Supplementary information for:

*Applying computer vision to digitised natural history collections for climate change research: temperature-size responses in British butterflies*

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SI Table 1. Factors used in multi-species analysis and their levels

|  |  |  |  |
| --- | --- | --- | --- |
| **Factor** | **Number of levels** | **Name of levels** | **Notes** |
| Family | 4 | Hesperiidae, Lycaenidae, Nymphalidae, Pieridae |  |
| Overwinter stage | 4 | Egg, larva, pupa, adult |  |
| Habitat type | 4 | Grass, wood, any, other | Grass=Grassland, Wood=Woodland, Any=species that live anywhere, Other=species that don’t fit into the other categories. |
| Size category | 3 | Small, Medium, Large | Based on average forewing lengths: Small=≥10mm-20mm, Medium=>20-30mm, Large=>30-40mm |

**SI Table 2.** Descriptive statistics of the NHM iCollections used in the analysis. All specimens were measured by Mothra. The average size of male and female forewing lengths are presented for species which were trained for sex identification. Except for seven species (p values in bold), all species have female biased sexual size dimorphism.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | Family | Total number of specimens (outliers removed) | Number of outliers | Total specimens | Average forewing length (mm) | Average size of female forewing lengths (mm) | Average size of male forewing lengths (mm) | p value (male v female forewing lengths) | Trained for gender ID (y/n) | Year range |
| *Hesperia comma* | Hesperidae | 716 | 7 | 723 | 13.28 | 13.91 | 12.69 | <0.0001 | y | 1860-1981 |
| *Ochlodes sylvanus* | Hesperidae | 1146 | 26 | 1172 | 13.83 | 14.43 | 13.44 | <0.0001 | y | 1873-1989 |
| *Thymelicus acteon* | Hesperidae | 632 | 13 | 645 | 10.71 | 11.04 | 10.47 | <0.0001 | y | 1866-1986 |
| *Thymelicus lineola* | Hesperidae | 776 | 11 | 787 | 11.85 | 12.42 | 11.53 | <0.0001 | y | 1866-1997 |
| *Thymelicus sylvestris* | Hesperidae | 1136 | 16 | 1152 | 12.39 | 12.80 | 12.13 | <0.0001 | y | 1837-1991 |
| *Carterocephalus palaemon* | Hesperidae | 798 | 22 | 820 | 12.39 | NA | NA | NA | n | 1831-1975 |
| *Erynnis tages* | Hesperidae | 1031 | 10 | 1041 | 12.21 | NA | NA | NA | n | 1869-1989 |
| *Pyrgus malvae* | Hesperidae | 1372 | 24 | 1396 | 10.56 | NA | NA | NA | n | 1876-1989 |
| *Callophrys rubi* | Lycaenidae | 965 | 10 | 975 | 13.19 | 13.28 | 13.14 | 0.007 | y | 1872-1991 |
| *Celastrina argiolus* | Lycaenidae | 1970 | 13 | 1983 | 14.74 | 14.71 | 14.77 | 0.185 | y | 1846-1991 |
| *Cyaniris semiargus* | Lycaenidae | 201 | 6 | 207 | 14.76 | 14.79 | 14.74 | 0.71 | y | 1830-1954 |
| *Lycaena dispar* | Lycaenidae | 1001 | 35 | 1036 | 20.24 | 20.94 | 19.65 | <0.0001 | y | 1816-1994 |
| *Lysandra bellargus* | Lycaenidae | 5715 | 53 | 5768 | 14.49 | 14.39 | 14.63 | **<0.0001** | y | 1867-1997 |
| *Lysandra coridon* | Lycaenidae | 11456 | 75 | 11531 | 15.81 | 15.48 | 16.22 | **<0.0001** | y | 1842-1997 |
| *Favonius quercus* | Lycaenidae | 935 | 3 | 938 | 15.68 | 15.40 | 15.96 | **<0.0001** | y | 1882-1988 |
| *Plebejus argus* | Lycaenidae | 6022 | 48 | 6070 | 12.18 | 11.88 | 12.53 | **<0.0001** | y | 1853-2006 |
| *Polyommatus icarus* | Lycaenidae | 8262 | 48 | 8310 | 14.25 | 14.13 | 14.50 | **<0.0001** | y | 1814-1995 |
| *Satyrium pruni* | Lycaenidae | 655 | 6 | 661 | 15.13 | 15.51 | 14.84 | <0.0001 | y | 1830-1966 |
| *Satyrium w-album* | Lycaenidae | 697 | 11 | 708 | 14.72 | 14.96 | 14.49 | <0.0001 | y | 1870-1977 |
| *Thecla betulae* | Lycaenidae | 968 | 11 | 979 | 17.11 | 17.44 | 16.79 | <0.0001 | y | 1859-1990 |
| *Aricia agestis* | Lycaenidae | 2679 | 29 | 2708 | 12.11 | NA | NA | NA | n | 1805-1997 |
| *Aricia artaxerxes* | Lycaenidae | 1194 | 16 | 1210 | 12.21 | NA | NA | NA | n | 1806-1982 |
