The impact of climate change on butterfly communities 1990-2009

Butterfly
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*The Comma (*Polygonia c-album*) is already expanding its range northwards. This mobile butterfly takes full advantage of the present climate change.*
Photo: Chris van Swaay

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Summary

- This report presents the second version of the European Butterfly Climate Change Indicator, covering the period 1990-2009.
- The indicator is based on national Butterfly Monitoring Schemes from thirteen countries from all over Europe, based on almost 4000 transects, most of them counted by trained volunteers.
- The indicator shows the long-term effect of climate change on butterfly communities.
- The indicator shows a significant and rapid increase in European butterfly communities becoming more and more composed of species associated with warmer temperatures (figure 1).
- Since 1990 the mean shift of communities is equivalent to a northward shift of 75 km.
- Butterfly communities can fluctuate considerably from year to year due to annual weather conditions, but the underlying long-term trend is more likely attributable to climate change and other factors.
- Over the same period the temporal trend of the temperature in Europe increased steeply, corresponding to a northward shift of 249 km. This indicates that butterflies are not keeping pace with climate change.
- There seems to be a gradient over Europe, with countries in Northern and Eastern Europe showing a stronger and more positive change than countries in Southwestern Europe (map 2).
- Conservation measures should focus on preserving large populations in large areas and encouraging mobility across the landscape. The Natura 2000 and Emerald networks are vital instruments to achieve that. In the wider countryside, agri-environment schemes could facilitate butterfly mobility and allow species to spread more easily.
- Continuing butterfly monitoring is vital to assess future changes and expanding Butterfly Monitoring Schemes to other countries will further improve the quality of future indicators.
- This indicator should be updated on a regular basis, so the reaction of our butterfly fauna to a changing environment can be monitored closely.

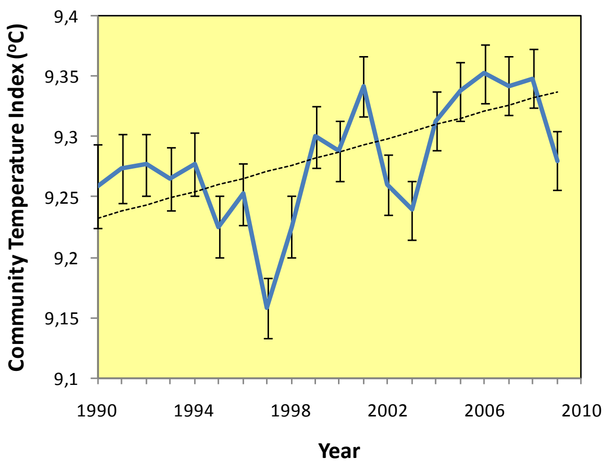


Figure 1: The European Butterfly Climate Change Indicator. *The indicator shows a significant increase of the Community Temperature Index (CTI) of 5.5×10^{-3} °C per year.*

Chapter 1 / Introduction

This is the second version of the European Butterfly Climate Change Indicator. It is based on changes in butterfly communities in thirteen countries. As more and more countries develop robust monitoring schemes, the value of butterflies as European biodiversity indicators grows.

Europe's butterflies are facing enormous changes in their environment. Changing economic pressures and land use policies have led to changes in farming practice, resulting in semi-natural grasslands being either abandoned or intensified (Van Swaay *et al*., 2010a; 2010b). The growing human population and increasing urbanisation have also led to an enhanced pressure on the remaining semi-natural habitats. On top of these factors, evidence is accumulating that climatic change in recent decades (IPCC, 2007) has had a major effect, leading to species declines and extinctions (Parmesan & Yohe, 2003). Settele *et al*. (2008) predict that the impact of the expected future changes on the populations and distribution of butterflies will be huge, and action is urgently needed.

Measuring the effect of climate change on butterflies is the first step in understanding how this affects our butterflies, with what speed it occurs and how much time there is left to take action. To quantify this, Van Swaay *et al.* (2008) investigated several methods to study the effect of a changing temperature on butterflies. Following the method of Devictor *et al.* (2008), the change of the Community Temperature Index (CTI) proved to be the most sensitive and easy to use indicator for the effect of climate change on butterflies.

The spectacular Swallowtail (*Papilio machaon*) is likely to profit from global warming and expected to extend its range further north, especially in Northwestern Europe. Photo: Chris van Swaay.

