**Local effects of climate change – has the date of first emergence changed in several species of *Lepidoptera* in Yorkshire during the period 1995 to 2014?**

**David R. R. Smith1 and Heather A. R. Smith**

1Department of Psychology, University of Hull, Hull, HU6 7RX, UK.

e-mail: [davidsmith.butterflies@gmail.com](mailto:davidsmith.butterflies@gmail.com)

**Introduction**

The Earth has undergone a period of sustained growth in global average temperature from the early twentieth century onwards (Stott *et al.*, 2000; IPCC, 2013). The impact of substantial climate change upon *Lepidoptera* includes such changes as shifts in first emergence date and peak flight date, flight period length and pattern, change in voltinism, abundance, distribution *etc* (e. g., Sparks & Yates, 1997; Roy & Sparks, 2000; Asher *et al*., 2001; Diamond *et al*., 2011; Karlsson, 2014). Given that climate change is likely to affect all flora and fauna to a greater or lesser extent, and that each species lies in the middle of a complex web of interdependencies with the rest of nature, the way that climate change ramifies upon any given species may not be simple.

Yorkshire is a particularly interesting arena to test for the effect of global temperature increases upon butterfly emergence patterns, lying as it does at a sufficiently northerly latitude (between 53o 18’ N and 54o 40’ N) that many butterflies are (or were) at the northern edge of their range where they are particularly sensitive to climate change. Interestingly, in the last few decades, we have seen butterfly species once rare or absent to Yorkshire, such as the Comma (*Polygonia c-album*), Speckled Wood (*Pararge aegeria*) and Holly Blue (*Celastrina argiolus*), sweep northwards to become commonplace (Asher *et al*., 2001; Fox *et al*., 2007). Butterflies are poikilothermic, being heavily dependent on external air temperature and incident sunlight to raise their body temperature to levels at which they are able to mate and lay eggs (at least 18-28oC). During winter months, butterflies enter diapause – a period of physiological dormancy to survive colder temperatures – in a variety of overwintering states (e.g., Brown Hairstreak *Thecla betulae*, egg; Meadown Brown *Maniola jurtina*, larva; Orange-tip *Anthocharis cardamines*, pupa; Brimstone *Gonepteryx rhamni*, adult). As global surface temperatures have increased since the early twentieth century onwards (IPCC, 2013), this has coincided with earlier emergence (e.g., Sparks & Yates, 1997; Roy & Sparks, 2000), perhaps because the insects are awakened from diapause at an earlier point of the year.

We wished to a) quantify date of *first emergence* of a range of butterfly species in Yorkshire from1995 to 2014, b) investigate what changes in temperature there might have been in Yorkshire over the same time period and c), explore the relationship between date of first emergence and temperature. The years between 1995 and 2014 represent the longest range over which we have detailed and plentiful records of butterflies in Yorkshire, representing a period of time of sufficient length to potentially demonstrate historical change in phenology (two decades, Roy & Sparks, 2000) and is the first systematic analysis of local effects of climate change upon date of first emergence in Yorkshire’s butterflies.

The criterion for choice of species was that the species should be a mix of habitat generalists and specialists, have an early spring emergence, be easily identifiable by recorders, do not overwinter as adults, were from different families and be present in sufficiently large numbers so as not to invite sampling problems. Some of these criteria are motivated by pragmatic reasons, such as a wish to increase our sampling pool, to reduce opportunities for recorder misidentifications[[1]](#footnote-1) and to discount early sightings of hibernating adults due to physical disturbance or one-off warm days. The choice of having a mix of generalists and specialists, across a range of families, is to strengthen the applicability of our results to all butterflies. Finally, studies have shown that earlier emergence of butterfly species is especially marked for spring species (Sparks & Yates, 1997; Roy & Sparks, 2000). As such, we chose a ‘Nymphalid’ (*Nymphalidae*), the Speckled Wood (*Pararge aegeria*); a ‘Blue’ (*Lycaenidae*), the Holly Blue (*Celastrina argiolus*); a ‘White’ (*Pieridae*), the Orange-tip (*Anthocharis cardamines*); and a ‘Skipper’ (*Hesperidae*), the Dingy Skipper (*Erynnis tages*).