| *Cupido minimus* | Lycaenidae | 1410 | 17 | 1427 | 10.82 | NA | NA | NA | n | 1879-1987 |
| *Lycaena phlaeas* | Lycaenidae | 5087 | 159 | 5246 | 13.63 | NA | NA | NA | n | 1826-1999 |
| *Maculinea arion* | Lycaenidae | 1576 | 6 | 1582 | 17.37 | NA | NA | NA | n | 1830-1958 |
| *Apatura iris* | Nymphalidae | 429 | 29 | 458 | 33.95 | 35.59 | 32.39 | <0.0001 | y | 1830-2000 |
| *Aphantopus hyperantus* | Nymphalidae | 1001 | 16 | 1017 | 20.55 | 21.68 | 20.13 | <0.0001 | y | 1833-1997 |
| *Speyeria aglaja* | Nymphalidae | 1572 | 93 | 1665 | 27.38 | 28.87 | 26.50 | <0.0001 | y | 1828-1998 |
| *Argynnis paphia* | Nymphalidae | 1849 | 31 | 1880 | 30.64 | 31.26 | 29.84 | <0.0001 | y | 1815-1998 |
| *Hipparchia semele* | Nymphalidae | 2081 | 22 | 2103 | 24.48 | 25.69 | 23.35 | <0.0001 | y | 1868-1993 |
| *Lasiommata megera* | Nymphalidae | 1625 | 34 | 1659 | 20.89 | 21.64 | 20.30 | <0.0001 | y | 1876-2004 |
| *Maniola jurtina* | Nymphalidae | 5293 | 58 | 5351 | 22.50 | 23.44 | 21.32 | <0.0001 | y | 1831-1998 |
| *Pararge aegeria* | Nymphalidae | 2389 | 25 | 2414 | 20.32 | 20.61 | 19.96 | <0.0001 | y | 1831-2004 |
| *Pyronia tithonus* | Nymphalidae | 2358 | 18 | 2376 | 18.38 | 19.66 | 17.36 | <0.0001 | y | 1820-1999 |
| *Aglais urticae* | Nymphalidae | 3338 | 112 | 3450 | 22.50 | NA | NA | NA | n | 1805-2005 |
| *Fabriciana adippe* | Nymphalidae | 1067 | 45 | 1112 | 26.94 | NA | NA | NA | n | 1849-1984 |
| *Boloria euphrosyne* | Nymphalidae | 2169 | 182 | 2351 | 19.85 | NA | NA | NA | n | 1829-1992 |
| *Boloria selene* | Nymphalidae | 2440 | 208 | 2648 | 19.04 | NA | NA | NA | n | 1870-1998 |
| *Coenonympha pamphilus* | Nymphalidae | 2615 | 42 | 2657 | 14.59 | NA | NA | NA | n | 1809-1993 |
| *Coenonympha tullia* | Nymphalidae | 2979 | 31 | 3010 | 17.86 | NA | NA | NA | n | 1850-1998 |
| *Erebia aethiops* | Nymphalidae | 1169 | 17 | 1186 | 20.50 | NA | NA | NA | n | 1848-1986 |
| *Erebia epiphron* | Nymphalidae | 1136 | 49 | 1185 | 16.17 | NA | NA | NA | n | 1826-1987 |
| *Euphydryas aurinia* | Nymphalidae | 5565 | 74 | 5639 | 18.98 | NA | NA | NA | n | 1840-1998 |
| *Aglais io* | Nymphalidae | 1164 | 39 | 1203 | 27.15 | NA | NA | NA | n | 1865-1996 |
| *Limenitis camilla* | Nymphalidae | 885 | 22 | 907 | 26.36 | NA | NA | NA | n | 1819-1990 |
| *Melanargia galathea* | Nymphalidae | 1876 | 55 | 1931 | 23.34 | NA | NA | NA | n | 1822-1987 |
| *Melitaea athalia* | Nymphalidae | 1664 | 33 | 1697 | 18.65 | NA | NA | NA | n | 1866-1982 |
| *Melitaea cinxia* | Nymphalidae | 1261 | 25 | 1286 | 19.12 | NA | NA | NA | n | 1823-1987 |
| *Nymphalis polychloros* | Nymphalidae | 706 | 21 | 727 | 28.07 | NA | NA | NA | n | 1860-1993 |
| *Polygonia c-album* | Nymphalidae | 1353 | 27 | 1380 | 22.53 | NA | NA | NA | n | 1871-1997 |
| *Vanessa atalanta* | Nymphalidae | 1002 | 64 | 1066 | 28.68 | NA | NA | NA | n | 1876-1999 |
| *Vanessa cardui* | Nymphalidae | 816 | 35 | 851 | 27.77 | NA | NA | NA | n | 1867-1999 |
| *Anthocharis cardamines* | Pieridae | 2279 | 25 | 2304 | 19.20 | 19.85 | 18.79 | <0.0001 | y | 1818-1991 |
| *Colias croceus* | Pieridae | 2428 | 59 | 2487 | 23.39 | 23.83 | 22.48 | <0.0001 | y | 1857-1996 |
| *Gonepteryx rhamni* | Pieridae | 655 | 73 | 728 | 27.52 | 27.75 | 27.28 | <0.0001 | y | 1824-1989 |
| *Pieris brassicae* | Pieridae | 1749 | 44 | 1793 | 29.73 | 30.07 | 29.27 | <0.0001 | y | 1876-1992 |
| *Pieris napi* | Pieridae | 6627 | 40 | 6667 | 21.19 | 20.97 | 21.48 | **<0.0001** | y | 1815-1998 |
| *Pieris rapae* | Pieridae | 1913 | 25 | 1938 | 22.61 | 22.49 | 22.74 | **0.003** | y | 1821-1995 |
| *Colias hyale* | Pieridae | 600 | 3 | 603 | 22.93 | NA | NA | NA | n | 1857-1972 |
| *Leptidea sinapis* | Pieridae | 1360 | 9 | 1369 | 18.86 | NA | NA | NA | n | 1834-2000 |
| TOTAL |  | **127,813** | **2,360** | **130,173** |  |  |  |  |  |  |

