Avocetta 33: 19-27 (2009)

Developing a butterfly indicator to assess changes in Europe's biodiversity

Tom Brereton[1], Chris van Swaay[2*], Arco van Strien[3]

[1] *Butterfly Conservation - Manor Yard, East Lulworth, Dorset, BH20 5QP (UK)*
[2] *De Vlinderstichting - Postbus 506, 6700 AM Wageningen, The Netherlands*
[3] *Statistics Netherlands - PO Box 24500, 2490 The Hague, The Netherlands*
** Corresponding author: chris.vanswaay@vlinderstichting.nl*

Abstract – To monitor progress towards the European Union target to halt the loss of biodiversity by 2010, biodiversity indicators at a European scale are required. Butterflies have been proposed as biodiversity indicators due to their rapid and sensitive responses to subtle habitat and climatic changes and as representatives for the diversity and responses of other wildlife, especially insects. Since the first butterfly monitoring scheme was established in the UK in 1976, schemes have now been established in over ten European countries. In each scheme, regular butterfly counts are made through the season each year along fixed routes under suitable weather criteria. Here, we used the counts to compile both national and supra-national annual indices for a number of species, in order to develop and test a preliminary European scale biodiversity indicator for the European Environment Agency. A multi-species grassland "European" Butterfly indicator was constructed by combining data from 17 characteristic grassland species, following closely the analytical method developed for the European Bird Indicator. The indicator showed a strong decline in butterfly abundance (of about 40% in 15 years from 1990). The European Environment Agency has subsequently proposed a number of indicators for inclusion in the set of European biodiversity indicators, butterflies being one of the most highest ranked. We hope to update and develop the indicator further (including compiling an indicator for woodland butterflies), make further analytical improvements and extend butterfly monitoring schemes to other countries in order to improve the quality and representativeness of the indicator.

INTRODUCTION

Recent years have seen global political consensus on the need to address the loss of biodiversity. The 1994 Convention on Biological Diversity (CBD) put an obligation on individual governments to develop national strategies for the conservation and sustainable use of biological diversity. As part of the response, in 2001 the European Union set an ambitious target to halt biodiversity loss across Member States by 2010, which was backed up by agreement under international law in 2002 through the CBD. In 2006, the EU published an Action Plan as a road map to delivering the 2010 target, including concrete measures and outlining the responsibilities of EU institutions and Member States. An important component of the Action Plan was the requirement to develop biodiversity indicators (surrogate measures for a wider range of biodiversity) to enable timely assessment of conservation progress towards the target. In 2004 a European initiative co-ordinated by the European Environment Agency, SEBI 2010 ('Streamlining European 2010 Biodiversity Indicators'), was launched to develop a first European set of Biodiversity Indicators for 2010 target assessment (European Environment Agency 2007).

Components of biodiversity requiring assessment include trends in the abundance and distribution of species. Unfortunately, at a European scale the development of species indicators is problematic because systematic monitoring of biodiversity is scant, with birds providing the best available dataset. Due to the establishment of butterfly monitoring schemes in a number of European countries in recent years that collect annual data to a scientific standard over a wide geographical area, population trends of butterflies now represent an important new possibility as an indicator.

Butterflies are considered as important components of biodiversity because they have considerable resonance with both the general public and decision-makers (Kühn *et al.*, 2008).

Information of trends in butterflies is increasingly used by a number of north-west European governments. For example, in 2005 the English Government used three butterfly indicators, including a Headline Indicator *Popu-*

lations of Butterflies, and *Populations of* both *Woodland* and *Farmland Butterflies*, to help assess progress in implementing the England Biodiversity Strategy and assessing the effectiveness of biodiversity conservation policies (Department for Environment, Food and Rural Affairs 2006). In the Netherlands, butterflies are included in a headline indicator based on the Red List status of species as well included in several other indicators, e.g. to show effects of climate change (www.natuurcompendium.nl).

Butterflies have been proposed as biodiversity indicators due to their rapid and sensitive responses to subtle habitat and climatic changes and as representatives for the diversity and responses of other wildlife, especially insects (Rosenberg *et al*. 1986, Erhardt & Thomas, 1991, Fleishman *et al*., 2000, Kremen 1992, New *et al*. 1995, Hammond, 1995, Beccaloni and Gaston 1995, Oostermeijer and van Swaay 1998, Ehrlich 2001, Ehrlich 2003, Parmesan, 2003, Thomas 2005). Representation for insects would be particularly important as insects comprise 56% of known species (Groombridge 1992) and an estimated 80% of the global species stock (Stork 1993).

In this paper, we evaluate the suitability of butterfly population data as a biodiversity indicator at a European scale for 2010 target assessment. We discuss the strengths and weaknesses of the preliminary grassland European Butterfly Indicator as reported by Van Swaay & Van Strien (2005), and compare this indicator with the farmland bird indicator as developed by Gregory *et al*. (2005). We also discuss briefly how well trends in butterflies may represent trends in other insects groups. Grasslands are vitally important to European butterflies, providing habitat for 88% of species and the main habitat for 57% of species (Blab and Kudrna, 1982, Tax, 1990, Van Swaay & Warren, 1999; Van Swaay *et al*., 2006). In many cases grassland butterflies are dependent on agricultural management for their long-term survival, thus there are strong linkages to EU policy mechanisms such as the Common Agricultural Policy and agri-environment schemes.

