E

OUTLOOK: CLIMATE CHANGE AND BUTTERFLY CONSERVATION

E.1 Direct and indirect climate change impacts on butterflies and biodiversity

Climate change affects biodiversity and ecosystem processes both directly and indirectly. An example of a direct effect is when critical climate limits are altered, which directly affect species physiological mechanisms (e.g. winter temperatures or annual or seasonal precipitation patterns). Indirect effects can be through complex interactions with other processes, such as invasion of exotics, loss of pollinators and interactions with environmental chemicals. Further responses to climate are due to interactions with land use and land use change.

Habitats and trophic interactions

Biodiversity responds to the distribution of habitats as well as to climate factors (and other pressures), so understanding habitat change is also critical. Climate change may alter: (i) the distribution of climatically-suitable areas for a given species, and thus change the geographic match between otherwise suitable habitats and climate (potentially endangering the species), (ii) the distribution of suitable habitats, for example if vegetation structure is affected by climate, (iii) the distribution of land-use, and (iv) what is currently recognised as suitable habitat for a given species may change if habitat choice is at least partly determined by thermal environment. In addition, (v) land-use may change for reasons unconnected to climate.

Although we do not expect particular habitats to move with climate change as intact collections of species, climate-driven changes to the boundaries of structural elements of the vegetation (e.g., of evergreen and deciduous forest; tree lines) may be as predictable as the boundaries of individual species. Such changes would have major implications for the community structure of all taxonomic groups. A map of the changes of the potential natural vegetation (PNV) under the BAMBU scenario is shown if Figure E.1.1 for the presence and the conditions around 2080.

Many of the other habitat/trophic interactions mentioned above have been researched in recent years with the project ALARM (Settele et al. 2005, 2007, 2008). In the context of butterflies, analyses have been started to study effects of climate change in combination with other factors. An example is the study on *Boloria titania* (see page 638ff). Here the model was not able to predict the occurrence of this species in the Baltic States, but the model became far more accurate when the constraints of the larval host plant *Polygonum bistorta* were included (Schweiger et al. in press). This shows that including other essential abiotic and biotic environmental factors can help to improve model accuracy, but in most

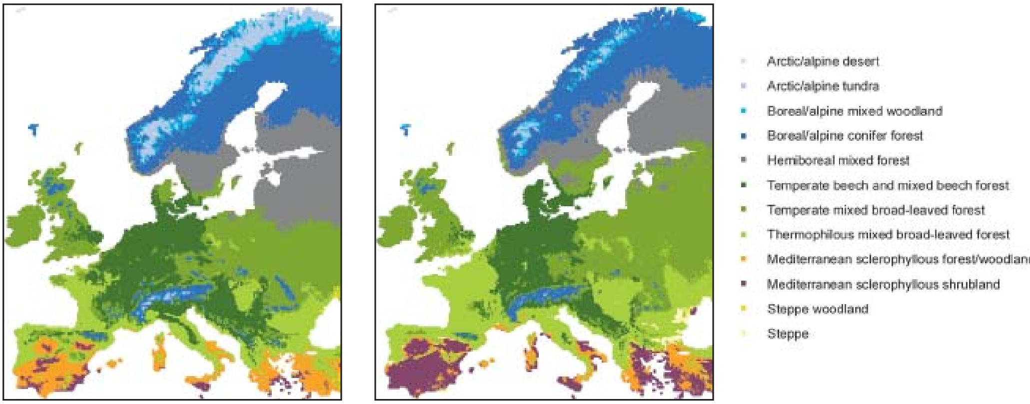

Fig. E.1.1: Modelled current (averaged for 1961-1990) and future (2071-2100) potential natural vegetation (PNV) in Europe under the BAMBU (IPCC A2; HadCM3) emission scenario; from Hickler et al. (in press, modified).

cases we lack crucial information about the multitude of species interactions that may add to the effects of climate.

Climate envelopes for European butterflies as a starting point for future research and conservation

"Pure" climate change models as presented in this atlas are only a first, but very important step. Until more sophisticated methods and models become available, we have to rely on what we have in order to draw conclusions for conservation actions. Moreover, until we determine exactly how climate change (in concert with other factors) will affect biodiversity, it is sensible to consider worst case scenarios under the cautionary principle. Consequently, we have selected the worst case result under all the given scenarios until 2080 for our classification of climate risk.

However, even under a very conservative classification of risk, the vast majority of European butterfly species has to be regarded to be at risk through climate change. An important next step will thus be to test model outputs against field data for butterflies, as these are a group of species that are expected to track climate changes quickly due to their sensitivity and short generation time. In particular, we can expect the habitat generalists and mobile species to be the first and quickest to respond.