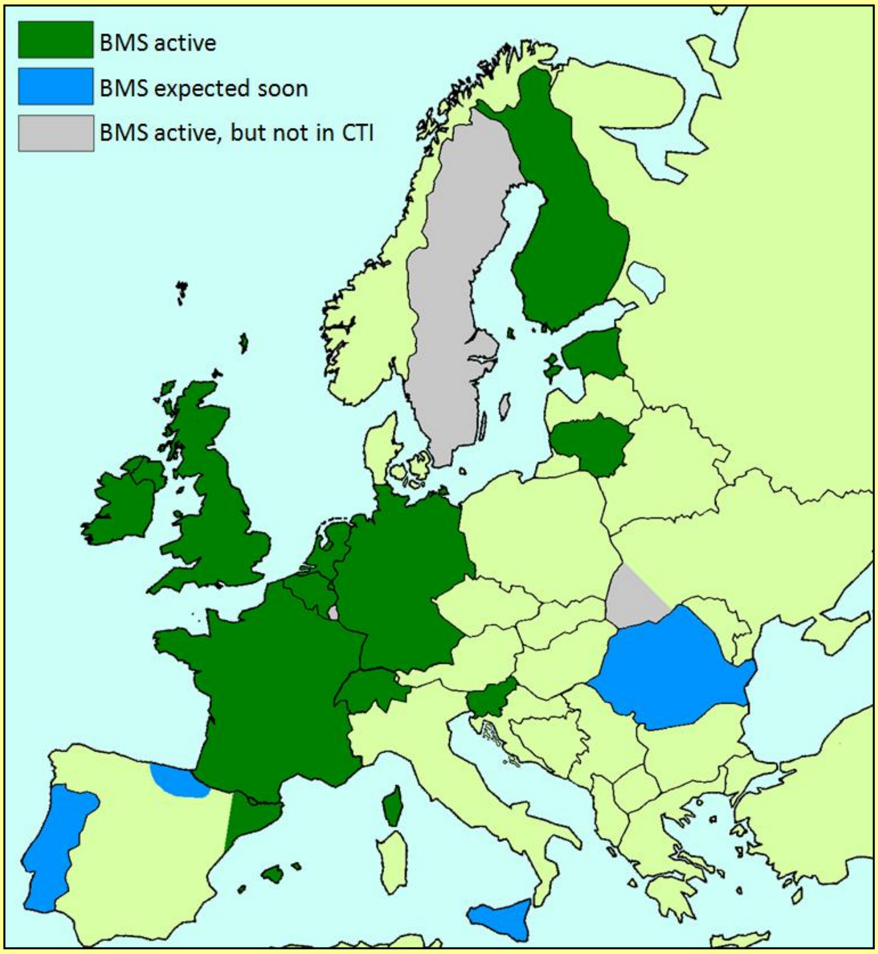
The indicator uses the counts of butterflies made in Butterfly Monitoring Schemes all over Europe. Thousands of expert volunteers and professionals count butterflies on a regular basis using standardised methods, thus providing us with a superb dataset to investigate changes in butterflies all over the continent.

Butterfly monitoring enjoys a growing popularity in Europe. Map 1 shows the current Butterfly Monitoring Schemes (BMS) and the countries where they are expected soon. Although Butterfly Monitoring Schemes are present in a growing number of countries and new ones are being initiated in many places, long time-series are only available for a limited number of countries. For this indicator data were used from 13 countries: Belgium, Estonia, Finland, France, Germany, Ireland, Lithuania, Jersey, Slovenia, Spain, Switzerland, The Netherlands and the United Kingdom. Andorra is included in the Catalonian (Spanish) scheme.

***Map 1: Countries contributing their data to the European Butterfly Climate Change Indicator**:*
Belgium (Flanders): since 1991
Estonia: since 2004
Finland: since 1999
France: since 2005
Germany: since 2005
Ireland: since 2007
Lithuania: since 2009
Jersey: since 2004
Spain (Catalonia, including Andorra): since 1994
Slovenia: since 2007
Switzerland: since 2003
The Netherlands: since 1990
United Kingdom: since 1976 (data since 1990 were used)

Sweden and Luxemburg started their counts in 2010, so they could not be used for this report.
Data for Ukraine (Transcarpathia) was not made available.

Since 1990 almost 4000 transects have been counted at least one year, and could be used for this analysis.



In this report we update the European Butterfly Climate Change Indicator, first published by Van Swaay *et al*. in 2008. The updated indicator not only has a longer time-series, with data from the 2008 and 2009 field seasons now included, but also the method of calculating the indicator has been improved and enhanced. Furthermore nine new countries have been added.

The method closely follows the one developed for birds in France by Devictor *et al*. (2008) and described for butterflies in Van Swaay *et al.* (2008).

In Central Europe ***peatbogs*** *are relatively cool habitats, where species with a northern distribution have survived after the last ice-age. Here species like* Boloria aquilonaris *and* Coenonympha tullia *are among the species most at risk from global warming. Photos: Chris van Swaay, Jaap Bouwman and Henk Bosma.*

Chapter 2 / Butterflies and climate change

The expected climate change will have many effects on biodiversity. This chapter gives a short overview of the consequences of climate change on butterflies.

Butterflies require body temperatures of 30–35^{o}C for optimal growth and development (Porter, 1982; Shreeve, 1992). Although butterflies have all kinds of methods to raise their temperature to this level (e.g. sun basking, coloration, body movement), climate is one of the major factors determining the distribution of these insects. Therefore climatic warming allows range expansion of many species at the cool margins of their range, both in latitude and in altitude, and an eventual contraction at the warmer margins (Parmesan *et al.,* 1999; Warren *et al.,* 2001; Parmesan & Yohe, 2003; Wilson *et al.,* 2007). There are several ways in which climate change may affect butterflies:

- Direct effects on the physiology: butterflies and their caterpillars have an optimum temperature range, in which their body processes function best. If the microclimate changes, this will affect their survival and thus have an effect on their numbers and range.
- Effects on the abiotic environment. Apart from the direct effect of sea-level rise on coastal areas, the most direct effect of climate change will be on soil systems in terms of organic matter and especially water content. It could lead to drought-periods as well as heavy showers and flooding.
- Climate change has an impact on the vegetation structure, for example, leading to greater spring/summer grass growth in warm years.
- This makes conditions more suitable for some species and less suitable for others.
- Larval foodplants change their range. Many specialist butterflies depend on one or two species of foodplant. If their optimal range doesn't overlap with the new foodplant range, this can result in a change in the possible future range of such butterflies. This is demonstrated in the example of *Boloria titania* and its larval foodplant *Polygonum bistorta* (Schweiger *et al.*, 2008).

Boloria titania *is a butterfly depending on its foodplant* Polygonum bistorta *in most of its range*. As climate change will affect the ranges of both butterfly and foodplant, the butterfly can only survive where climate niches of both overlap.*
Photos: Chris van Swaay and Rudi Verovnik.

