log) total growth 2009-2013 with 95% Confidence Limits. Species with asterisks indicate a statistically significant difference ( $p < 0.05$ ).

Species	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2009-2013
<i>Thymelicus sylvestris</i>	-0.33 (-0.89, 0.23)	0.44 (-0.17, 1.05)	0.22 (-0.03, 0.47)	-0.04 (-0.29, 0.21)	0.15 (-0.10, 0.40)	-0.24 (-0.54, 0.06)	0.11(-0.22,0.40)
<i>Thymelicus lineola</i>	0.18 (-0.38, 0.74)	-0.04 (-0.73, 0.65)	-0.12 (-0.67, 0.43)	0.18 (-0.37, 0.73)	-0.47 (-1.02, 0.08)	1.40 (0.74, 2.06)*	0.98(0.40,1.58)*
<i>Ochlodes sylvanus</i>	-0.65 (-1.23, -0.07)*	0.12 (-0.47, 0.71)	-0.23 (-0.52, 0.06)	-0.10 (-0.37, 0.17)	0.56 (0.29, 0.83)*	0.15 (-0.14, 0.44)	0.38(0.02,0.74)*
<i>Gonepteryx rhamni</i>	0.00 (-0.52, 0.52)	-0.15 (-0.61, 0.31)	-0.01 (-0.26, 0.24)	0.07 (-0.25, 0.39)	-0.09 (-0.48, 0.30)	-0.05 (-0.47, 0.37)	-0.09(-0.51,0.35)
<i>Pieris brassicae</i>	-0.26 (-0.47, -0.05)*	-0.20 (-0.37, -0.03)*	0.24 (0.14, 0.34)*	0.03 (-0.08, 0.14)	0.42 (0.27, 0.57)*	-0.70 (-0.86, -0.54)*	0.00(-0.13,0.11)
<i>Pieris napi</i>	0.03 (-0.22, 0.28)	-0.28 (-0.50, -0.06)*	0.00 (-0.11, 0.11)	-0.18 (-0.29, -0.07)*	0.76 (0.62, 0.90)*	-0.61 (-0.79, -0.43)*	-0.03(-0.19,0.13)
<i>Pieris rapae</i>	0.04 (-0.15, 0.23)	-0.45 (-0.62, -0.28)*	0.17 (0.07, 0.27)*	0.06 (-0.05, 0.17)	0.26 (0.11, 0.41)*	-0.83 (-1.01, -0.65)*	-0.34(-0.48,-0.20)*
<i>Lycaena phlaeas</i>	0.20 (-0.67, 1.07)	-0.53 (-1.32, 0.26)	0.15 (-0.08, 0.38)	-0.17 (-0.4, 0.06)	0.30 (0.01, 0.59)*	-0.26 (-0.66, 0.14)	0.02(-0.36,0.40)
<i>Aricia agestis</i>	-1.46 (-4.27, 1.35)	-0.19 (-2.98, 2.60)	0.05 (-0.35, 0.45)	-0.11 (-0.5, 0.28)	-0.13 (-1.34, 1.08)	-0.40 (-2.49, 1.69)	-0.59(-2.36,1.18)
<i>Polyommatus icarus</i>	-0.94 (-1.58, -0.3)*	0.24 (-0.26, 0.74)	-0.09 (-0.26, 0.08)	0.46 (0.27, 0.65)	-0.11 (-0.44, 0.22)	-0.75 (-1.19, -0.31)*	-0.50(-0.86,-0.12)*
<i>Celastrina argiolus</i>	-0.37 (-0.72, -0.02)*	0.08 (-0.37, 0.53)	-0.40 (-0.72, -0.08)*	0.18 (-0.02, 0.38)	0.08 (-0.18, 0.34)	0.28 (-0.23, 0.79)	0.15(-0.43,0.71)
<i>Aglaia urticae</i>	0.54 (0.19, 0.89)*	-0.77 (-1.09, -0.45)*	0.02 (-0.14, 0.18)	0.35 (0.18, 0.52)*	0.05 (-0.16, 0.26)	-0.39 (-0.61, -0.17)*	0.02(-0.16,0.22)
<i>Aglaia io</i>	0.37 (0.12, 0.62)*	-0.54 (-0.79, -0.29)*	0.29 (0.13, 0.45)*	0.06 (-0.14, 0.26)	0.20 (0.00, 0.40)	-0.29 (-0.5, -0.08)*	0.25(0.06,0.46)*
