B

METHODOLOGY

B.1 The MEB project data as basis for the atlas

The distribution data used in this atlas originated exclusively from the 'Mapping European Butterflies' project (MEB; www.european-butterflies.eu). Within MEB butterfly occurrences were assigned to more than 9000 reference localities, which were distributed evenly across Europe and identified by their geographical coordinates. These data formed the basis of 'The Distribution Atlas of European Butterflies' (Kudrna 2002), which was the first systematic compilation of butterfly distribution data on a European scale. At present the atlas is being updated within the MEB2 project, which is run by the German Society for Lepidoptera Conservation (GfS: "Gesellschaft für Schmetterlingsschutz").

Although national distribution data are available at a finer resolution in many countries, we used the MEB database in order to have the same standard in terms of quality control and coverage throughout this atlas. The availability of such a database is a tribute to Otakar Kudrna, the approx. 250 recorders contributing directly, and many thousands of recorders who contributed to numerous data bases which have been used as well.

To construct climate envelopes which mirror the conditions at the end of the second millennium, only the most recent distribution data have been used for the period from 1981 until the publication of Kudrna (2002). Data from previous periods (which also had larger gaps) as well as newer data have not been included.

To account for local differences in sampling effort and to obtain reliable absence data, the distributional data where aggregated to the Universal Transverse Mercator (UTM) coordinate system at a 50 x 50 km^2 resolution (Fig. B.1.1). Due to low levels of recording and very uneven coverage, Belarus, Ukraine, Moldova, and Russia were excluded from data used for the model development. However, these countries are shown on maps of present species distribution as well as the scenarios the potential niche spaces. Excluded were also data from the Atlantic islands under European administration (the Azores, Madeira and Canary Islands) and from Cyprus. Iceland has no resident butterfly species.

B.2 Scenarios used to assess climate change risks for European Butterflies

Within the framework described above, we have restricted the analyses used in this atlas to the climate aspect of three global change scenarios. These are based on storylines developed within the EU funded project ALARM (Settele et al. 2005, Spangenberg 2007) which integrated the Intergovernmental Panel on Climate Change (IPCC 2001) Special Report on Emission Scenarios (SRES).