**in northern Europe it is also reported to feed on other foodplants.*

Species interactions: It is inevitable that range changes for plants and animals will lead to new interactions between species. Changes in temperature may result in asynchrony between food sources and breeding, causing starvation of offspring that emerges too early (e.g. Visser & Holleman, 2001). This will mostly affect specialist species and butterflies with complex interactions with other species. In this respect species of the former genus *Maculinea* (now *Phengaris*), depending not only on foodplants, but also on host-ants, can be vulnerable (Wynhoff *et al.*, 2008). Changes and disruptions in the interactions between butterflies and their parasitoids, pathogens and predators are also highly likely (Both *et al.*, 2006; Menéndez *et al.*, 2008).

The overall impact of climate change on butterflies will be a new balance of gains and losses: species will tend to expand their range at the cold edge of their distribution, and loose populations at the southern edge (Parmesan *et al*., 1999). At the same time, as numbers are expected to rise in the northern part of their range, they are predicted to decline in their southern part. Mountain species will be forced uphill, with the risk of local extinction after the summit is reached.

The Alcon Blue (**Phengaris alcon*** ***above) has a complex relationship with a plant and an ant.*** *After feeding on the foodplant* Gentiana pneumonanthe *(right) for a few weeks, the larvae are taken into the nest of an ant species of the genus* Myrmica *(right). Here, the larvae hibernate and pupate and the adult butterflies emerge next summer. Climate change can disrupt such complex interactions, leading to the local extinction of the butterfly. Photos: Chris van Swaay. Drawing: Marjolein Spitteler.*

Chapter 3 / Building the Climate Change Indicator for Butterflies

The European Butterfly Climate Change Indicator uses count data from national monitoring schemes to measures changes in butterfly communities attributable to climate change.

Fieldwork

The Butterfly Indicator is based on the fieldwork of thousands of trained professional and volunteer recorders, counting butterflies on almost 4000 transects scattered widely across Europe (see map 1). These counts are made under standardised conditions. Regional and national coordinators collect the data and perform the first quality control. More details can be found in Annex I.

Species Temperature Index (STI)

With a few exceptions, all butterflies have a distribution which is restricted to a part of the world. In Europe, some species are typical of the colder northern regions, whereas others occur primarily in the warm, southern part of our continent. This is illustrated in figure 2, where *Plebejus optilete* is a characteristic species of cool bogs and forests in the north or high in the Alps. In contrast, *Hipparchia fidia* favours warm conditions and can be found in the Mediterranean.

The preference of a species for a specific climate can be expressed by the long term average temperature over its range. This is called the **Species Temperature Index (STI)**. The STI was calculated for each European species using the European distribution atlas of Kudrna (2002) and the Climatic Risk Atlas of European Butterflies (Settele *et al.*, 2008). *Plebejus optilete*, with its preference for high altitudes and latitudes, has an STI of 4.2 °C, whereas *Hipparchia fidia* is characterized by an STI of 13.5 °C.

Butterflies are recorded along transects. Most of these counts are done by volunteers, who are vital to the Butterfly Monitoring Schemes and to produce the indicator.