**SI Table 3**. Results of the linear models for predicting average forewing length for all species (sex and generations were analysed separately where applicable) using mean monthly temperatures as variables; values are adjusted R2 (AR2), the F statistic (F), degrees of freedom (df) and the p-value (p).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Family | Species | Sex | AR2 | F | df | p |
| Hesperiidae | *Erynnis tages* | Both | 0.0396 | 5.208 | 6, 606 | <0.001 |
| *Hesperia comma* | Male | 0.05312 | 3.263 | 6, 236 | 0.00422 |
| Female | 0.0214 | 1.862 | 6, 221 | 0.0951 |
| *Ochlodes sylvanus* | Male | 0.0432 | 4.734 | 7, 516 | <0.001 |
| Female | 0.0283 | 2.333 | 7, 313 | 0.0247 |
| *Pyrgus malvae* | Both | 0.0245 | 4.365 | 6, 797 | <0.001 |
| *Thymelicus lineola* | Male | 0.0283 | 3.260 | 4, 306 | 0.0122 |
| Female | 0.0143 | 1.846 | 4, 230 | 0.121 |
| *Thymelicus sylvestris* | Male | 0.00462 | 1.497 | 4, 425 | 0.202 |
| Female | 0.00522 | 1.413 | 4, 311 | 0.230 |
| Lycaenidae | *Favonius quercus* | Male | 0.0429 | 2.120 | 5, 120 | 0.0676 |
| Female | 0.0171 | 1.518 | 5, 144 | 0.188 |
| *Plebejus argus* | Male | 0.0469 | 3.756 | 5, 275 | 0.00263 |
| Female | 0.0339 | 1.905 | 5, 124 | 0.0982 |
| *Polyommatus bellargus* generation 1 | Male | 0.142 | 4.432 | 3, 59 | 0.00708 |
| Female | 0.104 | 5.786 | 3, 121 | <0.001 |
| *Polyommatus bellargus* generation 2 | Male | 0.00691 | 1.466 | 3, 198 | 0.225 |
| Female | -0.00551 | 0.405 | 3, 323 | 0.750 |
| *Polyommatus coridon* | Male | 0.0573 | 2.603 | 5, 127 | 0.0281 |
| Female | 0.0379 | 3.227 | 5, 278 | 0.00754 |
| *Thecla betulae* | Male | 0.0472 | 1.78 | 4, 59 | 0.145 |
| Female | 0.00147 | 1.026 | 4, 68 | 0.400 |
| Nymphalidae | *Aglais io* | Both | 0.00403 | 1.528 | 3, 388 | 0.207 |
| *Aglais urticae* generation 1 | Both | 0.0109 | 2.716 | 3, 463 | 0.0443 |
| *Aglais urticae* generation 2 | Both | 0.0111 | 2.123 | 3, 297 | 0.0974 |
| *Apatura iris* | Male | 0.0638 | 1.682 | 7, 63 | 0.130 |
| Female | 0.156 | 2.510 | 7, 50 | 0.0272 |
| *Argynnis paphia* | Male | 0.0112 | 2.227 | 5, 539 | 0.0503 |
| Female | 0.0397 | 6.051 | 5, 606 | <0.001 |
| *Euphydryas aurinia* | Both | 0.0111 | 5.070 | 6, 2174 | <0.001 |
| *Fabriciana adippe* | Both | 0.0245 | 4.289 | 5, 649 | <0.001 |
| *Hipparchia semele* | Male | 0.0242 | 3.450 | 7, 684 | 0.00123 |
| Female | 0.00502 | 1.413 | 7, 565 | 0.198 |
| *Melitaea athalia* | Both | 0.0180 | 3.721 | 6, 887 | 0.00116 |
| *Melitaea cinxia* | Both | -0.00279 | 0.789 | 5, 373 | 0.558 |
| *Speyeria aglaja* | Both | 0.0294 | 9.773 | 4, 1156 | <0.001 |
| Pieridae | *Anthocharis cardamines* | Male | 0.0001 | 1.053 | 6, 796 | 0.389 |
| Female | 0.0129 | 1.861 | 6, 388 | 0.0864 |
| *Gonepteryx rhamni* | Male | -0.0223 | 0.0848 | 4, 164 | 0.987 |
| Female | -0.0268 | 0.112 | 4, 132 | 0.978 |
| *Pieris napi generation 1* | Male | 0.0246 | 3.425 | 4, 381 | 0.00909 |
| Female | 0.0158 | 1.732 | 4, 178 | 0.145 |
| *Pieris napi generation 2* | Male | 0.00613 | 1.664 | 3, 320 | 0.175 |
| Female | 0.00432 | 1.530 | 3, 364 | 0.206 |