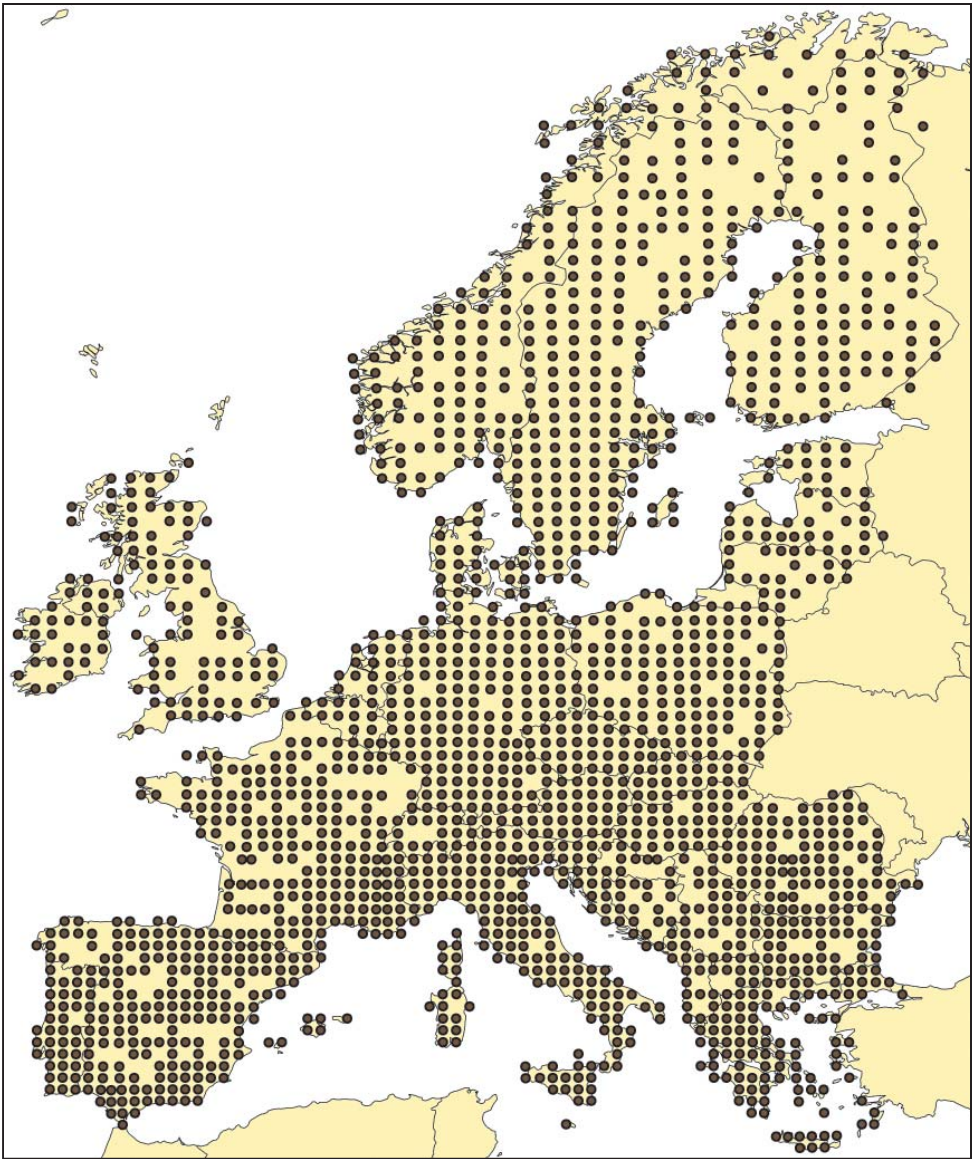


Fig. B.1.1. Geographical coverage and distribution of reference localities aggregated to 50 x 50 km² UTM grid (derived from the database which also was used for Kudrna, 2002).

The main source for future climate scenarios was a coupled Atmosphere-Ocean General Circulation Model (HadCM3; New et al. 2000). The complete ALARM scenarios as explained in chapter A.2 cover a broad range of potential developments in demography, socio-economics and technology during the 21st century. Specifically for climate the following frame conditions apply in addition to the more general aspect mentioned above:

- SEDG (Sustainable Europe Development Goal) – a storyline for moderate change:

The scenario of moderate change approximates the IPCC B1 climate change scenario. Mean expected temperature increase in Europe until 2080 is 2.4°C.

- BAMBU (Business As Might Be Usual) – a storyline for intermediate change:

The scenario of intermediate change approximates the IPCC A2 climate change scenario. Mean expected increase in temperature is 3.1°C.

- GRAS (GRowth Applied Strategy) – a storyline for maximum change:

The scenario of maximum change approximates the IPCC A1FI climate change scenario. Mean expected increase in temperature is 4.1°C.

Based on the storylines, projections of future changes in climate were developed on a 10 x 10 min grid of Europe. Monthly projected climate data (see chapter B.3) were averaged for the two periods 2021-2050 and 2051-2080.

B.3 Climate niche modeling

Climatic factors of butterfly distribution

The climatic requirements of butterflies were modelled using monthly interpolated climate data at the same 50 x 50 km² UTM grid (New et al. 2000, Mitchell et al. 2004) that was used to present the distribution of the species (see chapter B.1). Mean values of the following 22 climate variables (absolute values and annual variations) for the period 1971-2000 were considered for the analysis of climate requirements of the butterflies:

- annual temperature (°C);
- range in annual temperature (°C);
- quarterly temperature (e.g. March - May = spring; °C);
- range in quarterly temperature (°C);
- diurnal temperature range per year (°C);
- diurnal temperature range per quarter (°C);
- annual summed precipitation (mm);
- range in annual precipitation (mm);
- quarterly summed precipitation (mm);
- range in quarterly precipitation (mm);
- annual water deficiency (annual equilibrium evapotranspiration minus annual precipitation; Sykes et al. 1996);
- range in annual water deficiency;
- soil water content for both upper and lower horizon retrieved from a dynamic vegetation model (LPJ-GUESS; Smith et al. 2001, Rickebusch et al. 2008);

- annual cloudiness (%);
- quarterly cloudiness (%);
- accumulated growing degree days with a base temperature of five degrees until February, April, June, and August.