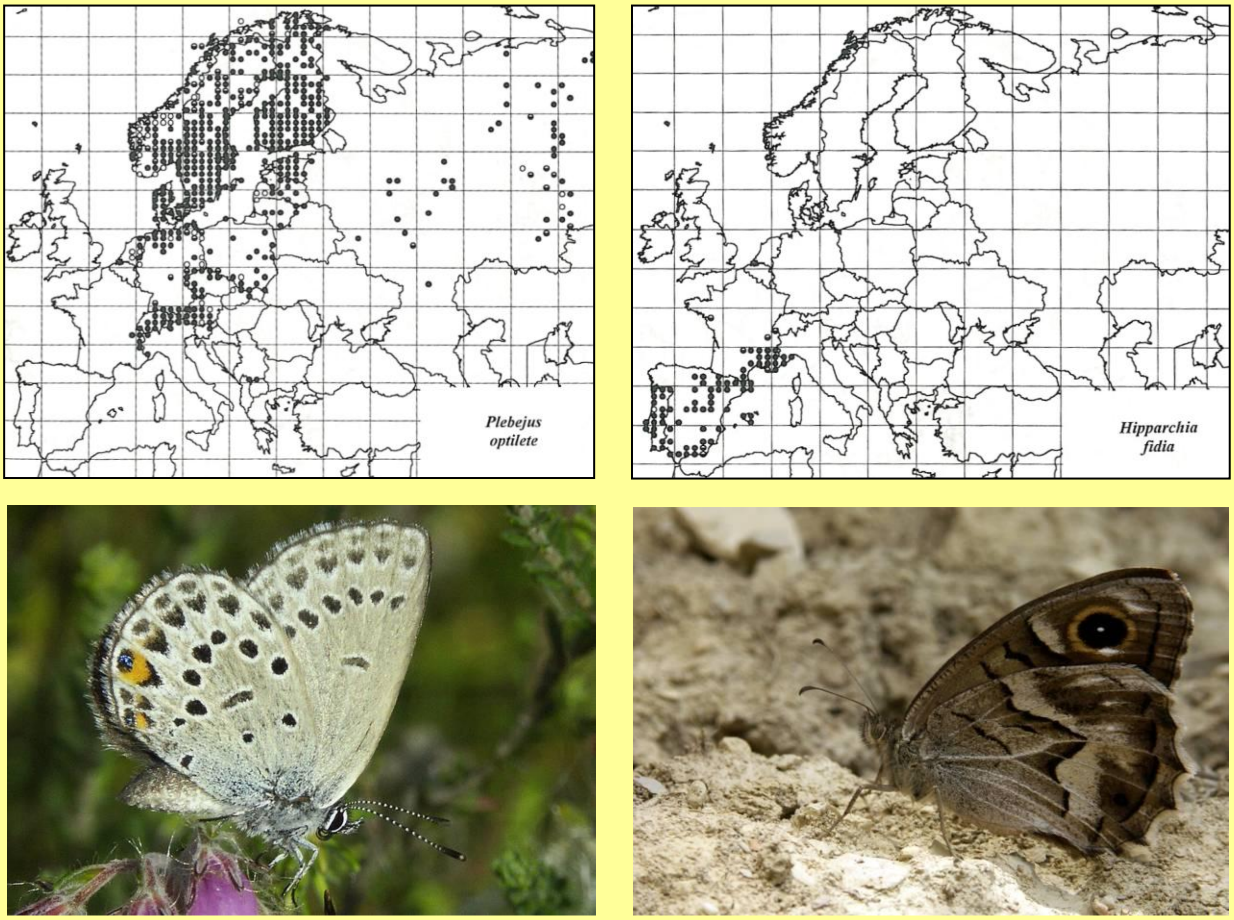


Figure 2: The Species Temperature Index (STI) *is the average temperature over the range of a species in the distribution atlas of Kudrna (2002) (upper maps). This is illustrated by a butterfly with a preference for high altitudes and latitudes (*Plebejus optilete*, left) with an STI of 4.2 °C, and a warmth loving species (*Hipparchia fidia*, right) with an STI of 13.5 °C. Photos: Chris van Swaay.*

Community Temperature Index (CTI)

The number of butterflies of each species occurring at a certain site in a certain year can be described as a community. As each species has its own specific STI (Species Temperature Index), a **Community Temperate Index (CTI)** can be calculated as the average of each individual's STI present in the assemblage. A high CTI would thus reflect a large proportion of species with a high STI, i.e. of more high-temperature dwelling species such as *Hipparchia fidia* in figure 2. This way, the CTI can be used to measure local changes in species composition. If climate warming favours species with a high STI, then the CTI should increase locally (Devictor *et al*., 2008).

The Butterfly Climate Change Indicator

Following temperature increase, a new value of CTI will result from the adjustment of population densities according to each species-specific temperature requirement. A temporal increase in CTI indicates that the species assemblage is increasingly composed of individuals belonging to species dependent on higher temperature. The change of the CTI is thus a simple means to measure the rate of change in each community composition in response to climate change. The speed of increase shows how fast butterfly communities adapt. The Indicator shows this change both at a national and European level (Devictor *et al.*, 2008). More details on the method can be found in annex 1.

Shift of butterfly communities

Butterfly communities in the northern countries will mainly consist of species preferring cool conditions (and thus having a low STI) and only occasional species with a high STI will occur on those transects. As a result the Community Temperate Index (CTI) of transects in Finland is much lower than in Spain (table 1): there is a gradient of the CTI over Europe.

This gradient can be used to assess the northward shift of butterfly communities as a reaction to the changing climate. The temporal slope of the change in CTI over Europe as a whole over time gives the rate of change in butterfly community composition in response to climate change through time (in °C per year). To give an impression of the northward shift, we can use the spatial gradient in CTI over Europe (in °C per km), provided there is a linear relationship. Devictor *et al*. (in prep.) show that there is such a relationship. We therefore use their gradient of the CTI over Europe in 2005 of 1.47 x 10-3 ± 0.08 °C loss of CTI per km.

Table 1: For each participating Butterfly Monitoring Scheme (BMS) *the mean Community Temperature Index CTI (± standard error) for the period 2006-2009 is presented, as well as the number of transects per BMS that have been counted in at least one year since 1990. Only transects with an altitude under 1000 m are used.*

Country	Mean CTI 2006-2009	s.e.	Total number of transects since 1990
Finland	7.98	0.01	141
Lithuania	8.30	0.01	13
Estonia	8.31	0.02	11
Republic of Ireland	9.06	0.04	63
Germany	9.09	0.06	398
Switzerland	9.10	0.05	190
The Netherlands	9.23	0.03	956
Slovenia	9.25	0.02	7
Belgium Flanders	9.28	0.04	78
United Kingdom	9.37	0.03	1226
Channel Islands Jersey	9.59	0.02	11
France	9.62	0.03	562
Spain Catalonia	10.76	0.01	86

Chapter 4 / The Indicator

The European Butterfly Climate Change Indicator has been updated by adding two years and nine countries since van Swaay *et al.* (2008).

Figure 3 shows the updated European Butterfly Climate Change Indicator. This indicator is based on the data from almost 4000 transects in thirteen countries (see map 1). The indicator shows fluctuations from year to year, probably reflecting annual temperature variation. However, over the period it shows a significant increase of +5.5 x 10^{-3} °C per year (± 0.5 x 10^{-3} s.e.; $p<0.001$). This means that the composition of butterfly communities is estimated to have shifted 75 km northward during 1990-2009, a rate of almost four km per year.

During the same period the temporal trend of the temperature in Europe increased steeply with +5.5 x 10^{-2} °C (± 0.61 x 10^{-2} s.e.; $p<0.001$), corresponding to a northward shift of 249 km (Devictor *et al*., in prep.). This indicates that although butterfly communities are shifting north, they cannot keep up with the much faster change of the climate, as measured by warming temperatures, in the past twenty years.