METHODS

Evaluation of using butterfly monitoring data as an EU Biodiversity Indicator

The potential use of butterfly monitoring data in a European indicator was evaluated in two ways. First, by applying the following criteria to butterfly monitoring data: policy relevance, biodiversity relevance, scientifically sound and well founded methodologically, broad acceptance and understandability, affordable monitoring, available and routinely collected data, affordable modelling, spatial and temporal coverage of data, representativeness of the data and sensitivity. These criteria were developed and applied by the European Environment Agency. The quality results for each criteria were scored on a scale from 0 (lowest score) to 3 (highest score), with the total enabling objective comparison with other candidate indicators.

Secondly, a trial indicator for grassland butterflies was made. This provides practical insights into the strengths and weaknesses of the monitoring data and methods.

Collation of butterfly monitoring data from European schemes

Regional and national butterfly trend data were collated through Dutch Butterfly Conservation/Butterfly Conservation Europe from a consortium of individuals and organizations from nine countries including: UK, Ukraine, Germany, Netherlands, Flanders (Belgium), Spain, Switzerland, Finland, and France (Table 1).

Butterfly monitoring methods

The main objective of European Butterfly Monitoring schemes is to assess changes in abundance at national and regional levels of butterflies, including Habitat Directive species. For the bulk of schemes the field method used closely follows that developed for the British Butterfly Monitoring Scheme, established in 1976 (Pollard & Yates 1993). Counts are made in a fixed area along line transects under set weather conditions and time of day criteria. Counts are made on a regular basis over the flight season of the species monitored and used to generate annual indices for each species at each site. The average number of visits per year varied considerably across the schemes (Table 1). Most of the transects are recorded by skilled volunteers, who have a good knowledge of the transect butterfly fauna and their results are checked by butterfly experts. In many national schemes, transect locations are not randomly selected, but are based on free choice of volunteers (Table 1). This may easily lead to oversampling of semi-natural grasslands, nature reserves and other protected areas and under-sampling of intensive grasslands on privately owned farmland in the wider countryside.

Preliminary European Butterfly Indicator: habitat and species selection

The habitat focus was grassland, as this is probably the single most important broad habitat type for butterflies in Europe (Van Swaay *et al*., 2006). A selection of 17 species was made by European butterfly experts, as species considered to be characteristic of European grassland using the following criteria: (1) widespread across Europe, (2) sampled by the majority of Butterfly Monitoring Schemes, and

Table 1. Characteristics of the Butterfly Monitoring Schemes. The data from countries or regions marked by *were used for the preliminary European Butterfly Indicator. [1)] after statistical adjustment. ** Assessed by expert opinion

	Starting year (-End Year)	**Number of transects per year**	**Number of visits on a transect per year**	**Field work by** (v = volunteers, p = professionals)	**Method to choose transects**	**Representative for grasslands in the wider countryside****	**Nature reserves over-represented in the indices****
Belgium - Flanders *	1991	10-20	15-20	V	free	no	no
Estonia	2004	7-10	9	P	by co-ordinator	no	no
Finland *	1999	50-60	10-16	V	free	yes	no
France	2005	75	4-8	V	random	yes	no
France - Doubs *	2001 (-2004)	10	10-15	P	by co-ordinator	yes	no
Germany	2005	400	15-20	V	free	yes	yes
Germany - Nordrhein Westfalen *	2001	50	15-20	V	free	no	yes
Germany - Pfalz * (*Maculinea nausithous* only)	1989 (-2002)	16	3	P	by co-ordinator	yes	no
Jersey	2004	15	15-25	V	free	yes	no
Spain - Catalunya *	1994	60-70	30	V	free	yes	no
Switzerland - Aargau *	2001	100	4-7	P	systematic	yes	no
The Netherlands *	1990	430	15-20	V	free	yes	no[1)]
Ukraine - Transcarpathia *	1974	60	2	P	free	yes	no
United Kingdom *	1976	750	15-20	V	free	?	yes

(3) grassland must be their main habitat as defined in Van Swaay *et al.* (2006).

Using widely accepted definitions (e.g. Asher *et al*. 2001) derived from autecological studies, grassland butterflies were grouped into two broad types: widespread species (mobile species occurring in a diverse range of grassland types) and specialists (low mobility species restricted to semi-natural grasslands). The seven widespread species were *Ochlodes faunus, Anthocharis cardamines*, *Lycaena phlaeas*, *Polyommatus icarus*, *Lasiommata megera*, *Coenonympha pamphilus* and *Maniola jurtina.* The ten specialist species were *Erynnis tages*, *Thymelicus acteon*, *Spialia sertorius*, *Cupido minimus*, *Maculinea arion*, *Maculinea nausithous*, *Polyommatus bellargus*, *Polyommatus semiargus*, *Polyommatus coridon* and *Euphydryas aurinia.*