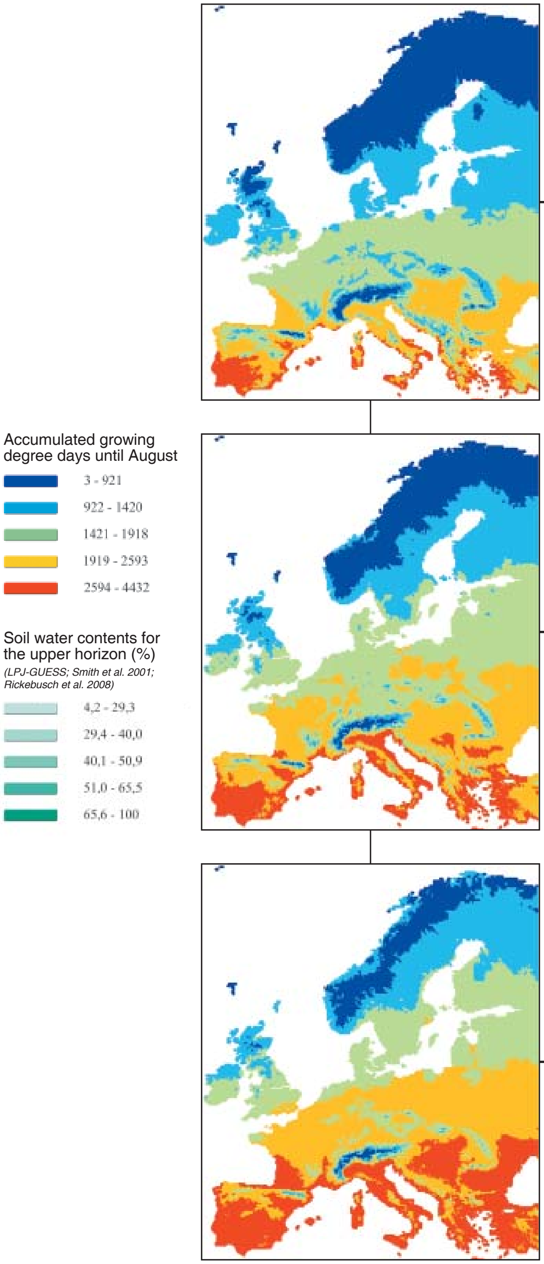
Many of these variables are partly redundant in their effects. Thus, to avoid statistical problems due to high levels of collinearity between climate variables we selected ecological relevant and least correlated variables by means of cluster analysis. The threshold for variable selection was a Pearson correlation coefficient lower than 0.3 (Graham 2003).

The remaining variables which have been used for the climate niche models of all species within this atlas were

- accumulated growing degree days until August, which is highly representative for general temperature gradients across Europe (Fig B.3.1);
- soil water content for the upper horizon, which is a realistic measure of water availability and near surface microclimate (Fig B.3.2);
- ranges in annual precipitation (Fig B.3.3) and
- ranges in annual temperature (Fig B.3.4); with the two last ones reflecting continentality and oceanity.