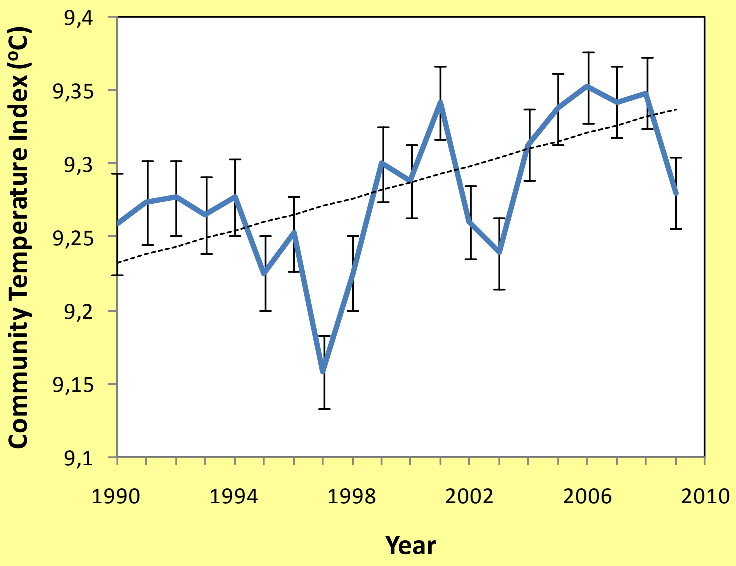


Figure 3: The European Butterfly Climate Change Indicator.
The indicator is based on the Butterfly Monitoring Schemes in the countries in map 1. In total, data from almost 4000 transects were used. The indicator shows a significant increase of the CTI of 5.5 x 10^{-3} °C per year. The dashed line illustrates the trend.

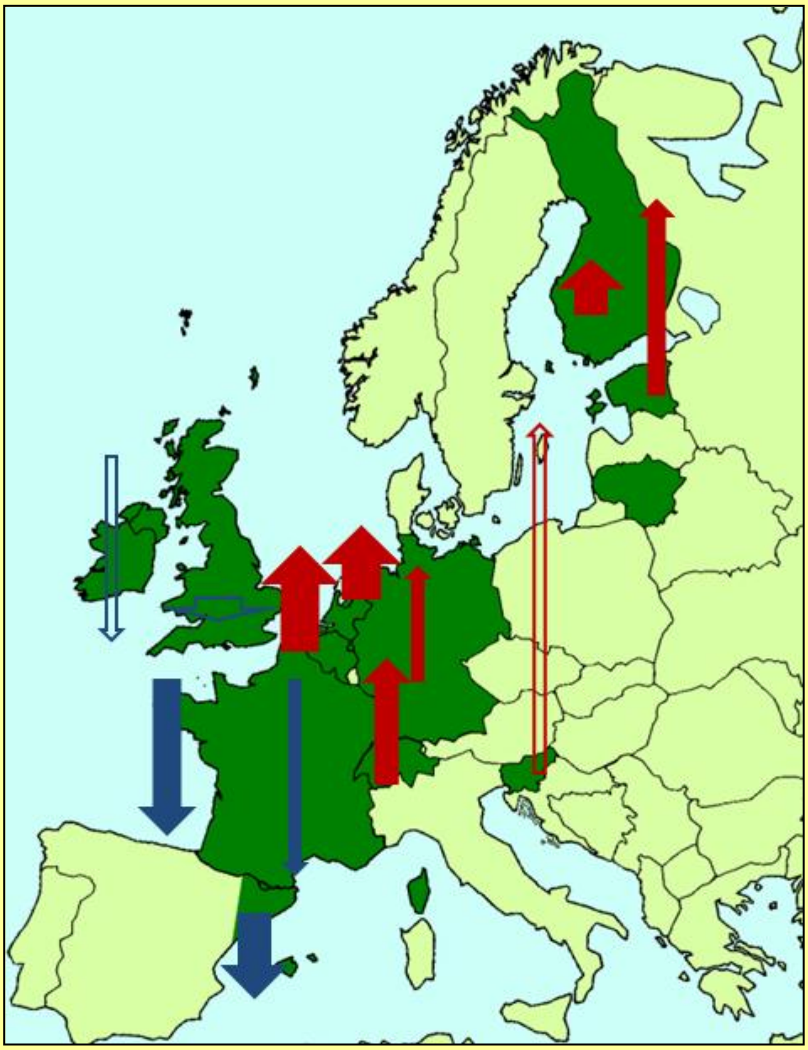
Chapter 5 / Changes per country

As well as for Europe as a whole, the change of CTI can also be calculated per country or a combination of countries.

The change of the Community Temperature Index can also be calculated for each Butterfly Monitoring Scheme separately. The result (map 2) shows a gradient over Europe. In south-western Europe the CTI seems to be declining, whereas the CTI in the north-eastern European countries is increasing. This suggests that butterfly communities are reacting differently over the continent. However, the regional variation in climate change impact requires much further research and other factors could be involved. The results should also be treated with some caution as many time-series are shorter than ten years, often even shorter than five years (e.g. France and Germany).

Map 2: Trends in Community Temperature Index (CTI) per country.
The arrows indicate the magnitude and direction of the change in CTI (red=increasing, blue=declining).
A filled arrow means the change is significant, an open arrow that the change is not significant.
The width of the arrow indicates the length of the time-series (narrow=less than five years, medium=5-10 years, broad=more than ten years:

Belgium (Flanders): since 1991
Estonia: since 2004
Finland: since 1999
France: since 2005
Germany: since 2005
Ireland: since 2007
Lithuania: since 2009 (only one year, so no trend available)
Jersey: since 2004
Spain (Catalonia, including Andorra): since 1994
Slovenia: since 2007
Switzerland: since 2003
The Netherlands: since 1990
United Kingdom: since 1976 (data since 1990 were used)



Chapter 6 / Implications

The European Butterfly Climate Change Indicator has been updated. It shows that butterfly communities have changed. What does it mean for butterflies in Europe?