Preliminary European Butterfly Indicator: indices and trends

Development of a preliminary European Butterfly Indicator for grasslands followed methods recently developed for European Birds (Gregory *et al.* 2005), with the work carried out in close consultation with experts from Statistics Netherlands, the European Topic Centre for Biodiversity and the European Bird Census Council/Birdlife. National indices were produced for each grassland species in each country, using the program TRIM, which models data across sites and years, accounting for missing indices and zero counts by log-linear modelling (Pannekoek & Van Strien 2003). European species trends were then calculated for each species by combining national results, with a weighting procedure accounting for the difference in national population size of each species in each country. As no precise national population estimates were available, the weighting was defined more precisely as the range proportion that each country (or region) held of the European distribution for each species (Van Strien *et al.* 2001, Van Swaay & Warren 1999). A further complication as compared to birds is that the count data per site concern several visits per year. The average number of visits of each scheme was taken into account in the weighting too. Missing year totals were estimated by TRIM in a way equivalent to imputing missing counts for particular sites within countries (Van Strien *et al.* 2001). Multi-species indices for all-species, widespread species and specialist grassland butterflies were derived by calculating the geometric mean index across each species assemblage (Gregory *et al.*

2005). In this, for each year separately, the log of each species index value was taken, then averaged across selected species and the exponential of the result calculated.

RESULTS

Trends in the European Grassland Butterfly Indicator

There was a steep populations decline of about 40% in the European Butterfly Indicator for grassland butterflies since 1990 (Figure 1a). Within this trend, the declines of specialist and widespread grassland species did not differ significantly (specialists average trend value -1.56 ± 4.40; widespread species average trend -1.94 ± 0.47; t-test p = 0.93). For all species assemblages, the index in 2004 was significantly lower than in the start year, 1990.

Changes in the grassland Butterfly Indicator were compared to changes in the indicator for European Farmland Birds using data from the Pan-European Common Bird Monitoring Scheme (PECBMS) (Gregory *et al.* 2007). From 1990 to 2004, farmland birds declined at a rate of about 20%. Although this suggests a steeper decline for butterflies (Figure 1b), the average trend value of farmland birds (-0.59; n = 33 species) did not differ significantly from grassland butterflies (-1.72; n = 17 species) (t-test p = 0.67).

Evaluation of using butterfly monitoring data as an EU Biodiversity Indicator

Based on the EEA criteria, overall the butterfly indicator scored highly, validating and confirming the potential of this indicator at a European scale. Policy relevance and biodiversity relevance of the butterfly indicator had the highest score (3); most other aspects had a score of 2. Spatial and temporal coverage and representativeness had scores from 1-3, indicating that further improvements are recommended. These last points were confirmed in the trial of the indicator. The spatial coverage is limited to nine countries, mainly in western Europe (fig. 1). The temporal coverage is also limited, with the longest time series in the UK, the Netherlands, Catalunya and Transcarpathia (table 1). These time series may well be influential for the indicator results. The representativeness of national trends varies across countries, depending on how transects are selected and if any statistical adjustments are made (table 1).

DISCUSSION

Trends in the European Grassland Butterfly Indicator

The declining trend in grassland butterflies underlines the policy relevance of a European Butterfly Indicator. Expert opinion predicted this decline, though the rate was more severe than expected. The decrease in grassland butterflies parallels recent historical declines shown though many studies at national (e.g. Asher *et al.* 2001, WallisDeVries *et al.* 2002) and international scales (Van Swaay & Warren 1999, Van Swaay *et al.* 2006). These declines have largely been attributable to habitat loss and modification through agricultural intensification (Asher *et al.* 2001, Van Swaay *et al.* 2006), a result largely consistent with studies of other wildlife taxa (Flowerdew 1997, Donald *et al*. 2001, Robinson & Sutherland 2002, Gregory *et al.* 2005). In Eastern and Southern Europe abandonment is a serious threat, es-

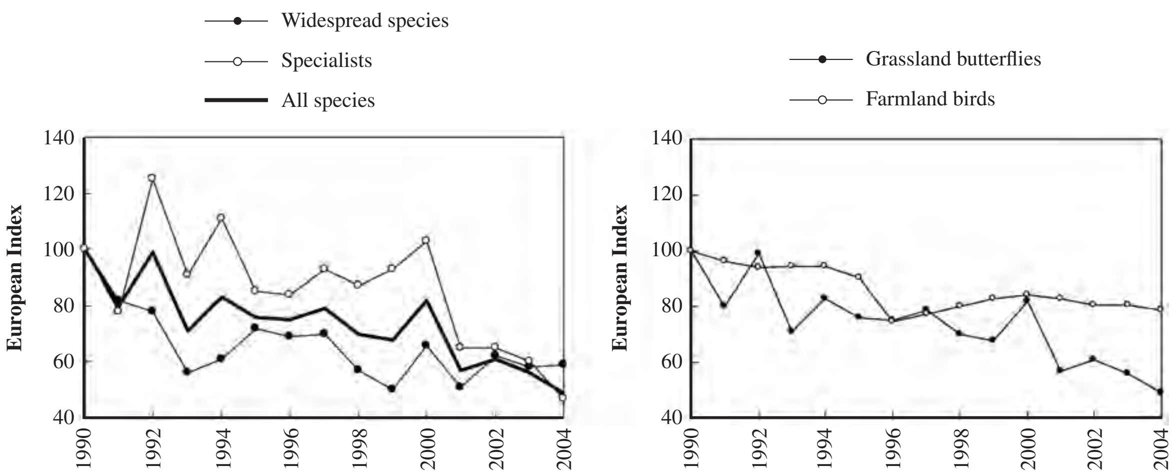

Figure 1. **a** (left): trends in the preliminary grassland butterfly indicator 1990-2004. **b** (right): comparisons of grassland butterflies and farmland bird trends. Bird data source: PECBMS.