Modelling procedure

To assess species response to climate change, we first need to identify the ecological niche that each species occupies with respect to key climatic variables. Climatic niche models relating such variables to presence and absence data were developed using generalized linear models (GLM) with a binomial error distribution and a logit link function. We allowed for additive and curvilinear effects by incorporating second order polynomials. Models were checked for spatial autocorrelation with Moran's I correlograms of model residuals, but none was detected. Initial models were simplified by stepwise regression, while minimizing Akaike´s information criterion (AIC; Sakamoto et al. 1986). Models were calibrated on an 80% random sample of the initial data set and model accuracy was evaluated on the remaining 20%. Agreements between observed presences and absences and projected distributions were evaluated by the Area Under the Curve (AUC) of a Receiver Operating Characteristic (ROC) plot which is independent of thresholds (Fielding & Bell 1997). Thresholds for calculating presence-absence projections were obtained by a maximizing Kappa approach (Manel et al. 2001). While the climatic niche models were developed at the 50 × 50 km^2 UTM grid, the future projections were downscaled to 10 × 10 min grid cells. Both were mapped within the geographical range of -10.417° to 31.917° (longitude) and 34.083° to 71.083° (latitude). All maps based on the WGS1984 coordinate system were projected in the Miller cylindrical projection using ArcGIS software (ESRI 2006).



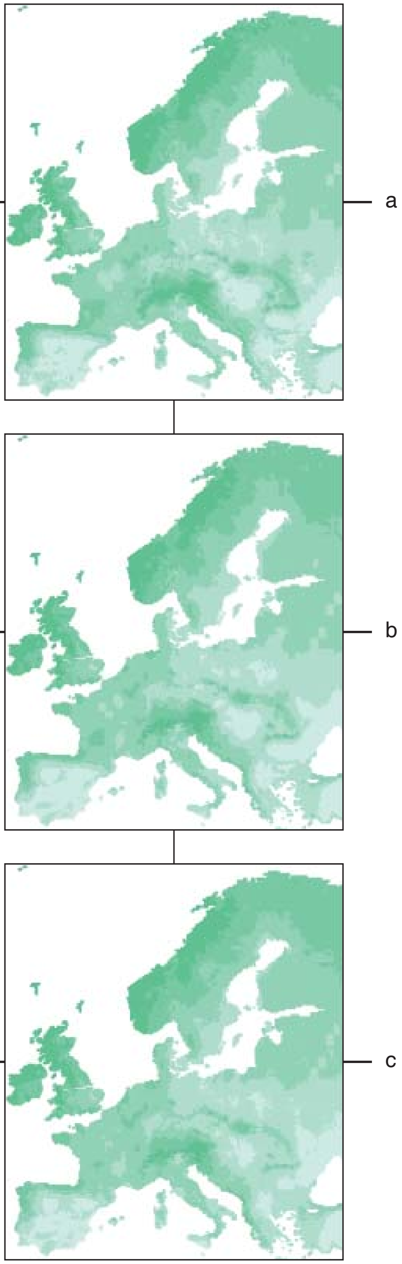


Fig. B.3.1 Accumulated growing degree days until August. (a) Current conditions (1971-2000); (b) future conditions for 2050 under the intermediate scenario (BAMBU); (c) future conditions for 2080 under the intermediate scenario (BAMBU).

Fig. B.3.2 Soil water content. (a) Current conditions (1971-2000); (b) future conditions for 2050 under the intermediate scenario (BAMBU); (c) future conditions for 2080 under the intermediate scenario (BAMBU).