**SI Table 4.** Outputs for variables included in significant linear models using mean monthly temperatures; t-value and significance (p) for each variable, slope estimate, standard error and upper and lower confidence intervals (CI), importance scores, variance inflation factors (VIF) and whether the variable was selected for the final model after stepwise regression in both directions. Slope estimates, standard error and confidence intervals are based on an average of all candidate models (using the IT-AIC approach), and variables in bold are those retained after nested models were removed. Importance scores are based on the number of candidate models the variable was present in, with a score of 1.0 indicating that the variable was present in all candidate models. Month categories with a “-1” refers to the monthly temperature in the year prior to the collection date.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | Month | *t-value* | *p* | *Slope estimate* | *Standard error* | *Lower CI* | *Upper CI* | *Importance* | *VIF* | *Final model (Y/N)* |
| *E. tages* | ***Jun-1*** | 0.904 | 0.366 | 0.034 | 0.031 | -0.027 | 0.094 | 0.390 | 1.245 | N |
| ***Jul-1*** | 0.165 | 0.869 | 0.012 | 0.028 | -0.043 | 0.067 | 0.290 | 1.501 | N |
| ***Aug-1*** | 2.117 | 0.035 | 0.075 | 0.029 | 0.019 | 0.132 | 0.940 | 1.745 | Y |
| ***March*** | -2.631 | 0.009 | -0.058 | 0.022 | -0.101 | -0.014 | 0.940 | 1.079 | Y |
| ***April*** | 3.884 | <0.001 | 0.098 | 0.025 | 0.049 | 0.146 | 1.000 | 1.092 | Y |
| *May* | -0.402 | 0.688 | -0.020 | 0.032 | -0.083 | 0.043 | 0.280 | 1.221 | N |
| *H. comma* (males) | *March* | 0.587 | 0.558 | 0.023 | 0.033 | -0.042 | 0.088 | 0.310 | 1.468 | N |
| *April* | 0.230 | 0.818 | 0.010 | 0.040 | -0.068 | 0.088 | 0.270 | 1.256 | N |
| *May* | -0.408 | 0.684 | -0.020 | 0.057 | -0.113 | 0.093 | 0.270 | 1.591 | N |
| ***June*** | 3.712 | 0.000 | 0.165 | 0.042 | 0.083 | 0.247 | 1.000 | 1.438 | Y |
| ***July*** | -1.607 | 0.109 | -0.063 | 0.042 | -0.146 | 0.020 | 0.520 | 1.298 | Y |
| *August* | 0.503 | 0.615 | 0.006 | 0.039 | -0.072 | 0.083 | 0.260 | 1.564 | N |
| *O. sylvanus* (males) | ***Aug-1*** | 1.291 | 0.197 | 0.045 | 0.030 | -0.014 | 0.104 | 0.550 | 1.255 | N |
| ***Sep-1*** | 1.676 | 0.094 | 0.060 | 0.031 | 0.000 | 0.120 | 0.720 | 1.285 | Y |
| ***March*** | 1.955 | 0.051 | 0.047 | 0.022 | 0.003 | 0.091 | 0.770 | 1.181 | Y |
| *April* | -0.024 | 0.445 | -0.024 | 0.031 | -0.085 | 0.038 | 0.330 | 1.171 | N |
| ***May*** | 3.399 | <0.001 | 0.116 | 0.032 | 0.054 | 0.179 | 1.000 | 1.260 | Y |
| *June* | 1.043 | 0.297 | 0.031 | 0.033 | -0.034 | 0.096 | 0.370 | 1.231 | N |
| ***July*** | -1.471 | 0.142 | -0.037 | 0.026 | -0.088 | 0.015 | 0.500 | 1.224 | Y |
| *O. sylvanus* (females) | ***Aug-1*** | 0.710 | 0.478 | 0.031 | 0.036 | -0.040 | 0.101 | 0.340 | 1.479 | N |
| *Sep-1* | 0.023 | 0.981 | 0.007 | 0.042 | -0.074 | 0.089 | 0.260 | 1.313 | N |
| *March* | -0.090 | 0.928 | 0.002 | 0.031 | -0.059 | 0.063 | 0.250 | 1.364 | N |
| ***April*** | 2.967 | 0.007 | 0.125 | 0.044 | 0.039 | 0.211 | 0.990 | 1.308 | Y |
| ***May*** | 2.841 | 0.005 | 0.124 | 0.041 | 0.043 | 0.206 | 1.000 | 1.314 | Y |
| *June* | -0.676 | 0.500 | -0.038 | 0.045 | -0.125 | 0.050 | 0.330 | 1.263 | N |
| *July* | -0.297 | 0.766 | -0.020 | 0.040 | -0.098 | 0.057 | 0.280 | 1.350 | N |
| *P. malvae* | ***May-1*** | 3.312 | <0.001 | 0.063 | 0.019 | 0.025 | 0.101 | 1.000 | 1.167 | Y |