pecially in areas that are too wet, steep, rocky or otherwise unsuitable for intensive farming. Following abandonment, some butterfly species flourish for a few years because of the lack of management, but thereafter scrub and trees invade and the grassland disappears, including its rich flora and butterfly fauna.

However, inappropriate conservation management (Davies *et al.* 2007, Konvicka *et al.* 2005), habitat fragmentation (Thomas 1995, Hanski 2003), and environmental change including climate change (Thomas *et al.* 2004, Franco *et al.* 2006) and increased nitrogen deposition (WallisdeVries *et al*. 2006) may also be important factors in recent declines.

Recent analyses of distribution data from the UK have shown that butterflies are declining in range more rapidly than either birds or plants in Britain (Thomas *et al*. 2004), emphasising the propensity for butterflies to react more quickly to environmental change than species at higher trophic levels. In contrast, Thomas (2005) has shown that rates of butterfly declines are more comparable to other terrestrial insect groups, although there are examples where this is not the case. Butterflies may respond more rapidly than birds and plants due to their (1) narrow niches, (2) low mobility and (3) their dependence on spatially and temporally dynamically distributed habitats (Thomas *et al*. 2004).

Comparing changes in the grassland butterfly indicator with changes in the farmland bird indicator suggests that butterflies are declining more rapidly than birds at a supranational level (Figure 1b). However, the average trend values between birds and butterflies did not differ significantly. This might be due to the still limited statistical power of butterfly trends (see next section). Also, the bird monitoring data cover a large part of Europe, whereas butterfly data mainly come from the western part of Europe where trends may be more severe than in Eastern Europe. A further point is that the two indicators are not directly comparable. The butterfly indicator chiefly samples butterfly trends on semi-natural grasslands, which are predominant in parts of Central and Eastern Europe but a minority grassland habitat over much of north-west Europe, whilst the bird indictor is more representative of the whole agricultural landscape, including arable land. Future more sensitive comparisons are required to assess whether birds and butterflies have indeed different trends at a supranational level.

Evaluation of using butterfly monitoring data as an EU Biodiversity Indicator

The Grassland Butterfly Indicator demonstrates how butterflies respond quickly to changes in the environment and how butterflies are thus a good 'early warning' indicator of changes in Europe's biodiversity. The Grassland Butterfly Indicator is disaggregated into (habitat) specialist and widespread species. The specialist index is likely to represent a large amount of biodiversity as habitat specialist butterflies are largely restricted to semi-natural habitats (Asher *et al.* 2001), which are among the most species-rich insect/plant habitats in farmland landscapes and are also critically important for rare species (Fry & Londsdale 1991, Thomas 2005). Semi-natural habitats may also be important in maintaining insect diversity in the wider agricultural landscape (Samways 2005, Tscharntke *et al*. 2005, Öckinger & Smith 2007).

Butterflies are relatively easy to recognize and data on butterflies has been collected for many years and by thousands of voluntary observers. The method for monitoring butterflies is well described, extensively tested and scientifically sound (Pollard 1977, Pollard & Yates 1993). Following the method used for European Birds was technically relatively straightforward - though there were more difficulties to overcome in terms of accounting for the different number of visits between schemes.

Apart from these strengths, several weaknesses should be noted that deserves future improvements. The standard errors of trend estimates of butterflies, especially for specialist species, were considerable and larger than for birds, leading to a more fluctuating grassland indicator as compared to the bird indicator. This is caused by the small total number of sampling transects, especially for the rare specialist species, the relatively short time series and the considerable year-to-year fluctuations of species. Low power may limit the opportunity to detect any trend. In practice, however, many trends appeared to be so strong that they were still detectable. The same accounts for the aggregate butterfly indicator.

There are concerns over the extent to which the trends on butterfly monitored sites reflect trends across the whole European grassland landscape, due to sampling bias. In particular, some butterfly schemes over-sample semi-natural grasslands in nature reserves and other protected areas, and under-sample intensive fields and linear grassland habitats in the wider countryside (Table 1). This is a particular problem for reporting on abundance trends of widespread grassland species in North-west Europe, where the majority of the total population is likely to be located in intensively farmed areas of the wider countryside. However, in the UK, studies have shown that abundance trends in widespread species are extremely similar (1) on semi-natural sites compared to the wider countryside and (2) in protected areas compared to non-protected areas (Brereton & Roy 2006), suggesting that this bias may not necessarily strongly influence national trends. In terms of nature reserves, it has been suggested (Buckland *et al.* 2005) that butterfly and other species trends may be biased due to more favourable trends on reserves compared to non-reserve land, as the primary objective of land management on reserves is biodiversity conservation. In the Netherlands, grassland butterflies have declined at the same rate in semi-natural grassland nature reserves compared to non-reserve farmland areas (Figure 2; paired t-test, $p = 0.86$). Studies in the UK that have assessed butterfly trends on reserves have shown that butterflies have performed equally poorly on reserves compared to elsewhere (Thomas 1984, Thomas 1991, Warren 1993, Thomas 1995, McLean *et al*. 1995, Brereton *et al*. 2002, Brereton *et al*. 2007). These results suggest that the suggested bias is not necessarily there.