As a reaction to a changing environment (for example climate change) individual butterflies will reproduce more or less successfully. This will lead to a growth or reduction of the population sizes of each species, eventually resulting in local extinctions or colonisations. On a larger scale species will shift their range, contracting in areas that have become less suitable and expanding into new areas thathave become suitable. In the case of climate change we expect this change to have a northern direction. Parmesan *et al*. (1999) and Settele *et al*. (2008) show that these changes in species range as a reaction to climate change can be substantial and are already taking place. Pöyry *et al*. (2009) measured large and rapid shifts in northern latitudes in Finland, where one third of the studied 48 species had shifted their range >100 km northwards in only eight years.

As local extinctions or colonisations can be rare events (even in a rapidly changing world), the relative changes in numbers between species on a local scale is a much more sensitive indicator. The European Butterfly Climate Change Indicator focuses on these small changes between species, by using butterfly communities as the starting point. This sensitive indicator shows that butterfly communities are changing. The significant increase in CTI reflects butterfly communities becoming increasingly composed of species associated with warmer temperatures. The speed of this change is, however, much smaller than the change of temperature over the same period. This means that butterflies react to the changing climate, but not fast enough. Therefore every year butterfly communities become a little less well adapted to their climatic environment. Eventually this phenomenon will probably lead to more declining than increasing species as well as local extinctions, especially of species associated with cool conditions.

The Large Copper (*Lycaena dispar*) is a butterfly expanding its range rapidly in Finland, probably because of the changing climate. Photo: Chris van Swaay.

Chapter 7 / Climate Change and Butterfly Conservation

Although butterflies may seem fragile and vulnerable insects, their capability of adapting to a changing environment is great. With proper conservation measures we can help them to better cope with ongoing climate change.

Butterflies occur across our continent and are a well-known and popular group of insects, enriching the lives of many people. Climate change poses a huge challenge to our butterflies, but there are ways to mitigate negative impacts and save them in our countryside (Settele *et al*., 2008). As butterflies are good biological indicators, measures to help them will help conserve Europe's rich biodiversity.

***The Alps** are the home of many butterflies, like this* Parnassius phoebus*. Mountain ranges often provide large and relatively intact landscapes, supporting large populations. Photo: Tom Nygaard Kristensen.*

- **Preserve large populations in large areas**
  Large and diverse landscapes offering a large variety of microclimatic conditions, can support larger and more stable butterfly populations and communities for a much longer time than small areas. Nature conservation should not only protect existing areas, but also try to extend them and manage them to create large, diverse habitats with strong butterfly populations.

- **Encouraging mobility across the landscape**
  Barriers across the landscape preventing butterflies to shift their ranges in northern direction should be removed as far as possible. The Natura 2000 network should focus on providing these connections, which should connect large and strong populations as much as possible. In the wider countryside, agri-environment schemes can create stepping stones in the landscape, as well as provide corridors. The value of some urban landscapes should also not be underestimated.

Although the European Butterfly Climate Change Indicator shows that butterflies are currently not keeping up with the changing climate, we should do all we can to create pathways that offer them the greatest chances to adapt.

- **Gain time to adapt**
  Targeted management on the ground should offer existing populations the time to adapt and move to new areas. This should not only take place in nature reserves, but also in the wider countryside and urban areas. By doing this we buy time to make it possible for other measurements to take effect.

- **Reduce the emission of greenhouse gasses**
  Only by a serious reduction in the emission of greenhouse gasses we can expect climate change to slow down, but that should not prevent us from doing what we can to reduce this impact.

- **Research**
  To understand what is happening in our continent and improve adaptation strategies in the future, research is a vital instrument. Butterflies are very suitable organisms, as their distribution and ecology is generally well known. Furthermore the Climatic Risk Atlas (Settele *et al*., 2008) provides a framework to follow changes as a result of climate change.

- **Monitoring**
  Butterfly monitoring is spreading over the continent, and more and more countries are developing schemes. This should be encouraged in other countries to build more robust and representative indicators. The schemes not only provide information on the effect of climate change on butterflies, but they also give direct information on biodiversity changes (e.g. the European Grassland Butterfly Indicator).

- **Updating the indicator**
  Only by regularly updating the indicator can we follow the change of butterfly communities and the impact climate change has on our butterflies.

Melitaea athalia ***is a widespread and common species in most of Europe, but declining in some NW European countries. Photo: Chris van Swaay.***

Chapter 8 / Conclusions

- This report gives an update of an indicator which measures the effect of climate change on butterfly communities.
- The indicator is compiled using count data collected through national Butterfly Monitoring Schemes in 13 countries, representing almost 4000 transects, most of them counted by trained volunteers.
- The indicator shows a significant and rapid change in butterfly communities becoming more and more composed of species associated with warmer temperatures.
- Since 1990, the change of communities is equivalent to a northward shift of 75 km.
- Conservation measurements should focus on preserving large populations over large areas and encouraging mobility across the landscape. The Natura 2000 and Emerald networks could be very useful instruments to achieve that. In the wider countryside agri-environment schemes could help provide escape routes for butterflies.
- Continuing butterfly monitoring and expanding Butterfly Monitoring Schemes to other countries will further improve the quality of future indicators.