**Method**

We searched the Butterfly Conservation database for records of our target species for the period 1995 to 2014 from the five Watsonian vice-counties (VC61-VC65) traditionally comprising the county of Yorkshire for recording purposes. For each year[[2]](#footnote-2) we found the dates of the five earliest records of each target species and took the mean. This provided a reasonably unbiased estimate of each year’s date of first emergence for each species.

We analysed the butterfly data using a bivariate Pearson’s correlation, with the variables of year of recording and mean date of the five earliest records for each year. We are interested in exploring how date of first emergence and year co-vary, so we adopted a non-directional two-tailed analysis. The equation of the best-fitting line (least squares linear regression) to the data was used for the purposes of quantifying changes in date of first emergence. This general statistical approach was used to analyse local and regional temperature data series (variables year of recording and temperature), and to compare temperature and date of first emergence.

**Results**

Date of first emergence was significantly inversely related to recording year for Speckled Wood (*r*(16)= -0.52, 95% BCa CI [-0.824, -0.057], *p* = 0.027), Orange-tip (*r*(18)= -0.57, 95% BCa CI [-0.781, -0.261], *p* = 0.009), Dingy Skipper (*r*(18)= -0.45, 95% BCa CI [-0.747, -0.180], *p* = 0.049), and insignificantly related to recording year for Holly Blue (*r*(18)= -0.19, 95% BCa CI [-0.680, 0.422], *p* = 0.422 *NS*). The scatter plots and lines of best-fit (linear regression) are shown in Figure 1.

=============== INSERT FIGURE 1 HERE ===============

The day of first emergence of Speckled Wood has shifted 17 days earlier[[3]](#footnote-3) in the year between 1997 and 2014; equivalent to 1 day per year or 10 days per decade. Thus in 1997 the mean date of first emergence, using the linear regression equation, would have been 18 April and this had shifted to 1 April by 2014. For the other three species between 1995 and 2014, the shifts are 23 days earlier in the year for the Orange-tip (equivalent to 1.21 days per year); 9 days earlier in the year for the Holly Blue (equivalent to 0.47 days per year) and 14 days earlier in the year for the Dingy Skipper (equivalent to 0.74 days per year). This is consistent with earlier work on British butterflies (Sparks & Yates, 1997; Roy & Sparks, 2000) which suggested climate warming of 3oC could advance date of first emergence by two to three weeks. Table 1 summarises these changes in phenology with additional statistical findings taking into account the variability of the data over the recording years. If a weighted correlation, that takes into account the variability of the data, is applied then the pattern of results is unchanged but the correlation coefficients and level of significance increase even more. There is an undeniable shift towards earlier emergence in the year over the last two decades for three of the butterfly species.

=============== INSERT TABLE 1 HERE ===============

What should be considered now is whether there has been an actual shift in average temperature in the Yorkshire region in the period of study. Figure 2 plots spring and summer temperature series covering the period from 1995 to 2014 – one from Sherburn in Elmet (roughly in the centre of the county with Lat. 53o 47’ 48’’ N, Long. 1o 15’ 26’’ W, Elev. 27 m) and the other from the Central England Temperature (CET) data series. The CET series gives mean temperature readings from the Midlands (extending back to 1659) and is taken to be a reasonable proxy for temperature in other parts of the UK (Duncan, 1991).

=============== INSERT FIGURE 2 HERE ===============

There is little discernible shift in mean spring (February—April), summer (May—July), autumn (August—Oct)[[4]](#footnote-4) and winter (November—January) temperature in Yorkshire between 1995 and 2014. Yorkshire seasonal temperature data series show no significant trends over the twenty year time period: spring temperature series *r*(18)= -0.18, 95% BCa CI [-0.680, 0.357], *p* = 0.44 *NS*; summer temperature series *r*(18)= -0.043, 95% BCa CI [-0.524, 0.423], *p* = 0.858 *NS*; autumn temperature series *r*(18)= -0.339, 95% BCa CI [-0.738, 0.258], *p* = 0.143 *NS*; winter temperature series *r*(18)= 0.168, 95% BCa CI [-0.317, 0.777], *p* = 0.478 *NS*. The cross-check from the CET temperature series against the Sherburn data series shows close agreement. An analysis of the CET and Sherburn data for spring and summer show them to be significantly correlated: spring *r*(18)= 0.96, 95% BCa CI [0.920, 0.986], *p* < 0.001; summer *r*(18)= 0.89, 95% BCa CI [0.746, 0.944], *p* < 0.001. Therefore we can be confident that the Sherburn data is representative of UK temperatures and is not anomalous. If we are to make some link between earlier date of first emergence and increased spring temperatures in the year of emergence (say), then it is not obviously to be found in increased mean spring temperature because there is no increase.