In the Netherlands, sampling bias (over-sampling of particular habitat types) has been corrected by post-stratification and statistical weighting (Van Swaay *et al.* 2002). However, if the number of monitored sites is low in habitats that comprise a large proportion of the land surface, it can be dubious to attempt such weighting procedures. For common species monitoring, it is advisable to establish a scheme with a more formal survey design (Yoccoz *et al*. 2001, Buckland *et al*. 2005, Legg & Nagy 2006). A number of more recent national butterfly schemes (e.g. in Switzerland and France, and planned in the UK - Roy, Rothery and Brereton 2007) have been designed with a greater emphasis on representative transect selection, based on random sampling, and efficiency savings, with a lower number of visits (table 1).

Finally, the coverage across Europe is still limited. It is important that more monitoring is started in as many countries as possible to improve the representativeness of the indicator for Europe as a whole. There are already encouraging developments in this respect, with for example new schemes proposed for Portugal, Ireland and Slovenia.

Butterflies as biodiversity indicators

Butterflies are the only invertebrate taxon for which it is currently possible to estimate rates of decline among terrestrial insects (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 (Pearson 1995, Hilty & Merenlender 2000, Balmford 2002). The distribution of butterflies has been found to be a good predictor of areas of high biodiversity, species richness and or habitat quality in the majority (though not all) of studies (Beccaloni & Gaston 1995, Brown 1991, Brown & Freitas 2000, Simonson *et al.* 2001, Fleishman *et al.* 2005, Grill *et al*. 2005, Kerr *et al*. 2000, Kremen *et al*. 2003, Thomas & Clarke, 2004, Maes & van Dyck 2005, Maes *et al*. 2005, Ricketts *et al*. 2002).

There is only limited evidence to indicate that changes in butterfly abundance, species-richness and distribution mirror changes in other taxa (Blair, 1999; Swengel & Swengel 1999, Brown & Freitas 2000, Conrad *et al*. 2004, Hickling *et al*. 2006, Thomas & Clarke, 2004, Thomas *et al*. 2004). However these studies are not fully conclusive and may be dependent on the taxa and the spatial scales considered (Ricketts *et al.* 2002). A particular problem is a lack of available data on trends in the abundance of other insects for comparison. In the UK, the best available long-term dataset is for moths, through the Rothamsted Insect Survey (Woiwood & Hartington 1994, Conrad *et al*. 2004,

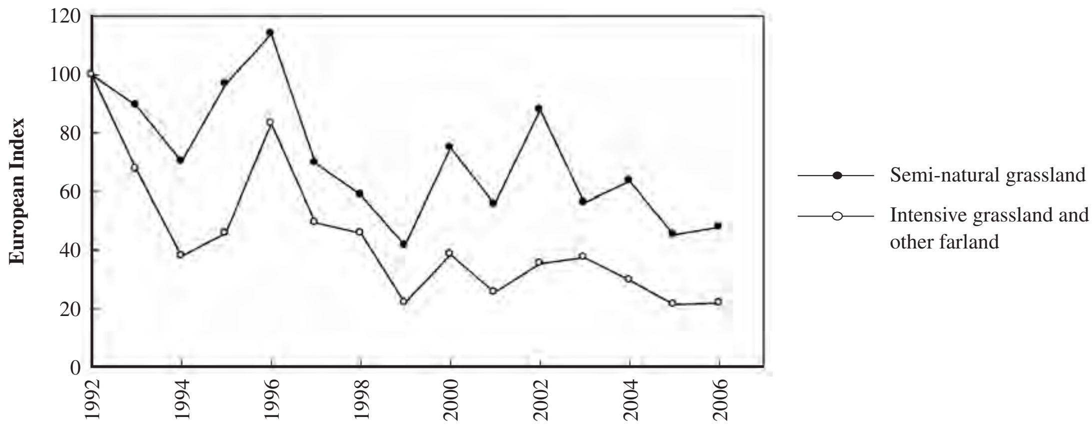

Figure 2. Trends in grassland indicators 1992-2007 in semi-natural areas in nature reserves and in farmland areas in the Netherlands. The indicators are based on 15 grassland species. Data are from the Dutch butterfly monitoring scheme. For details see www.natuurcompendium.nl

Conrad *et al*. 2006). Although the figures are not directly compatible because of the differing estimation methods, the decline in the composite measure for moth abundance (total catch of n = 337 species) is significantly negatively correlated with the composite measure for butterfly abundance (the UK Butterfly Indicator of n = 52 species) (r = 0.54, P = 0.03, N = 27 years, 1976-2002).