***Large and well managed nature reserves**, like this Natura 2000 area in Germany, offer butterflies a better chance of long-term survival under a changing climate. Good communication to visitors helps them understanding the importance of butterflies and biodiversity. Photo: Chris van Swaay*

Literature

Both, C., Bouwhuis, S., Lessells, C.M. & Visser, M.E. (2006). Climate change and population declines in a long-distance migratory bird. *Nature* **441**, 81-83.

Devictor, V.; Julliard, R.; Couvet, D. & Jiguet, F. (2008) Birds are tracking climate warming, but not fast enough. *Proceedings Royal Society of London. Biological Sciences* **275 (1652)**, 2743-2748

Devictor, V., Van Swaay, C.A.M., Brereton, T, Brotons, L., Chamberlain, D., Heliölä, J., Herrando, S., Julliard, R., Kuussaari, M., Lindström, Å, Reif, J., Roy, D., Schweiger, O., Settele, J., Stefanescu, C., Van Strien, A., Van Turnhout, C., Vermouzek, Z., WallisDeVries, M., Wynhoff, I., Jiguet, F. (in prep.) Differences in the climate debts of birds and butterflies at continental scale.

Henry, P.-Y., Manil, L., Cadi, A. & Julliard, R. (2005) *Two national initiatives for Butterfly Monitoring in France.* In: Kühn, E., R. Feldmann, J.A. Thomas & J. Settele (Editors) Studies on the ecology and conservation of butterflies in Europe. Vol. 1: General concepts and case studies. Conference Proceedings, UFZ Leipzig-Halle, December 2005 (Series Faunistica No 52) Pensoft, Sofia , pp 85

IPCC (2007) *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Solomon S, Qin D, Manning M, Chen Z, Marquis M et al. (eds.). Cambridge, UK and New York, USA: Cambridge University Press. 996 p.

Jiguet, F., Julliard, R., Thomas, C.D., Dehorter, O., Newson, S.E. & Couvet, D. (2006) Thermal range predicts bird population resilience to extreme high temperatures. *Ecol. Lett.* **9**, 1321–1330.

Kudrna, O. (2002) *The distribution atlas of European butterflies*. Oedippus nr. 20 - Naturschutzbund Deutschland e.V.

Kühn, E., Feldmann, R., Harpke, A., Hirneisen, N., Musche, M., Leopold, P. & Settele, J. (2008). Getting the public involved in butterfly conservation: lessons learned from a new monitoring scheme in Germany. *Israel Journal of Ecology & Evolution* **54**, 89-103

Menéndez, R., González-Megías, A., Lewis, O.T., Shaw, M.R. & Thomas, C.D. (2008). Escape from natural enemies during climate-driven range expansion: a case study. *Ecological Entomology* **33 (3)**, 413-421

Parmesan, C. & Yohe, G. (2003) A globally coherent fingerprint of climate change impacts across natural systems. *Nature* **421**, 37–42.

Parmesan, C.; Ryrholm, N.; Stefanescu, C.; Hill, J.K.; Thomas, C.D.; Descimon, H.; Huntley, B.; Kaila, L.; Kullberg, J.; Tammaru, T.; Tennett, W.J.; Thomas, J.A. & Warren, M. (1999) Poleward shifts in geographical ranges of butterfly species associated with regional warming. *Nature* **399**, 579-583

Pollard, E. & Yates, T.J. (1993). *Monitoring Butterflies for Ecology and Conservation*. Chapman & Hall, London.

Porter, K. (1982) Basking behaviour in larvae of the butterfly Euphydryas aurinia. *Oikos* **38 (3),** 308-312

Pöyry, J., Luoto, M., Heikkinen, R.K., Kuussaari, M. & Saarinen, K. (2009). Species traits explain recent range shifts of Finnish butterflies. *Global Change Biology* **15,** 732-743

Schweiger, O.; Settele, J.; Kudrna, O.; Klotz, S. & Kühn, I. (2008) Climate change can cause spatial mismatch of trophically interacting species. *Ecology* **89 (12),** 3472-3479

Settele, J.; Kudrna, O.; Harpke, A.; Kühn, I.; Swaay, C. van; Verovnik, R.; Warren, M.; Wiemers, M.; Hanspach, J.; Hickler, T.; Kühn, E.; Halder, I. van; Veling, K.; Vliegenthart, A.; Wynhoff, I.; Schweiger, O. (2008) Climatic risk atlas of European butterflies. *Biorisk* **1**, 1-710

Settele, J. & Kühn, E. (2009) Insect conservation. *Science* **325 (5936)**, 41-42

Shreeve, T.G. (1992). *Adult behaviour*. In: Dennis, R.L.H. (Editor) *The Ecology of butterflies in Britain*. Oxford University Press, Oxford, pp. 22-45

Sutherland, W.J. (2006). *Ecological Census Techniques*. 2ndedition Cambridge University Press, Cambridge.