<i>Polygonia c-album</i>	-0.21 (-0.48, 0.06)	-0.26 (-0.48, -0.04)*	0.06 (-0.07, 0.19)	0.21 (0.05, 0.37)*	0.26 (0.08, 0.44)*	-0.31 (-0.52, -0.1)*	0.23(0.03,0.41)*
<i>Argynnis aglaja</i>	-0.99 (-1.67, -0.31)*	-0.46 (-1.26, 0.34)	0.38 (-0.47, 1.23)	0.19 (-0.86, 1.24)	-0.22 (-1.15, 0.71)	1.15 (0.53, 1.77)*	1.49(0.67,2.33)*
<i>Argynnis paphia</i>	0.99 (0.50, 1.47)*	-0.34 (-0.74, 0.06)	0.2 (-0.14, 0.54)	-0.24 (-0.56, 0.08)	0.45 (0.06, 0.84)*	0.09 (-0.33, 0.51)	0.49(0.05,0.95)*
<i>Pararge aegeria</i>	-0.06 (-0.24, 0.12)	-0.25 (-0.41, -0.09)*	0.01 (-0.08, 0.10)	0.02 (-0.09, 0.13)	-0.09 (-0.22, 0.04)	-0.08 (-0.25, 0.09)	-0.13(-0.29,0.01)
<i>Lasiommata megera</i>	-0.64 (-2.24, 0.96)	0.25 (-0.99, 1.49)	0.00 (-0.40, 0.40)	-0.38 (-0.86, 0.1)	0.89 (0.36, 1.42)*	-0.97 (-1.51, -0.43)	-0.47(-0.97,0.05)
<i>Melanargia galathea</i>	-0.19 (-1.47, 1.09)	0.22 (-1.00, 1.44)	-0.29 (-0.67, 0.09)	0.80 (0.44, 1.16)*	-0.12 (-0.41, 0.17)	0.21 (-0.09, 0.51)	0.60(0.21,0.99)*
<i>Pyronia tithonus</i>	0.08 (-0.08, 0.24)	-0.06 (-0.20, 0.08)	0.07 (-0.02, 0.16)	-0.09 (-0.20, 0.02)	0.17 (0.06, 0.28)*	0.22 (0.08, 0.36)*	0.37(0.23,0.51)*
<i>Maniola jurtina</i>	0.14 (0.00, 0.28)	-0.05 (-0.19, 0.09)	0.02 (-0.07, 0.11)	-0.15 (-0.24, -0.06)*	-0.00 (-0.09, 0.09)	0.36 (0.25, 0.47)*	0.23(0.13,0.33)*
<i>Aphantopus hyperantus</i>	-0.27 (-0.63, 0.09)	-0.03 (-0.35, 0.29)	-0.09 (-0.25, 0.07)	0.16 (-0.01, 0.33)	0.18 (0.03, 0.33)*	0.22 (0.05, 0.39)*	0.47(0.28,0.66)*
<i>Coenonympha pamphilus</i>	0.25 (-0.20, 0.70)	-0.63 (-1.09, -0.17)*	-0.43 (-0.72, -0.14)*	0.03 (-0.24, 0.30)	0.16 (-0.09, 0.41)	0.23 (-0.04, 0.50)	-0.01(-0.31,0.29)
<i>Erebia aethiops</i>	-0.16 (-1.27, 0.95)	0.27 (-0.68, 1.22)	0.10 (-0.55, 0.75)	-0.65(-1.41,0.11)	-0.07(-0.75,0.61)	-0.66 (-1.89, 0.57)	-1.29(-2.50,-0.06)*
<i>Vanessa atalanta</i>	0.01 (-0.22, 0.24)	-0.12 (-0.35, 0.11)	-0.17 (-0.33, -0.01)*	-0.09 (-0.22, 0.04)	0.38 (0.24, 0.52)*	0.15 (-0.08, 0.38)	0.28(0.02,0.52)*
<i>Vanessa cardui</i>	0.59 (-0.92, 2.10)	-1.4 (-2.83, 0.03)	2.05 (1.63, 2.47)*	-0.36 (-1.20, 0.48)	0.83 (-0.29, 1.95)	-1.03 (-2.3, 0.24)	1.49(0.49,2.49)*
N. species with WCBS growth higher (N sign.)	13 ( 3)	6 (0)	17 (4)	14 (3)	17 (11)	11 (5)	17 (12)
N. species with tBMS growth higher (N sign.)	13 (5)	19 (8)	9 (3)	12 (2)	9 (0)	15 (7)	9 (3)