The literature already contains many examples of apparent responses to climate change (e.g., Walther et al. 2002, Parmesan & Yohe 2003), but genuine tests against model predictions are largely lacking. If we have a closer look at our simulation results, which are based on the distribution of species from roughly 1980 to 2000, we can see that some predictions seem to have become true already. Good examples are

- *Cacyreus marshalli*, which has already spread across Italy;
- *Plebejus argiades*, which has moved northward e.g. in Southern Germany;

- *Pieris mannii*, which in 2008 has suddenly expanded its Northern range limit in Switzerland and in August 2008 has reached Germany;
- *Brenthis daphne*, which has extended its range from Alsace to Southwest Germany since the mid 1990s.

In future studies considerable attention will have to be paid to the development of a global climate change envelope model and model testing, because statistically appropriate and ecologically plausible predictive models are a key prerequisite for the assessment of the biodiversity risks resulting from the projected climate change. Models will also have to be improved to assess impacts of climate and landscape change scenarios on biodiversity at the European scale, assessing the role of species characteristics in projected susceptibility. Physiological traits (e.g., temperature thresholds for development; evapotranspiration) will have to be considered as well as functional characteristics, such as the types of habitats occupied and dispersal capacity (Warren et al. 2001, Luoto & Heikkinnen 2008).

Climate change and evolution

Recent reviews and meta-analyses of aquatic and terrestrial studies from throughout the world have revealed consistent evidence of climate change effects on species. These include the advancement of the timing of life-cycles (phenology), northward expansions, southern retractions, movement up mountain slopes, and abundance changes such that species with southerly distributions have tended to increase in the northern hemisphere, whilst northerly distributed species have declined (e.g. Parmesan 1996, Parmesan et al. 1999, Walther et al. 2001, Parmesan & Yohe 2003, Wilson et al. 2005). Furthermore, recent evolutionary shifts in phenology, habitat choice and migration direction are also consistent with a response to climate warming (Berthold et al. 1992, Berthold & Pulido 1994, Berthold 1998, Bradshaw & Holzapfel 2001, Thomas et al. 2001).

At the receding edge of a species range, local populations are forced "outside the niche". This raises the question whether sufficient evolutionary speed is available to rescue such a species which clearly faces extinction (Pease et al. 1989, Holt 1990, 2008, Gomulkiewicz & Holt 1995)? Here we need deeper insight to understand both niche *conservatism* (species seem to have much the same niche limits over a broad geographical range or over long periods of evolutionary history; Bradshaw 1991, Holt & Gaines 1992, Wiens & Graham 2005) and rapid niche *evolution* (Reznick & Ghalambor 2001).

Butterflies can evolve quite rapidly in ways that could influence their distributional limits. There are examples of species shifting host preferences over periods of less than ten years (Singer et al. 1993), and if these host species have different geographical distributions, a large shift in the butterfly's range can easily be expected. Rapid evolution of dispersal abilities is likewise known from butterflies (Hill et al. 1999), with spreading species developing both a larger thorax and a greater ability to fly in newly colonised patches. Geographical ranges reflect both niches and dispersal abilities, which can each evolve and lead to range shifts. In other cases, butterfly niches can be maintained, even over very large ranges (Crozier & Dwyer 2006). In a study of a North-American skipper, one basic aspect of the species' niche – the thermal environments in which it can persist, versus where it declines toward extinction - appears to have been conserved over an enormous distance (Holt 2008).

Understanding the reasons and mechanisms of niche conservatism, and anticipating when to expect rapid niche evolution instead, is of crucial importance. However, our current level of understanding is extremely limited. Much of the literature on niche conservatism is essentially phenomenological in nature, reporting correlations between species distributions and various environmental attributes ("ecological niche models"). This provides an essential starting point but, according to Holt (2008), what we really need is a deeper mechanistic understanding of the factors that either constrain or facilitate niche evolution. He states that "this understanding requires one to take a highly integrative approach to science, as explanations for niche conservatism can reflect a wide spectrum of forces and constraints, from limitations on genetic variation (Blows & Hoffmann 2005), to tradeoffs emerging from how organisms are engineered from the gene to the whole phenotype (Hansen & Houle 2004), to the details of demography and spatial movement patterns (Holt & Gaines 1992, Holt 1996, Kawecki 1995), to the nexus of interspecific interactions (Ackerly 2003, Case et al. 2005)." (Holt 2008, p. 3).