| ***Jun-1*** | 2.173 | 0.030 | 0.047 | 0.022 | 0.003 | 0.090 | 0.770 | 1.151 | Y |
| ***Jul-1*** | 2.666 | 0.008 | 0.054 | 0.019 | 0.016 | 0.091 | 0.980 | 1.457 | Y |
| *Aug-1* | -0.459 | 0.646 | -0.009 | 0.022 | -0.051 | 0.033 | 0.270 | 1.309 | N |
| *March* | -0.748 | 0.454 | -0.011 | 0.016 | -0.043 | 0.020 | 0.320 | 1.053 | N |
| *April* | -0.135 | 0.893 | -0.003 | 0.018 | -0.039 | 0.032 | 0.260 | 1.030 | N |
| *T. lineola* (males) | ***April*** | 2.192 | 0.029 | 0.078 | 0.037 | 0.005 | 0.150 | 0.790 | 1.146 | Y |
| *May* | -0.202 | 0.840 | -0.013 | 0.043 | -0.097 | 0.070 | 0.280 | 1.238 | N |
| ***June*** | -1.789 | 0.075 | -0.101 | 0.042 | -0.184 | -0.017 | 0.870 | 1.462 | Y |
| ***July*** | -0.880 | 0.380 | -0.036 | 0.041 | -0.116 | 0.045 | 0.370 | 1.320 | N |
| *P. argus* (males) | ***March*** | -3.075 | 0.003 | -0.110 | 0.045 | -0.198 | -0.021 | 0.940 | 1.518 | Y |
| ***April*** | 1.846 | 0.066 | 0.094 | 0.051 | -0.006 | 0.194 | 0.660 | 1.476 | Y |
| ***May*** | 2.168 | 0.031 | 0.119 | 0.054 | 0.013 | 0.225 | 0.800 | 1.606 | Y |
| ***June*** | 1.615 | 0.107 | 0.175 | 0.092 | -0.006 | 0.357 | 0.700 | 1.312 | Y |
| *July* | 0.129 | 0.897 | 0.011 | 0.039 | -0.066 | 0.087 | 0.280 | 1.253 | N |
| *P. bellargus* (G1 males) | ***March*** | -2.181 | 0.033 | -0.291 | 0.096 | -0.482 | -0.100 | 0.590 | 2.320 | Y |
| ***April*** | 2.373 | 0.021 | 0.294 | 0.169 | -0.043 | 0.630 | 0.640 | 2.360 | Y |
| ***May*** | 3.114 | 0.003 | 0.157 | 0.070 | 0.016 | 0.297 | 0.970 | 1.040 | Y |
| *P. bellargus* (females) | *March* | -1.216 | 0.226 | -0.069 | 0.075 | -0.217 | 0.079 | 0.350 | 1.536 | N |
| *April* | 1.143 | 0.255 | 0.074 | 0.089 | -0.101 | 0.249 | 0.330 | 1.285 | N |
| ***May*** | 3.042 | 0.002 | 0.176 | 0.049 | 0.079 | 0.274 | 1.000 | 1.232 | Y |
| *P. coridon* (males) | ***March*** | 1.901 | 0.060 | 0.224 | 0.108 | 0.011 | 0.436 | 0.760 | 1.814 | Y |
| *April* | -1.395 | 0.165 | -0.101 | 0.096 | -0.292 | 0.089 | 0.390 | 1.600 | Y |
| ***May*** | -1.497 | 0.137 | -0.154 | 0.164 | -0.479 | 0.170 | 0.410 | 3.459 | Y |
| ***June*** | 2.227 | 0.028 | 0.211 | 0.113 | -0.012 | 0.434 | 0.680 | 1.573 | Y |
| ***July*** | -1.783 | 0.077 | -0.158 | 0.093 | -0.342 | 0.027 | 0.610 | 1.871 | Y |
| *P. coridon* (females) | *March* | 0.840 | 0.402 | 0.036 | 0.047 | -0.056 | 0.127 | 0.330 | 1.650 | N |
| *April* | -0.648 | 0.517 | -0.015 | 0.064 | -0.141 | 0.110 | 0.280 | 1.637 | N |
| ***May*** | -1.874 | 0.062 | -0.115 | 0.058 | -0.229 | -0.001 | 0.720 | 1.729 | Y |
| *June* | -0.117 | 0.907 | -0.009 | 0.060 | -0.127 | 0.108 | 0.280 | 1.330 | N |
| ***July*** | -3.807 | <0.001 | -0.144 | 0.042 | -0.226 | -0.063 | 1.000 | 1.533 | Y |
| *A. urticae* (G1) | *April* | 1.091 | 0.276 | 0.060 | 0.072 | -0.082 | 0.202 | 0.350 | 1.111 | N |
| ***May*** | 2.046 | 0.041 | 0.146 | 0.083 | -0.017 | 0.308 | 0.640 | 1.153 | Y |
| ***June*** | -2.397 | 0.017 | -0.180 | 0.084 | -0.345 | -0.015 | 0.790 | 1.068 | Y |
| *A. iris* (females) | *Aug-1* | 0.416 | 0.680 | 0.035 | 0.203 | -0.371 | 0.442 | 0.200 | 1.579 | N |
| *Sep-1* | 0.425 | 0.672 | 0.136 | 0.233 | -0.330 | 0.602 | 0.230 | 1.211 | N |
| *March* | -0.917 | 0.363 | -0.134 | 0.153 | -0.441 | 0.173 | 0.280 | 1.268 | N |
| *April* | -0.452 | 0.653 | -0.026 | 0.255 | -0.537 | 0.486 | 0.190 | 1.416 | N |
| ***May*** | 2.207 | 0.032 | 0.535 | 0.259 | 0.015 | 1.054 | 0.750 | 1.207 | Y |