Based on a comprehensive review of studies into their life-history traits, biology, relative sensitivity to climate change and adjusted extinction rates, recent reviews (Ehrlich 1994, Ehrlich 2001, Thomas 2005) have concluded that butterflies may be considered reasonable, albeit imperfect representative indicators of trends observed in the majority of other terrestrial insects (excluding for example invertebrate groups that are predominantly predators and parasitoids). We therefore believe they have a valuable role to play in understanding trends in this crucial part of biodiversity and that the greater risk is to exclude an insect indicator altogether. We suggest adoption of butterflies in the EU Headline suite would complement the European Bird Indicator by providing a more appropriate representation for insects and for species-rich semi-natural habitat fragments.

Next stages

Currently (April 2007) butterflies along with birds have been put forward as one of the 26 indicators in the first 2010 target headline set. In addition to a grassland butterfly indicator, it is proposed to develop also a butterfly indicator for woodlands. This will enable trends in European butterflies to be disaggregated by woodlands and grassland habitats. European butterfly monitoring data may also play a crucial role in assessing: (1) future climate change impacts (2) whether protected areas (e.g. Natura 2000 sites) are being managed appropriately to maintain the full complement of species with differing fine-scale habitat requirements, and (3) whether efforts to mitigate against the effects of habitat fragmentation are successful.

Acknowledgements – We would like to thank partners in BC Europe and the co-ordinators of European Butterfly Monitoring Schemes who supplied data including David Roy, Sergey Popov, Patrick Leopold, Josef Settele, Dirk Maes, Constanti Stefanescu, Petra Ramseier, Mikko Kuussaari, Dominique Langlois and Tim Pavlicek. Adriaan Gmelig Meyling helped with statistical aspects in producing the final European Grassland Butterfly Indicator. Petr Voříšek supplied bird data from the PECBMS. The European Environment Agency helped provide funding to develop the European Butterfly indicator. Tom Brereton's attendance at the EBCC conference was funded through the UKBMS project that is sponsored by Defra and a consortium of other UK government agencies. The Ministry of Agriculture, Nature and Food quality of the Netherlands and the Dutch National Data Authority for Nature financially supported the Dutch Butterfly Monitoring Scheme. Finally, we would like to thank David Roy and Ian Middlebrook for commenting on an earlier version of this manuscript.

REFERENCES

Asher J, Warren MS, Fox R, Harding P, Jeffcoate G, Jeffcoate S 2001. The Millennium Atlas of Butterflies in Britain and Ireland. Oxford University Press, Oxford.

Balmford A 2002. Selecting sites for conservation. In: Norris K, Pain DJ (eds). Conserving bird biodiversity: general principles and their application. Cambridge University Press, Cambridge, pp. 74-104.

Beccaloni GW, Gaston KJ 1995. Predicting species richness of Neotropical forest butterflies: Ithominae (Lepidoptera: Nymphalidae) as indicators. Biological Indicators 71: 77-86.

Blair RB 1999. Birds and butterflies along an urban gradient: surrogate taxa for assessing biodiversity. Ecological Applications 9: 164-170.

Brereton TM, Warren MS, Stewart K 2002. BD1427: Developing a system for assessing the effect of agri-environment schemes on butterfly populations. Butterfly Conservation Final Project Report, supplied to DEFRA.

Brereton TM, Roy DBR 2006. Technical Annexe: Butterfly Indicators Supporting Information. Butterfly Conservation, Dorset.

Brereton TM, Warren MS, Roy DBR, Stewart 2007. The changing status of the Chalkhill Blue butterfly *Polyommatus coridon* in the UK: the impacts of conservation policies and environmental factors. Journal of Insect Conservation, pubished online July 2007.

Brown KS 1991. Conservation of neotropical environments: insects as indicators. In: Collins NM, Thomas JA (eds) The conservation of insects and their habitats. Academic Press, London, pp. 350-404.

Brown KS, Freitas AVL 2000. Atlantic forest butterflies: indicators for landscape conservation. Biotropica 32: 934-956.

Buckland ST, Magurran AE, Green RE, Fewster RM 2005. Monitoring change in biodiversity through composite indices. Philosophical Transactions of the Royal Society, B 360: 243-254.

Conrad KF, Woiwod IP, Parsons M, Fox R , Warren MS 2004. Long-term population trends in widespread British moths. Journal of Insect Conservation 8: 119-136.

Conrad KF, Warren MS, Fox R, Parsons MS, Woiwod IP 2006. Rapid declines of common, widespread British moths provide evidence of an insect biodiversity crisis. Biological Conservation 132: 279-291.

Davies H, Brereton T, Roy DBR, Fox R 2007. Government targets for protected area management: will threatened butterflies benefit? Biodiversity and Conservation 16 (13): 3719-3736.

De Heer M, Kapos V, Ten Brink BJE 2005. Biodiversity trends in Europe: development and testing of a species trend indicator for evaluating progress towards the 2010 target. Philosophical Transactions of the Royal Society, B 360: 297-308.

Department for Environment, Food and Rural Affairs 2006. Working with the Grain of Nature-taking it Forward. Volume II. Measuring Progress on the England Biodiversity Strategy: 2006 Assessment. Defra, London.