We sincerely hope that this atlas also serves as a tool to encourage research into these topics, as butterflies seem to be an ideal group of organisms to study. We know a lot about the species, they can be raised in the laboratory (genetic and functional studies of traits), they have short generations, they are popular and diurnal, and they are ectotherms (hence sensitive to thermal conditions). They also typically have close interactions with other species (host plants, predators, parasitoids; e.g., van Nouhuys & Hanski 2004, Anton et al. 2007, Schweiger et al. in press), which makes the interspecific dimensions of their niches amenable to quantitative modelling (e.g., Mouquet et al. 2005, Johst et al. 2006). Thus Holt (2008) suggests that these traits collectively make butterflies potentially highly useful in developing a deeper understanding of the phenomenon of niche conservatism, which not only would be a satisfying intellectual endeavour in its own right, but also of vital importance for conservation (see chapter E.3, page 658f.).

Biodiversity Risk Assessment

Our study has also shown that biodiversity risk assessment to environmental changes is heavily based on species modelling for current and future conditions (e.g. Segurado & Araújo 2004, Thuiller et al. 2003) and conservation planning for biodiversity (e.g. Araújo & Williams 2000, Araújo & Williams 2001, Araújo 2002). The first vulnerability assessments of European biodiversity were undertaken in a global change context, but the challenge is now turning these broad-scale assessments of vulnerability into probabilistic assessments of risk at the regional (e.g. national) and local scales at which mitigation strategies must be developed.

E.2 Butterflies as indicators of environmental change

Butterfly indicator developments

Government representatives at the 2002 World Summit of Sustainable Development pledged 'a significant reduction in the current rate of biodiversity loss by 2010'. The commitment of the EU to protecting biodiversity is even stronger by aiming at halting biodiversity loss by 2010 (Balmford et al. 2005, Gregory et al. 2005). Butterflies may be useful as biodiversity indicators for reporting on the development towards the EU 2010 target. Unlike most other groups of insects, butterflies have considerable resonance with both the general public and decision-makers (Kühn et al. 2008a). Butterflies are also relatively easy to recognize and data on butterflies have been collected for a long time and by many voluntary observers. The method of monitoring butterflies is well described, extensively tested and scientifically sound (Pollard 1977, Pollard & Yates 1993).

As a result butterflies are the only invertebrate taxon for which it is currently possible to estimate rates of decline in many parts of the world (de Heer et al. 2005, Thomas 2005). However, butterflies can only be regarded as good biodiversity indicators if it is possible to generalise their trends to a broader set of species groups (Gregory et al. 2005). There is still some debate on how well butterflies meet this criterion. Hambler & Speight (1996, 2004) claimed that this group is likely to experience greater declines than other organisms due to their herbivorous life strategies and thermophily, but Thomas & Clarke (2004) convincingly rejected both arguments. Based on a comprehensive review of studies into their life-history traits, relative sensitivity to climate change, and adjusted extinction rates, Thomas (2005) concluded that butterflies may be considered representative indicators of trends observed in most other terrestrial insects, which together form a major part of biodiversity.

Trends per butterfly species can be combined into a unified measure of biodiversity. To achieve this, Van Swaay et al. (in press) followed Gregory et al. (2005) in averaging indices of species to give each species an equal weight in the resulting indicators. When positive and negative changes of indices are in balance, we would expect their mean to remain stable. If more species decline than increase, the mean should go down and vice versa. Thus, the mean of such an index is considered a measure of biodiversity change.

The results of national butterfly monitoring schemes may be combined to create an indicator at a supra-national level (see also Henry et al. in press). Based on the procedure described for European birds (see Gregory et al. 2005), a preliminary grassland butterfly indicator has been developed (Van Swaay & Van Strien 2005). The countries covered were mainly from Western Europe. The results showed that average grassland butterfly abundance has declined by almost 50% during the last 15 years, which is most probably linked with the agricultural intensification in Western Europe (Van Swaay & Warren 1999, Gregory et al. 2005). The decline is much stronger than the decline of the farmland bird indicator, which has fallen by 19% in the same period (Gregory et al. 2008). This corresponds with the findings in the UK where butterflies have experienced greater losses than birds (Thomas et al. 2004).

The European Environmental Agency has already recommended the development of **European butterfly indicators** (EEA 2007a), and these may lead to indicators that are comparable to the farmland bird indicator, which has been adopted as a biodiversity indicator by the EU (Gregory et al. 2005). The addition of a butterfly indicator would be valuable to complement the bird indicator to report against political targets (e.g. the EU's 2010 target), because butterflies operate at smaller spatial scales and more closely represent insects.

The grassland butterfly indicator offers the possibility to detect large scale effects of either abandonment of agricultural land (especially occurring in Eastern and Southern Europe) or intensification of agricultural practices, a process that has slowed in parts of Western Europe, but is ongoing in many other European regions.