| ***June*** | -1.715 | 0.093 | -0.401 | 0.251 | -0.903 | 0.102 | 0.530 | 1.160 | Y |
| ***July*** | 2.545 | 0.014 | 0.458 | 0.178 | 0.103 | 0.814 | 0.940 | 1.301 | Y |
| *A. paphia* (females) | *March* | -0.799 | 0.425 | -0.037 | 0.047 | -0.130 | 0.056 | 0.330 | 1.147 | N |
| ***April*** | -3.167 | <0.001 | -0.251 | 0.059 | -0.293 | -0.055 | 1.000 | 1.331 | Y |
| *May* | -0.255 | 0.799 | -0.004 | 0.060 | -0.123 | 0.114 | 0.270 | 1.262 | N |
| ***June*** | -1.170 | 0.243 | -0.104 | 0.074 | -0.248 | 0.041 | 0.500 | 1.183 | Y |
| *July* | -0.903 | 0.367 | -0.054 | 0.052 | -0.156 | 0.047 | 0.390 | 1.475 | N |
| *E. aurinia* | *Jul-1* | -0.989 | 0.323 | -0.034 | 0.031 | -0.095 | 0.028 | 0.400 | 1.452 | N |
| *Aug-1* | 0.245 | 0.807 | -0.011 | 0.036 | -0.081 | 0.060 | 0.300 | 1.715 | N |
| ***March*** | -1.618 | 0.106 | -0.051 | 0.030 | -0.110 | 0.008 | 0.600 | 1.234 | Y |
| *April* | 0.752 | 0.452 | 0.024 | 0.034 | -0.043 | 0.091 | 0.320 | 1.064 | N |
| ***May*** | 3.713 | <0.001 | 0.136 | 0.035 | 0.068 | 0.204 | 1.000 | 1.132 | Y |
| ***June*** | -3.724 | <0.001 | -0.138 | 0.036 | -0.209 | -0.067 | 1.000 | 1.082 | Y |
| *F. adippe* | ***March*** | -0.998 | 0.319 | -0.052 | 0.047 | -0.144 | 0.534 | 0.410 | 1.104 | N |
| ***April*** | -1.902 | 0.058 | -0.115 | 0.059 | -0.231 | 0.054 | 0.720 | 1.171 | Y |
| ***May*** | 3.730 | <0.001 | 0.213 | 0.059 | 0.098 | 1.206 | 1.000 | 1.061 | Y |
| *June* | 0.335 | 0.738 | 0.025 | 0.082 | -0.135 | 0.684 | 0.280 | 1.098 | N |
| ***July*** | 2.163 | 0.031 | 0.115 | 0.055 | 0.007 | 0.819 | 0.760 | 1.136 | Y |
| *H. semele* (males) | *Aug-1* | 0.216 | 0.829 | -0.010 | 0.062 | -0.132 | 0.112 | 0.260 | 1.201 | N |
| ***Sep-1*** | -1.779 | 0.076 | -0.100 | 0.058 | -0.213 | 0.013 | 0.630 | 1.162 | Y |
| ***March*** | -2.444 | 0.015 | -0.088 | 0.040 | -0.166 | -0.011 | 0.850 | 1.247 | Y |
| ***April*** | 2.187 | 0.029 | 0.098 | 0.051 | -0.002 | 0.197 | 0.710 | 1.187 | Y |
| *May* | -0.479 | 0.632 | -0.026 | 0.054 | -0.132 | 0.079 | 0.270 | 1.145 | N |
| ***June*** | 3.848 | <0.001 | 0.193 | 0.055 | 0.086 | 0.300 | 1.000 | 1.105 | Y |
| *July* | -1.165 | 0.245 | -0.056 | 0.055 | -0.163 | 0.051 | 0.370 | 1.153 | N |
| *M. athalia* | ***Jul-1*** | 2.528 | 0.012 | 0.127 | 0.044 | 0.041 | 0.213 | 0.990 | 2.373 | Y |
| ***Aug-1*** | -3.040 | 0.002 | -0.148 | 0.047 | -0.240 | -0.056 | 1.000 | 2.400 | Y |
| ***March*** | 3.027 | 0.003 | 0.092 | 0.032 | -0.030 | 0.154 | 1.000 | 1.291 | Y |
| *April* | -0.456 | 0.648 | -0.013 | 0.042 | -0.096 | 0.069 | 0.270 | 1.174 | N |
| ***May*** | 2.026 | 0.043 | 0.094 | 0.040 | 0.015 | 0.172 | 0.850 | 1.313 | Y |
| ***June*** | 1.003 | 0.316 | 0.062 | 0.055 | -0.046 | 0.169 | 0.420 | 1.395 | N |
| *S. aglaja* | ***March*** | -1.689 | 0.094 | -0.056 | 0.036 | -0.127 | 0.015 | 0.550 | 1.102 | Y |
| *April* | 0.594 | 0.552 | 0.025 | 0.046 | -0.066 | 0.115 | 0.300 | 1.025 | N |
| ***May*** | 4.901 | <0.001 | 0.230 | 0.045 | 0.142 | 0.319 | 1.000 | 1.111 | Y |
| ***June*** | 1.825 | 0.068 | 0.089 | 0.052 | -0.013 | 0.190 | 0.620 | 1.044 | Y |
| *P. napi* (G1 males) | ***Aug-1*** | -2.877 | 0.004 | -0.194 | 0.061 | -0.315 | -0.073 | 1.000 | 1.116 | Y |
| *Sep-1* | -1.260 | 0.208 | -0.089 | 0.074 | -0.234 | 0.055 | 0.430 | 1.086 | N |
| *March* | -0.611 | 0.542 | -0.023 | 0.042 | -0.106 | 0.060 | 0.290 | 1.062 | N |
| *April* | 0.496 | 0.620 | 0.022 | 0.061 | -0.098 | 0.142 | 0.280 | 1.056 | N |