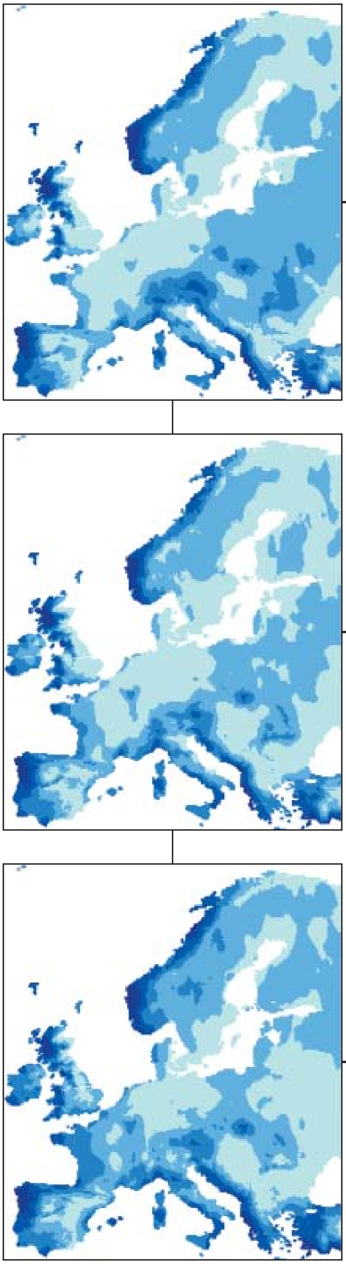


Fig. B.3.3 Range in annual precipitation. (a) Current conditions (1971-2000); (b) future conditions for 2050 under the intermediate scenario (BAMBU); (c) future conditions for 2080 under the intermediate scenario (BAMBU).

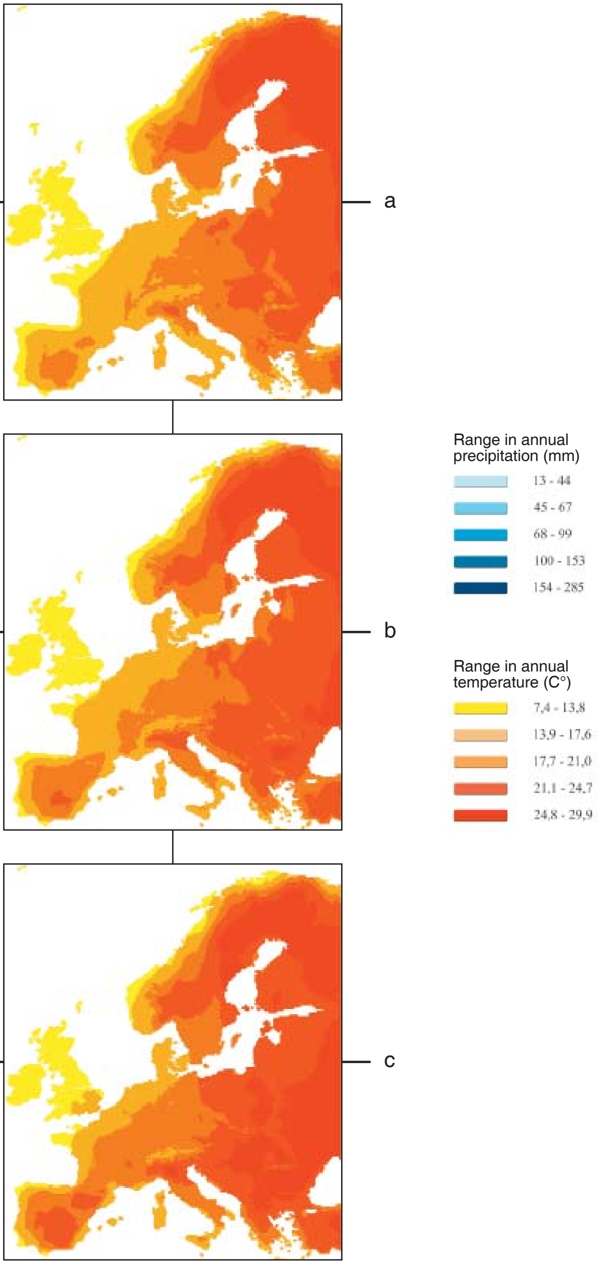


Fig. B.3.4 Range in annual temperature. (a) Current conditions (1971-2000); (b) future conditions for 2050 under the intermediate scenario (BAMBU); (c) future conditions for 2080 under the intermediate scenario (BAMBU).

Assumptions for species dispersal

The next key factor we need to incorporate is the ability of a species to colonise new potentially suitable areas in the course of climate change. For butterflies, this depends closely on a species' dispersal ability. However, detailed dispersal distances are not available for most species and we thus examined two extreme assumptions:

1. Unlimited dispersal, such that the entire projected niche space denotes the actual future distribution.
2. No dispersal, in which the future distribution results solely from the overlap between current and future niche space.