Van Swaay, C.A.M., Plate, C.L. & Van Strien, A. (2002). Monitoring butterflies in the Netherlands : how to get unbiased indices. *Proceedings of the Section Experimental and Applied Entomology of The Netherlands Entomological Society (N.E.V.)* **13**, 21-27

Van Swaay, C.A.M.; Strien, A.J. van; Julliard, R.; Schweiger, O.; Brereton, T.; Heliölä, J.; Kuussaari, M.; Roy, D.; Stefanescu, C.; Warren, M.S.; Settele, J. (2008). *Developing a methodology for a European Butterfly Climate Change Indicator.* Report VS2008.40 - De Vlinderstichting, Wageningen

Van Swaay, C.A.M.; Cuttelod, A.; Collins, S.; Maes, D.; López Munguira, M.; Šašic, M.; Settele, J.; Verovnik, R.; Verstrael, T.; Warren, M.; Wiemers, M.; Wynhoff, I. (2010a). *European Red List of butterflies*. IUCN Red List of Threatened Species - Regional Assessment - Office for Official Publications of the European Communities, Luxembourg

Van Swaay, C.A.M.; Strien, A.J. van; Harpke, A.; Fontaine, B.; Stefanescu, C.; Roy, D.; Maes, D.; Kühn, E.; Õunap, E.; Regan, E.; Švitra, G.; Heliölä, E.; Settele, J.; Warren, M.S.; Plattner, M.; Kuussaari, M.; Cornish, N.; Garcia Pereira, P.; Leopold, P.; Feldmann, R.; Jullard, R.; Verovnik, R.; Popov, S.; Brereton, T.; Gmelig Meyling, A.; Collins, S. (2010b) *The European Butterfly Indicator for Grassland species 1990-2009.* Report VS2010.10, De Vlinderstichting, Wageningen

Visser, M.E. & Holleman, L.J.M. (2001). Warmer springs disrupt the synchrony of oak and winter moth phenology. *Proceedings Royal Society of London. Biological Sciences* **268 (1464)**, 289-294

Warren, M.S.; Hill, J.K.; Thomas, J.A.; Asher, J.; Fox, R.; Huntley, B.; Roy, D.B.; Telfer, M.G.; Jeffcoate, S.; Harding, P.; Jeffcoate, G.; Willis, S.G.; Greatorex-Davies, J.N.; Moss, D. & Thomas, C.D. (2001) Rapid responses of British butterflies to opposing forces of climate and habitat change. *Nature* **414**, 65-69

Wilson, R.J., Gutiérrez, D., Gutiérrez, J. & Monserrat, V.J. (2007). An elevational shift in butterfly species richness and composition accompanying recent climate change. *Global Change Biology* **13 (9)**, 1873-1887

Wynhoff, I., Grutter, M. & Van Langevelde, F. (2008) Looking for the ants: selection of oviposition sites by two myrmecophilous butterfly species. *Animal Biology* **58**, 371-388.

Annex I / Butterfly Monitoring Schemes and method

Since the start of the first Butterfly Monitoring Scheme in the UK in 1976 more and more countries have joined in. This annex summarizes the most important features of the schemes used for the indicator.

Field methods

All schemes apply the method originally developed for the British Butterfly Monitoring Scheme (Pollard & Yates, 1993). The counts are conducted along fixed transects of 0.5 to 3 kilometres, consisting of smaller sections, each with a homogeneous habitat type, but the exact transect length varies among countries. The fieldworkers record all butterflies 2.5 metres to their right, 2.5 metres to their left, 5 metres ahead of them and 5 metres above them (Van Swaay *et al.*, 2002). Butterfly counts are conducted between March-April to September-October, depending on the region. Visits are only conducted when weather conditions meet specified criteria. The number of visits varies from every week in e.g. the UK and the Netherlands to 3-5 visits annually in France.

Transect selection

To be able to draw proper inferences on the temporal population trends at national or regional level, transects should best be selected in a grid, random or stratified random manner (Sutherland, 2006). Several recent schemes, e.g. in Switzerland and France, have been designed in this manner (Henry *et al.*, 2005). If a scheme aims to monitor rare species, scheme coordinators preferably locate transects in areas where rare species occur, leading to an overrepresentation of special protected areas. In the older schemes, such as in the UK and the Netherlands, but also in the recently established scheme in Germany, transects were selected by free choice of observers, which in some cases has led to the overrepresentation of protected sites in semi-natural habitats and the undersampling of the wider countryside and urban areas (Pollard & Yates, 1993), while in Germany this effect was not that pronounced (Kühn *et al.*, 2008). Obviously, in such a case the trends detected may be only representative for the areas sampled, while their extrapolation to national trends may produce biased results. For the Butterfly Climate Change Indicator only transects under an altitude of 1000 m were used.

Method

We used the method extensively described in Devictor *et al*. (2008), which was preferred in the first version of the Butterfly Climate Change Indicator (Van Swaay *et al.*, 2008). In brief, the northward shift was estimated in two steps. First, we calculated the annual change in the Community Temperature Index (CTI) reflecting the relative composition of high versus low-temperature dwellers. The CTI of a taxonomic group for a given year in a given plot is the average of each Species Temperature Index (STI) detected in this plot weighted by the species' abundance. The STI of a given species is the long-term average temperature over the species' entire European range. This species characteristic is taken as a proxy for the thermal niche optimum of the species (Jiguet *et al*. 2006). The STIs were obtained from the distribution data from Kudrna (2002) and the climate data as used by Settele *et al*. (2008). For most species the STI is thus based on a subset of whole species distribution (e.g., the African distribution is ignored). However to calculate CTI, we are only interested in the relative STI values of the species considered (Devictor *et al.* 2008).

A single regression model was performed on CTI considered as a dependent variable, country as a fixed independent factor, year as a continuous independent variable and site as a random effect with the Statistical Package R (version 2.12.0) and the function lme. In this model, we used country area divided by the number of sites in a country in a year as a weight to account for unequal error contribution of each country. Although the data were available for different periods in the different countries, we focused on the 20 year period, 1990-2009. This analysis provided the estimated overall slope (±s.e.) of the change in the pan-European CTI through time. Note that in this model, the temporal trend in CTI is not affected by eventual turnover of plots within countries.

Butterflies are counted on fixed transects and under standardised weather conditions (which can be summarised to: nice, sunny weather).
Photo: Kars Veling