|  |  |  |  |
| --- | --- | --- | --- |
|  | Variables | Data scale | Values |
| Biological traits | Vagrancy | Ordinal | (1) rare record ex habitat, (2) occasional colonization events over <10 km, (3) urban areas and gardens, (4) occasional colonization events over >10 km, (5) rapid range expansions over >100 km in 10 years, (6) short-distance overseas dispersal - at sea records - island populations, (7) incidental long-distance (mass) movements, (8) regular reversed long distance migrations |
| Voltinism | Ordinal | (1) 0.5, (2) 1, (3) 1–2, 4) 2, (5) 2–3, (6) 3–4 (generations per year) |
| Overwintering | Ordinal | (1) egg), (2) first instar larva, (3) half-grown, (4) last instar, (5) pupa, (6) adult, (7) no hibernation |
| Wing size | Continuous | mm (average male / female) |
| Egg volume | Continuous | mm³ |
| Specialization | Ordinal | (1) polyphagous (multiple species, >1 plant family), (2) polyphagous (multiple species, 1 plant family), (3) oligophagous, (4) monophagous |
| Climatic traits | Temperature index | Continuous | °C (monthly average across species range) |
| Precipitation sum | Continuous | mm (annual sum across species range) |
| Temperature range | Continuous | °C (maximum – minimum monthly average across species range) |
| Temperature range | Continuous | mm (maximum – minimum monthly average across species range) |
| Soil water content | Continuous | Units 0 to 1, water availability in the upper horizon (0.5 m) |
| Vulnerability | Red List status | Binary | (0-1); 0) least concern, 1) near threatened, vulnerable endangered or critically endangered |
| Range size | Continuous | Occupancy in number of 50 km² grid cells |
| Endemicity | Binary | (1) European endemics, (0) species also occurring outside Europe |
| Habitat use | Binary | (0) natural, (1) anthropogenic |
| Habitat specificity | Continuous | SSI index\* |

**Table 1**. Species traits and indicators for species vulnerability used in this study. \*See text.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Biological traits | |  | Climate traits | |
| Rotated PCs | PC-B1 | PC-B2 | PC-B3 | PC-C1 | PC-C2 |
| Variance | 1.99 | 1.68 | 1.01 | 2.20 | 2.19 |
| % Explained | 33.2 | 28.0 | 16.8 | 44.1 | 43.7 |
| Vagrancy | **+0.83** | -0.26 | -0.10 |  |  |
| Voltinism | **+0.84** | +0.19 | +0.02 |  |  |
| Overwintering stage | **+0.71** | +0.04 | -0.05 |  |  |
| Wingspan | +0.18 | **-0.91** | +0.01 |  |  |
| Egg Volume | -0.21 | **-0.86** | -0.07 |  |  |
| Foodplant specialisation | -0.08 | 0.04 | **+0.99** |  |  |
| Range Annual Temperature |  |  |  | **+0.92** | -0.05 |
| Range Annual Precipitation |  |  |  | **-0.85** | +0.05 |
| Species Temperature Index |  |  |  | **-0.74** | **-0.65** |
| Soil Water Content |  |  |  | +0.16 | **+0.96** |
| Annual Precipitation |  |  |  | -0.25 | **+0.91** |
| PC-C1 | -0.15 | +0.01 | -0.15 |  |  |
| PC-C2 | -0.33 | -0.09 | -0.13 |  |  |

**Table 2.** Principal components of trait associations for 384 European butterfly species with correlation coefficients of trait variables with the rotated principal component axes. The strongest correlations for each variable have been marked in bold. Correlation coefficients between biological and climatic trait components are listed below. (PC: Principal Component of combined traits, B for biological and C for Climatic traits).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Biological traits |  |  | Climate traits |  |
| Family | N species | PC-B1 | PC-B2 | PC-B3 | PC-C1 | PC-C2 |
| Hesperiidae | 43 | -0.23b | +0.53b | -0.09ab | -0.12a | -0.10ab |
| Lycaenidae | 104 | +0.02b | +1.10a | +0.27a | -0.03a | -0.25b |
| Nymphalidae | 193 | -0.20b | -0.63d | -0.12b | +0.03a | +0.22a |
| Pieridae | 43 | 0.96a | +0.04c | -0.09ab | +0.16a | -0.24ab |
| Other | 14 | +0.34ab | -1.22e | +0.19ab | -0.39a | -0.11ab |
|  |  | F4,392=14.4\*\*\*\* | F4,70.6=142.3\*\*\*\* | F4,70.6 = 2.9\* | F4,392 = 1.0ns | F4,70.9=4.7\*\* |