SI TABLE 5 Percentage changes in size per °C change in temperature for each developmental stage for each species (or sex/generation) for significant models of average forewing length versus monthly temperatures. NS (not significant) - monthly temperatures during that stage were not significant variables in the model. NA (not applicable) - the stage was excluded from analysis. Where there was more than one significant monthly temperature within a developmental stage, the most significant variable was used to calculate the percentage change.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *Family* | *Species* | *Sex* | *Change in size with temperature in Late larval stage (%)* | *Change in size with temperature in Early larval stage (%)* | *Change in size with temperature in Pupal stage (%)* |
| Hesperiidae | *H. comma* | Male | 1.31 | NS | -0.48 |
| *O. sylvanus* | Male | 0.87 | NS | NS |
| Female | 0.87 | NS | NS |
| *T. lineola* | Male | NS | 0.67 | NS |
| *E. tages* | Both | 0.61 | NS | 0.80 |
| *P. malvae* | Both | 0.53 | 0.61 | NS |
| Nymphalidae | *F. adippe* | Both | 0.81 | NS | 0.45 |
| *A. iris* | Female | 1.53 | NS | 1.31 |
| *A. paphia* | Female | NS | -0.82 | NS |
| *M. athalia* | Both | 0.48 | -0.80 | 0.50 |
| *S. aglaja* | Both | 0.83 | NS | NS |
| *H. semele* | Male | 0.40 | -0.39 | 0.85 |
| *E. aurinia* | Both | 0.72 | NS | -0.72 |
| *A. urticae (G1)* | Both | 0.67 | NS | -0.83 |
| Lycaenidae | *P. argus* | Male | 0.95 | -0.88 | NS |
| *P. coridon* | Male | 1.40 | NS | NS |
| Female | NS | NS | -0.99 |
| *P. bellargus (G1)* | Male | 1.41 | -1.25 | NA |
| Female | 1.23 | NS | NA |
| Pieridae | *P. napi (G1)* | Male | NS | -0.92 | NS |

