European Grassland Butterfly Indicator 1990-2020

Technical report

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Contents

Chapter 1 / Introduction

There is mounting evidence of widespread declines in the diversity and abundance of insects across the globe (Sánchez-Bayo and Wyckhuys 2019, Seibold *et al*. 2019, van Klink *et al*. 2020, Wagner 2020). This gives a stark warning of the precarious state of biodiversity, and demonstrates that addressing the gap in knowledge of the status of insects is vital (Cardoso et al. 2020, Samways et al. 2020). Insects are estimated to comprise more than half of all described species and are a dominant component of biodiversity in most ecosystems (Bar-On *et al*. 2018). Insects also provide a crucial role in the functioning of ecosystems. They are not only related to the supply of many ecosystem services such as pollination, biological control, soil fertility regulation and diverse cultural ecosystem services but also to disservices such as damage to crops and spread of diseases to livestock and humans (Gutierrez-Arellano and Mulligan 2018, Noriega *et al*. 2018). There is a pressing need to assess the status of insects to set and evaluate conservation targets.

At the Convention on Biological Diversity (CBD) meeting in Nagoya (Japan), the Strategic Plan for Biodiversity 2011–2020 was adopted. It proposed five goals and 20 "Aichi" biodiversity targets. In line with this plan, a new EU biodiversity strategy was adopted by the European Commission in May 2011. This strategy provided a framework for the EU to meet its biodiversity targets and global commitments as a party to the CBD. The Headline Target in the existing EU Biodiversity Strategy 2020 is to halt the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, and restore them, in so far as feasible, while stepping up the EU contribution to averting global biodiversity loss. Under Target 3A the EU is committed to increasing the contribution of agriculture to biodiversity recovery. Further, the EU Biodiversity Strategy 2030 includes the development of a coherent framework for monitoring, assessing and reporting on progress in implementing actions. Such a framework is needed to link existing biodiversity data and knowledge systems with the strategy, to help assess achievement of the goals and to streamline EU and global monitoring, reporting and review obligations.

Some of the EU biodiversity indicators provide specific measurements and trends on genetic, species and ecosystem/landscape diversity, but many have a more indirect link to biodiversity. Very few have been explicitly established to assess biodiversity. The status indicators on species only cover birds, bats and butterflies, since these are the only taxa/species groups for which reasonably harmonized European monitoring data are available (EEA, 2012). This technical report builds upon previous technical reports for the EU Grassland Butterfly Indicator (e.g., van Swaay *et al.* 2019).

Butterflies are ideal biological indicators: they are well-documented, measurable, sensitive to environmental change, occur in a wide range of habitat types, represent many other insects, and are popular with the public because of their beauty. Field monitoring is essential to assess changes in their abundance. Indicators based on butterfly monitoring data are valuable to understand the state of the environment and help evaluate policy and implementation. Trained volunteers are a cost-effective way of gathering robust data on butterflies, more so when supported by informative materials and efficient online recording.

Chapter 2 / Butterfly Monitoring in Europe

Butterfly monitoring enjoys a growing popularity in Europe, mainly supported by Butterfly Conservation Europe (BCE) and its partners. While Butterfly Monitoring Schemes are present in a growing number of countries and new ones are being initiated in many places, long time-series are currently only available for a limited number of countries. For the indicators in this report, we used data from 22 countries (Figure 1): Andorra, Austria, Belgium, Czech Republic, Estonia, Finland, France, Germany, Hungary, Ireland, Jersey, Latvia, Lithuania, Luxembourg, Norway, Romania, Slovenia, Spain, Sweden, Switzerland, The Netherlands and the United Kingdom.

The indicators use field data up to and including the 2020 field season. The method for calculating indicators has been greatly improved and enhanced. During 2020, more than 2,500 standardised butterfly transects distributed across 22 monitoring schemes were used to inform the EU27 Grassland Butterfly Indicator and almost 5,000 from 25 schemes for the European Grassland Butterfly Indicator (Figure 2). Since 1990 over 6,350 and 11,500 separate transects have contributed to the EU27 and Europe indicators, respectively.

Europe's semi-natural grasslands contain a wealth of butterfly species and numbers.