Donald PF, Green RE, Heath MF 2001. Agricultural intensification and the collapse of Europe's farmland bird populations. Proceedings of the Royal Society of London, B 268: 25-29.

Ehrlich PR 1994. Energy use and biodiversity loss. Philosophical Transactions of the Royal Society, B 344: 99-104.

Ehrlich PR 2001. Tropical butterflies: A key model group that can be "completed". Lepidoptera News 2: 1, 10-12.

Ehrlich PR 2003. Introduction: Butterflies, test systems, and biodiversity. In: Boggs L. Watt WB, Ehrlich PR (eds). Butterflies: Ecology and Evolution Taking Flight. University of Chicago Press, Chicago, pp 1-6.

European Environment Agency 2007. Halting the loss of biodiversity by 2010: proposal for a first set of indicators to monitor progress in Europe. European Environment Agency, Copenhagen.

Fleishman E, Thomson JR, MacNally R, Murphy DD, Fay JP 2005. Using indicator species to predict richness of multiple taxonomic groups. Conservation Biology 19: 1125-1137.

Flowerdew JR 1997. Mammal biodiversity in agricultural habitats. In: Kirkwood, RC (ed). Biodiversity and Conservation in Agriculture. British Crop Protection Council, Hampshire, pp. 25-40.

Franco AMA, Hill JK, Kitschke C, Collingham YC, Roy DB, Fox R, Huntley B, Thomas CD 2006. Impacts of climate warming and habitat loss on extinctions at species low-latitude range boundaries. Global Change Biology 12: 1545-1553.

Fry R, Lonsdale D 1991. Habitat Conservation for Insects - a Neglected Green Issue. Amateur Entomological Society, London.

Gregory RD, Van Strien AJ, Vorisek P, Gmelig Meyling, AW, Noble DG, Foppen RPB, Gibbons DW 2005. Developing indicators for European birds. Philosophical Transactions of the Royal Society, B 360: 269-288.

Gregory RD, Vorisek P, Noble DG, Van Strien AJ, Klvanova A, Eaton M, Gmelig Meyling AW, Joys A, Foppen RPB, Burfield IJ 2007. The generation and use of bird population indicators in Europe. Bird Conservation International 18: 223-244.

Grill A, Knoflach B, Cleary DFR, Kati V 2005. Butterfly, spider, and plant communities in different land-use types in Sardinia, Italy. Biodiversity and Conservation 14: 1281-1300.

Hanski I, 2003. Biology of extinctions in butterfly metapopulations. In: Boggs L. Watt WB, Ehrlich PR (eds). Butterflies: Ecology and Evolution Taking Flight. University of Chicago Press, Chicago, pp. 577-602.

Hickling R, Roy DB, Hill JK, Fox R, Thomas CD 2006. The distributions of a wide range of taxonomic groups are expanding polewards. Global Change Biology 12: 450-455.

Hilty J, Merenlender A 2000. Faunal indicator taxa selection for monitoring ecosystem health. Biological Conservation 92: 185-197.

Kerr JT, Sugar A, Packer L 2000. Indicator taxa, rapid biodiversity assessment, and nestedness in an endangered ecosystem. Conservation Biology 14: 1726-1734.

Konvicka M, Cizek O, Filipova L, Fric Z, Benes J, Krupka M, Zamecnik J, Dockalova Z 2005. For whom the bells toll: demography of the last population of the butterfly *Euphydryas maturna* in the Czech Republic. Biologia 60:551-557.

Kremen C, Lees DC, Fay JP 2003. Butterflies and conservation planning in Madagascar: from pattern to practice. In: Boggs L. Watt WB, Ehrlich PR (eds). Butterflies: Ecology and Evolution Taking Flight. University of Chicago Press, Chicago, pp. 517-540.

Legg CJ, Nagy L 2006. Why most conservation monitoring is, but need not be, a waste of time. Journal of Environmental Management 78: 194-199.

Maes D, Van Dyck H 2005. Habitat quality and biodiversity indicator performances of a threatened butterfly versus a multispecies group for wet heathlands in Belgium. Biological Conservation 123: 177-187.

Maes D, Bauwens D, de Bruyn L, Anselin A, Vermeersch G, van Landuyt W, de Knijf G, Gilbert M 2005. Species richness coincidence: conservation strategies based on predictive modelling. Biodiversity and Conservation 14: 1345-1364.

McLean IFG, Fowles AP, Kerr AJ, Young MR, Yates TJ 1995. Butterflies on Nature Reserves in Britain. In: Pullin AS (ed). Ecology and conservation of butterflies. Chapman and Hall in association with Butterfly Conservation, London, UK, pp 67-83.

Öckinger E, Smith HG 2007. Asymmetric dispersal and survival indicate population sources for grassland butterflies in agricultural landscapes. Ecography 30: 288-298.

Oostermeijer JGB, van Swaay CAM 1998. The relationship between butterflies and environmental indicator values: a tool for conservation in a changing landscape. Biological Conservation 86: 271-280.

Pannekoek J, Van Strien AJ 2003. TRIM 3 manual. Trends and Indices for Monitoring data. CBS, Statistics Netherlands, Voorburg.