**Table 3.** Mean values of biological and climatictrait components for different butterfly families. Species of families Papilionidae (N=13) and Riodinidae (N=1), were grouped in ”Other”. Different Letters a-e indicate significant differences between families (Tukey HSD); F-values from ANOVA with lower d.f. values after accounting for inhomogeneity of variances (significance: \* P<0.05, \*\* P<0.01, \*\*\*\* P<0.0001). (PC: Principal Component of combined traits, B for biological and C for Climatic traits).

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Biological traits | |  | Climate traits | |  |  |  |
| Variable | Regression type | PC-B1 | PC-B2 | PC-B3 | PC-C1 | PC-C12 | PC-C2 | PC-C22 | R2 |
| Red List status | Logistic | 4.8- | 2.8ns | 0.1ns | 12.3+++ |  | 5.0- | 11.0+++ | 0.105 |
| Edemicity | Logistic | 19.4---- | 1.5ns | 14.1+++ | 35.8---- |  | 15.3++++ |  | 0.272 |
| Range Size | Least Squares | 68.6++++ | 0.3ns | 27.4---- | 128.4++++ | 172.8---- | 127.2++++ | 175.9---- | 0.638 |
| Habitat specificity | Least Squares | 96.1---- | 0.9ns | 6.0+ | 62.8---- | 51.4++++ | 23.9---- | 69.0++++ | 0.487 |
| Affinity for Natural Habitats | Logistic | 63.0---- | 0.0ns | 6.7++ | 4.0- |  | 0.0ns |  | 0.364 |
|

**Table 4.** Results of the multiple regression between species-specific vulnerability indicators and Principal Component of combined traits, B for biological and C for Climatic traits (significance: \* P<0.05, \*\* P<0.01, \*\*\*\* P<0.0001).

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**Figure 1.** Relative contribution (out of 100%) of biological traits (black bars) and climate traits (grey bars) in explaining variation in vulnerability indicators for European butterfly species.

**Supplementary material in separate Excel file attached.**

**Suppl. Mat. Table 1**: Species list of European butterflies used in this study, with *Red List categories* (LC least concern, NT near threatened, VU vulnerable, EN endangered, CR critically endangered, NA not assessed), *Endemicity* and *Range size* from van Swaay et al. (2010), Species specialization index (SSI) based on Julliard et al. (2006), *Affinity for natural habitat* as recorded occurrence in CORINE biotopes (Moss & Wyatt 1994), and correlation scores with PCA axes (B for biological variables and C for climatic variables).

**Suppl. Mat. Table 2:** Classification of Corine habitat types as natural, anthropogenic or indistinct (i.e. if habitat types may be natural, but often are significantly modified by anthropogenic influence). Species classification after relative proportion of habitat mentions in Van Swaay et al. (2006). Classification criteria were: (i) exceedance of the median value of the percentage of habitat mentions in either natural or anthropogenic habitats, (ii) the difference in percentage of habitat mentions in natural habitats minus the percentage in anthropogenic habitats being 50% or greater, (iii) the percentage of habitat mentions in indistinct habitats: if this was >50%, then species were only assigned as ‘anthropogenic’ if the percentage in anthropogenic habitats exceeded 10%, (iv) for 8 species exclusively listed in indistinct habitats, we assigned an intermediate value of 0.5.

**Suppl. Mat. Table 3:** Correlations between the species scores of five main trait component from this study and values from the four main trait components for 145 nortwest-European butterfly species from WallisDeVries (2014) (significance: \* P<0.05, \*\* P<0.01, \*\*\*\* P<0.0001).

**Suppl. Mat. Table 4:** A tentative list of 56 candidate Red List species (present status LC or NA) with below-median values for PC-B1 and for range size (in number of occupied 50x50 km grid cells); a further 18 species that satisfy the criteria already are included on the Red List (status NT, EN or CR). Red List categories: LC least concern, NT near threatened, VU vulnerable, EN endangered, CR critically endangered, NA not assessed).