Visualisation of the multi-dimensional climatic niche

To visualise the multi-dimensional climatic niche independent from the species' geographic distribution, we provide a 4 x 4 panel of graphs. In each graph the occurrence probability surface is presented, according to the climatic niche model and the threshold beyond which occurrence is most likely, considering accumulated growing degree days until August (Gdd; x-axis) and soil water content (Swc; y-axis). Additionally, for most species the relationship between occurrence probability, Gdd and Swc varies with the other two considered variables annual temperature range and annual precipitation range. Since a continuous visualisation of this four-dimensional niche would be outside the scope of human perception, we provide 4 × 4 discrete combinations of the latter two variables. Therefore, we depict the relationship between occurrence probability, Gdd and Swc for combinations of minimum, lower tercile, upper tercile and maximum values of annual temperature range and annual precipitation range.

B.4 Climate change risk assessment for butterflies

Definitions of climate change risk categories for European butterflies

Each butterfly species assessed was placed in a risk category (see below) according to the loss of grid cells in each scenario. Categories were only assigned for species whose distributions were modelled reasonably accurately by the model (AUC > 0.75, see chapter B.3). Species whose distributions were not modelled reasonable accurately were assigned the category "PR – Potential climate change risk".

The categories of model quality are as follows:

AUC: > 0.95:	Present distribution can be very well explained by climatic variables
AUC: > 0.85 – 0.95:	Present distribution can be well explained by climatic variables
AUC: > 0.75 – 0.85:	Present distribution can be explained by climatic variables to a moderate extent
AUC: ≤ 0.75:	Present distribution can be explained by climatic variables to only a limited extent

The climate risk categories which have been derived from the analysis and which are used throughout the atlas are as follows:

Category		% loss of grid cells	AUC
HHHR	extremely high climate change risk	> 95	> 0.75
HHR	very high climate change risk	> 85 – 95	> 0.75
HR	high climate change risk	> 70 – 85	> 0.75
R	climate change risk	> 50 – 70	> 0.75
LR	lower climate change risk	≤ 50	> 0.75
PR	potential climate change risk	0 - 100	≤ 0.75

Integrated overall risk categories for European species – integrating all scenarios and time steps

In the short description of the ecology of each species in chapter C.2, each species was given an overall risk category. These are defined as follows:

HHHR (extremely high climate change risk): Climate change poses a very high risk to the species because more than 95% of the grids with currently suitable climate may no longer be suitable in 2080 under at least one scenario (under the "no dispersal" assumption). Present distribution can be explained by climatic variables at least to a moderate extent (AUC > 0.75).

HHR (very high climate change risk): Climate change poses a very high risk to the species because more than 85% of the grids with currently suitable climate may no longer be suitable in 2080 under at least one scenario (under the "no dispersal" assumption). Present distribution can be explained by climatic variables at least to a moderate extent (AUC > 0.75).

HR (high climate change risk): Climate change poses a high risk to the species because more than 70% of the grids with currently suitable climate may no longer be suitable in 2080 under at least one scenario (under the "no dispersal" assumption). Present distribution can be explained by climatic variables at least to a moderate extent (AUC > 0.75).

R (climate change risk): Climate change poses a risk to the species because more than 50% of the grids with currently suitable climate may no longer be suitable in 2080 under at least one scenario (under the "no dispersal" assumption). Present distribution can be explained by climatic variables at least to a moderate extent (AUC > 0.75).

LR (lower climate change risk): Climate change poses a lower risk to the species because 50% or less of the grids with currently suitable climate may no longer be suitable in 2080 under at least one scenario (under the "no dispersal" assumption). Present distribution can be explained by climatic variables at least to a moderate extent (AUC > 0.75).

PR (potential climate change risk): At the moment, climate change can only be regarded as a potential risk for the species' long-term survival in Europe. All species whose present distribution can be explained by climatic variables to only a limited extent (AUC: ≤ 0.75) have been categorised as PR, independent of the rate of decline of their climatic niche distribution.