Pearson DL 1995. Selecting indicator taxa for the quantitative assessment of biodiversity. Philosophical Transactions of the Royal Society London, B 345: 75-79.

Pollard E 1977. A method for assessing changes in the abundance of butterflies. Biological Conservation 12:, 115-134.

Pollard E, Yates TJ 1995. Monitoring butterflies for ecology and conservation. Chapman and Hall, London.

Ricketts TH, Daily GC, Ehrlich PR 2002. Does butterfly diversity predict moth diversity? Testing a popular indicator taxon at local scales. Biological Conservation 103: 361-370.

Robinson RA, Sutherland WJ 2002. Post-war changes in arable farming and biodiversity in Great Britain. Journal of Applied Ecology 39: 157-76.

Roy DB, Rothery P, Brereton T 2007. Reduced-effort schemes for monitoring butterfly populations. Journal of Applied Ecology 44: 993-1000.

Samways MJ 2005. Insect Diversity Conservation. Cambridge University Press, Cambridge.

Tscharntke TA, Klein AM, Kruess A, Steffan-Dewenter I, Thies C 2005. Landscape perspectives on agricultural intensification and biodiversity-ecosystem service management. Ecology Letters 8:857-874.

Swengel SR, Swengel AB 1999. Correlations in abundance of grassland songbirds and prairie butterflies. Biological Conservation 90: 1-11.

Thomas CD 1995. Ecology and conservation of butterfly metapopulations in the fragmented British landscape. In: Pullin AS (ed). The ecology and conservation of butterflies. Chapman & Hall, London, pp. 46-63.

Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC,

Erasmus BFN, Ferreira de Siqueira M, Grainger A, Hannah L, Hughes L, Huntley B, van Jaarsveld AS, Midgley GF, Miles L, Ortega-Huerta MA, Peterson AT, Phillips OL, Williams SE 2004. Extinction risk from climate change. Nature 427: 145-148.

Thomas JA 1984. The conservation of butterflies in temperate countries: past efforts and lessons for the future. In: Vane-Wright RI, Ackery PR (eds). The Biology of Butterflies Symposium 11 of the Royal Entomological Society. Academic Press, London, pp. 333-353.

Thomas JA 1991. Rare species conservation: case studies of European butterflies. In: Spellerberg IF, Goldsmith FB, Morris MG (eds). The Scientific Management of Temperate Communities for Conservation. Blackwell's Scientific, Oxford,149-197.

Thomas JA 1995. The ecology and conservation of *Maculinea arion* and other European species of large blue butterfly. In: Pullin AS (ed). The ecology and conservation of butterflies. Chapman & Hall, London, pp. 180-197.

Thomas JA 2005. Monitoring change in the abundance and distribution of insects using butterflies and other indicator groups. Philosophical Transactions of the Royal Society, B 360: 339-357.

Thomas JA, Clarke RT 2004. Extinction rates and butterflies. Science 305: 1563-1564.

Thomas JA, Telfer MG, Roy DB, Preston CD, Greenwood JJD, Asher J, Fox R, Clarke RT, Lawton JH 2004. Comparative losses of British Butterflies, Birds, and Plants and the Global Extinction Crisis. Science 303: 1879-1881.

Van Strien AJ, Pannekoek J, Gibbons DW 2001. Indexing European bird population trends using results of national monitoring schemes: a trial of a new method. Bird Study 48: 200-213.

Van Swaay CAM, Warren MS 1999. Red Data Book of European Butterflies (Rhopalocera). Nature and Environment series, No. 99. Council of Europe, Strasbourg.

Van Swaay CAM, Plate, CL, 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 CAM, Van Strien AJ 2005. Using butterfly monitoring data to develop a European grassland butterfly indicator. In: Kuehn E, Thomas J, Feldmann R, Settele J (eds). Studies on the Ecology and Conservation of Butterflies in Europe. Vol 1: general concepts and case studies. Proceedings of the Conference held in UFZ Leipzig, 5-9th of December, 2005. Pensoft, SoWa, pp. 106-108.

Van Swaay CAM, Warren MS, Loïs G 2006. Biotope use and trends of European butterflies. Journal of Insect Conservation 10: 189-209.

WallisDeVries MF, Poschlod P, Willems JH 2002. Challenges for the conservation of calcareous grasslands in Northwestern Europe: integrating the requirements of flora and fauna. Biological Conservation 104: 265-273.

WallisDeVries MF, Van Swaay CAM 2006. Global warming and excess nitrogen may induce butterly decline by microclimatic cooling. Global Change Biology 12(9):1620-1626.

Warren, MS 1993. A review of butterfly conservation in central southern Britain: I. Protection, evaluation and extinction on prime sites. Biological Conservation 64: 25-35.

Woiwod IP, Harrington R 1994. Flying in the face of change: The Rothamsted Insect Survey. In: Leigh RA, Johnson AE (eds). Long-Term Experiments in Agricultural and Ecological Sciences. CAB International, Wallingford, pp. 321-342.

Yoccoz NG, Nichols JD, Boulinier T 2001. Monitoring of biological diversity in space and time. Trends in Ecology and Evolution 16: 446-453.

Angela Maria Russo

Alessandro Sacchetti