We should not (and logically cannot) rule out the date of first emergence as being temperature dependent. The problem is that what exactly is driving earlier emergence could be buried deep within the temperature series. It is beyond the scope of this report to exhaustively chase all possible factors. We checked for correlations with preceding season (autumn, winter, spring, summer) temperatures and date of first emergence in the subsequent year. In no instance was there a significant correlation between preceding season and subsequent year date of first emergence (see Table 2). There are then no obvious associations between the temperature data and changes in the dates of first emergence. Perhaps earlier trends in increased temperature (such as the 1.5 OC increase in central England spring temperatures between 1976 and 1998 (Roy & Sparks, 2000)) have induced a long-term change that takes years to work through the gene pool of the population? This is beyond the scope of this short report.

=============== INSERT TABLE 2 HERE ===============

Another concern is a possible intervening relationship between increased observer effort and earlier emergence dates. Basically, the more ‘abundant’ the butterfly (which again might be no more than an intervening variable for having more observers around actively recording), then the greater the chance for a given individual butterfly to be seen. Thus increased observer effort or increased abundance can theoretically lead to a pattern of apparent earlier emergence. This is hinted at in Figure 1 for Speckled Wood, where the mean date of first emergence for 1995 and 1996 were both late in the year and associated with a great deal of uncertainty (shown by the large standard deviations). The dates of first emergence were presumably late in the year and more variable because Speckled Wood was present in very small numbers in those years (having only just reached the southern borders of Yorkshire in a general northwards movement, see Asher *et al*., 2001), so the chance of spotting a Speckled Wood was relatively small. This could lead to a confounding effect where the specimens seen are not necessarily newly emerged but could be post-emergent adults by a number of days or even weeks. However, it is hard to see how changes of up to 17 days (Speckled Wood) could be accounted for by an increased chance to spot individual butterflies once a species has become relatively well established in the region. Interestingly, Speckled Wood abundance peaked in Yorkshire in 2009 with recorded numbers in the last five years dropping by a factor of two but with little discernible change in observed date of first emergence. The particularly late date of first emergence in 2013 was attributable to the severe spring in that year. Further work on possible interactions of increased observer effort and changes in recorded first emergence will be needed to clarify the role of climate change upon driving changes in phenology, both at the local and global scale.

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Figure 1. Day in year of first emergence, as a function of recording year, for Speckled Wood (*Pararge aegeria*), Orange-tip (*Anthocharis* *cardamines*), Holly Blue (*Celastrinia aegiolus*) and Dingy Skipper (*Erynnis tages*). Day of first emergence in each year calculated by taking the mean of the dates of the five earliest records of each target species. The number of records for 1995 and 1996 were so few for Speckled Wood that those years were omitted from the analysis, hence Speckled Wood is analysed between 1997 to 2014. The best-fitting least squares linear regression line for 1995 to 2014 (Speckled Wood) is dotted and shown for illustrative purposes only. Solid best-fitting least squares linear regression lines are calculated for 1995 to 2014 for all species, except Speckled Wood where it is calculated for 1997 to 2014. Equation shown is for solid least squares linear regression lines. Error bars represent ± 1 standard deviation.