Butterflies as climate change indicators

Recent climate change has already affected the distributions of many species (Hill et al. 2001, Walther et al. 2002, Parmesan & Yohe 2003, Wilson et al. 2005, Franco et al. 2006, Hickling et al. 2006) but future changes are likely to have even more severe impacts (Sala et al. 2000, Thomas et al. 2004, Thuiller et al. 2005, Araujo et al. 2006, Broenniman et al. 2006). These impacts are often assessed with bioclimatic envelope models which relate the current distribution of species to climatic variables to derive projected future distributions under climate change (e.g. Huntley et al. 2004, Heikkinen et al. 2006).

The restriction of studies just to climatic variables has been criticized by some authors (e.g. Davis et al. 1998, Pearson & Dawson 2003) and there have been calls for the consideration of other factors that determine species distributions such as dispersal, land cover, and biotic interactions (Guisan & Thuiller 2005, Ohlemuller et al. 2006, Ibanez et al. 2006, Heikkinen et al. 2006, Schweiger et al. in press). However, we decided to base the current atlas entirely on climatic variables in order to provide a complete overview of potential climate change impacts for a group of ectothermic insects which are expected to react relatively quickly on climatic changes.

In addition to the grassland butterfly indicator, there is a good possibility of producing a **climate change indicator** for European butterflies that would summarise trends in species whose distributions may be most affected by climate change. Similar indicators are also in progress for European birds (Gregory et al. 2007).

The development of the indicator can, among others, be based on the results of the present atlas, which highlights species for which we might expect changes within longer time periods. As the relationship between abundance and distribution of species is well supported scientifically, we can test whether species that are expected to gain niche space actually increase in abundance within their core areas of distribution, and where there are decreases in abundance towards the trailing (mostly southerly or low altitude) edge of distribution.

E.3 Climate change and butterfly conservation

The results of this atlas show that climate change is likely to have a profound effect on European butterflies. Although some aspects may seem unstoppable, there are still some ways to mitigate some of the negative impacts.

1) Maintain large populations in diverse habitats

In order to allow species to adapt and give them more time to evolve, we should adjust land use and management practices to maintain large populations of butterflies and create or maintain diverse microclimatic conditions which could mitigate climate change effects on the larger scale. There are many examples of how microclimatic conditions are able to support populations of butterflies in areas that are by macroclimatic standards far out of their climatic niche. Good examples are species like *Lycaena helle*, *Conenonympha oedippus*, *Boloria eunomia* and *Boloria aquilonaris*. We need to ensure effective conservation of existing protected areas and important habitats and manage them to maintain large, diverse populations. The deliberate creation of habitat heterogeneity within such sites may also give species scope to shift within their habitats and move to cooler microclimatic conditions. To achieve this on the ground we need well resourced and targeted agri-environment schemes, and place biodiversity at the heart of forestry and land use policies.

2) Encourage mobility across the landscape

We need to ensure that we reduce, and if possible remove, any barriers to dispersal in the landscape. Many butterfly habitats are now highly fragmented and we should place far more effort on habitat restoration and improving the links between habitat patches to give butterflies a chance to move and respond to climate change. We need to place far more emphasis on the conservation of whole landscapes and to build ecosystem resilience and connectivity – in particular in connection with the Natura 2000 network and its coherence. Well resourced and targeted agri-environment schemes are essential in delivering on the ground, together with enlightened planning policies.

3) Reduce emissions of greenhouse gasses

There is a great opportunity to influence the general policy on reducing greenhouse gas emissions (as generally described in the SEDG scenario; see chapter A.2, page 13f.). As we have mentioned in the methods, the results of our scenarios are not actual predictions and we should use them for what they are most suited: to compare different overall futures. If we translate the overall pictures presented in chapter C.4 (page 629ff.) into action for conservation, the vast majority of species would have a more sustainable future under the SEDG scenario compared to the futures under GRAS.

4) Allow maximum time for species adaptation

The results show us that the climate change risks for butterflies increase much faster after a certain lag phase. This could give us hope that if we take immediate action there is a chance to avoid some of the worst effects on the majority of our butterfly species – and most probably on other aspects of biodiversity! Our hope is that we can direct environmental change to encourage as much adaptation by natural selection as possible, which might contribute to the evolutionary rescue of species. Given the pace of environmental change we are inflicting upon the rest of the diversity on the planet, the living world needs all the help it can get (Holt, 2008) – and we hope that we can contribute to this through this atlas, particularly as a risk communication tool.

5) Conduct further research on climate change and its impacts on biodiversity

Further research is needed so that we continue to improve our understanding of climate change and its impacts on biodiversity. The findings will be vital to improve our adaptation strategies in the future. This study is an important step in understanding the impact on butterflies, but highlights the limitations of current models. In particular, we need to develop models for the approx. 150 species that have such restricted distributions that they could not be reasonably modelled using the current method.