**SI Table 6.** Coefficients (with standard errors) of the linear mixed effects model for examining the significant effects of monthly temperatures on butterfly forewing length in the early larval, late larval and pupal stages. A negative symbol shows a negative relationship between size and the variable. Significant levels are indicated as \*, \*\*, \*\*\* for *p*<0.05, 0.01 and 0.001, respectively for fixed effects (monthly temperatures and sex). For random effects, coefficients represent the variance explained by that factor.

i) Model for all data: Average forewing length (Ln) ~ Late T + Early T + Pupal T + (1|Family)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variables | Monthly temperatures per stage | | | Intercept | Random effects |
| Early larval | Late larval | Pupal | Family |
| Coefficients | -0.0169\*\*\*  0.000258 | 0.0118\*\*\*  0.000391 | 0.0147\*\*\*  0.000345 | 2.681\*\*\*  0.166 | 0.111  0.333 |

ii) Model species which can be sexed: Average forewing length (Ln) ~ Late T + Early T + Pupal T + Sex + (1|Family)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Variables | Monthly temperatures per stage and sex | | | | Intercept | Random effects |
| Early larval | Late larval | Pupal | Sex | Family |
| Coefficients | 0.00185\*\*\* ±0.000335 | 0.0104\*\*\* ± 0.000517 | 0.0114 \*\*\*± 0.000436 | -0.0430\*\*\* ±0.00234 | 2.578 \*\*\*± 0.218 | 0.131 ± 0.362 |

**SI Figure 1**

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**SI Figure 1.** Temporal distribution of the specimens used for the temperature-size response analyses (1830-2000, mode =1919).

**SI Figure 2**

**Chart, box and whisker chart

Description automatically generatedSI Figure 2.** Boxplots of percentage change in adult size per °C change during the early larval, late larval and pupal stages for all species grouped by general habitat type. The habitat type “Any” is for species which occur in both habitat types, and “Other” is for species which do not occur in either woodland or grassland. Species associated with grassland generally decreased in adult size with increasing temperature in the pupal stage and showed varied responses to temperature in the early larval stage. In contrast, woodland species generally increased in adult size with increasing temperature in the pupal stage but decreased in adult size with increasing temperature in the early larval stage.