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| Table 1. Species statistical summary | | | | | | | | | |
| Species | *r1* | *p2* | Day(s)/ yr  shift | Start  yr3 | End yr3 | Start year  Dfe4 | End year dfe | *rw5* | *pw* |
| Speckled Wood (*Pararge aegeria*) | -0.52 | 0.027\* | 1.0 | 1997 | 2014 | 18 April | 1 April | -0.53 | 0.025\* |
|  |  |  |  |  |  |  |  |  |  |
| Orange-tip (*Anthocharis cardamines*) | -0.57 | 0.009\*\* | 1.21 | 1995 | 2014 | 20 April | 28 March | -0.86 | <0.00001\*\*\* |
|  |  |  |  |  |  |  |  |  |  |
| Holly Blue (*Celastrina argiolus*) | -0.19 | 0.422 (*NS*) | 0.47 | 1995 | 2014 | 17 April | 8 April | -0.30 | 0.205 (*NS*) |
|  |  |  |  |  |  |  |  |  |  |
| Dingy Skipper (*Erynnis tages*) | -0.45 | 0.049\* | 0.74 | 1995 | 2014 | 15 May | 2 May | -0.54 | 0.013\* |
| 1Pearson’s *r* 2two-tailed 3Start and end year within UK BMS (BCY) database 4Date of first emergence 5Pearson’s *r* calculated with each year’s data weighted in proportion to its variability  \*significant *p*<0.05 \*\*significant *p*<0.01 \*\*\*significant *p*<0.001 | | | | | | | | | |

Figure 2. Temperature time series for spring (mean February—April) and summer (mean May—July) calculated from a weather station at Sherburn in Elmet and the Central England Temperature (CET) data set, between the years 1995—2014. Best-fitting lines (least squares linear regression) are solid for Sherburn in Elmet and dotted for CET.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Table 2. Correlation between preceding season temperature and date of first emergence in  subsequent year (statistical summary) | | | | | |
| Species | Season | *r1* | *p2* | 95% BCa CI3 [lower, upper] | df |
| Speckled Wood (*Pararge aegeria*) | autumn | -0.27 | 0.298 | [-0.636, 0.202] | 17 |
|  |  |  |  |  |  |
|  | winter | -0.06 | 0.810 | [-0.567, 0.194] |  |
|  |  |  |  |  |  |
|  | spring | 0.27 | 0.293 | [-0.261, 0.742] |  |
|  |  |  |  |  |  |
|  | summer | -0.29 | 0.268 | [-0.676, 0.355] |  |
|  |  |  |  |  |  |
| Orange-tip (*Anthocharis cardamines*) | autumn | 0.30 | 0.213 | [-0.257, 0.649] | 19 |
|  |  |  |  |  |  |
|  | winter | 0.03 | 0.896 | [-0.525, 0.400] |  |
|  |  |  |  |  |  |
|  | spring | 0.26 | 0.290 | [-0.138, 0.639] |  |
|  |  |  |  |  |  |
|  | summer | -0.07 | 0.776 | [-0.478, 0.321] |  |
|  |  |  |  |  |  |
| Dingy Skipper (*Erynnis tages*) | autumn | 0.20 | 0.414 | [-0.532, 0.640] | 19 |
|  |  |  |  |  |  |
|  | winter | 0.07 | 0.774 | [-0.494, 0.473] |  |
|  |  |  |  |  |  |
|  | spring | 0.37 | 0.123 | [-0.127, 0.770] |  |
|  |  |  |  |  |  |
|  | summer | -0.09 | 0.716 | [-0.702, 0.374] |  |
| 1Pearson’s *r* 2two-tailed 3Bias corrected accelerated confidence intervals for the correlation coefficient | | | | | | |

1. Small Whites (*Pieris rapae*) and female Green-veined Whites (*Pieris napi*) being an obvious misidentification pair [↑](#footnote-ref-1)
2. The number of records for 1995 and 1996 were so few for Speckled Wood that all analysis of Speckled Wood is taken from 1997 to 2014 [↑](#footnote-ref-2)
3. The least-squares line of best fit has equation *y*=-*x* + 2104.6 (see Figure 1). This is the straight-line linear form *y*=*mx* + *c*, where *y* is date of first emergence (day in year), *x* is recording year, *c* is y-axis intercept (=constant) and *m* is the gradient (=1). The first year of recording period was 1997 so, substituting into the equation, gives the answer of day in year of 108 (rounded to nearest whole integer). This equates to 18 April. Similarly, substituting in last year of the recording period of 2014, gives the answer of day in the year of 91 (=1 April). This is a difference of 17 days. See Table 1 for further details and the other species calculations. [↑](#footnote-ref-3)
4. To avoid clutter the autumn and winter temperature series for Sherburn and CET not shown in Figure 2. [↑](#footnote-ref-4)