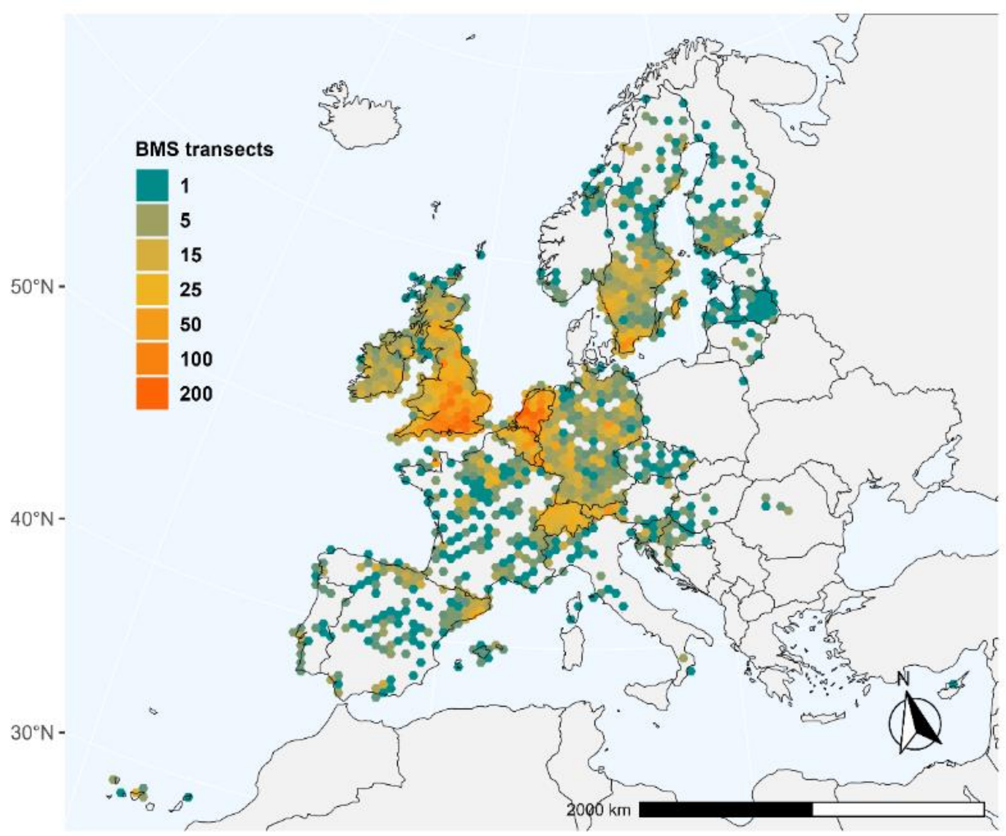


Figure 1: The density of Butterfly Monitoring transects visited per 50 km grid across all schemes that have contributed to the eBMS database. Densities are calculated from sites that have been visited at least once since 1990.

Schemes contributing to the European Indicators up to 2020 (schemes in the EU27 are marked with [EU27])	***Other active schemes (data not yet included within indicators)***
Andorra: since 2004 *Austria (Tirol) [EU27]: since 2018* *Belgium (Flanders) [EU27]: since 1991* *Belgium (Wallonie) [EU27]: since 2010* *Czech Republic [EU27]: since 2010* *Estonia [EU27]: since 2004* *Finland [EU27]: since 1999* *France [EU27]: since 2005* *Germany [EU27]: since 2005* *Hungary [EU27]: since 2016* *Ireland [EU27]: since 2007* *Italy [EU27]: since 2016* *Jersey: since 2004* *Latvia [EU27]: since 2015* *Lithuania [EU27]: since 2009* *Luxembourg [EU27]: since 2010* *Netherlands [EU27]: since 1990* *Norway: since 2009* *Romania [EU27]: since 2013* *Spain (Catalonia) [EU27]: since 1994,* *Spain (Basque Country) [EU27]: since 2010* *Spain (other regions) [EU27]: since 2014* *Slovenia [EU27]: since 2007* *Sweden [EU27]: since 2009* *Switzerland: since 2003* *United Kingdom: since 1976*	*Armenia: since 2003* *Austria (other regions) [EU27]: since 2020* *Cyprus Island [EU27]: since 2019* *Israel: since 2009* *Portugal [EU27]: since 2019* *Russia (Bryansk region): since 2013* *Ukraine (Transcarpathia): since 1974* *Malta [EU27]: since 2020* *Bulgaria [EU27]: since 2020* *Poland [EU27]: since 2020* *Croatia [EU27]: since 2020*

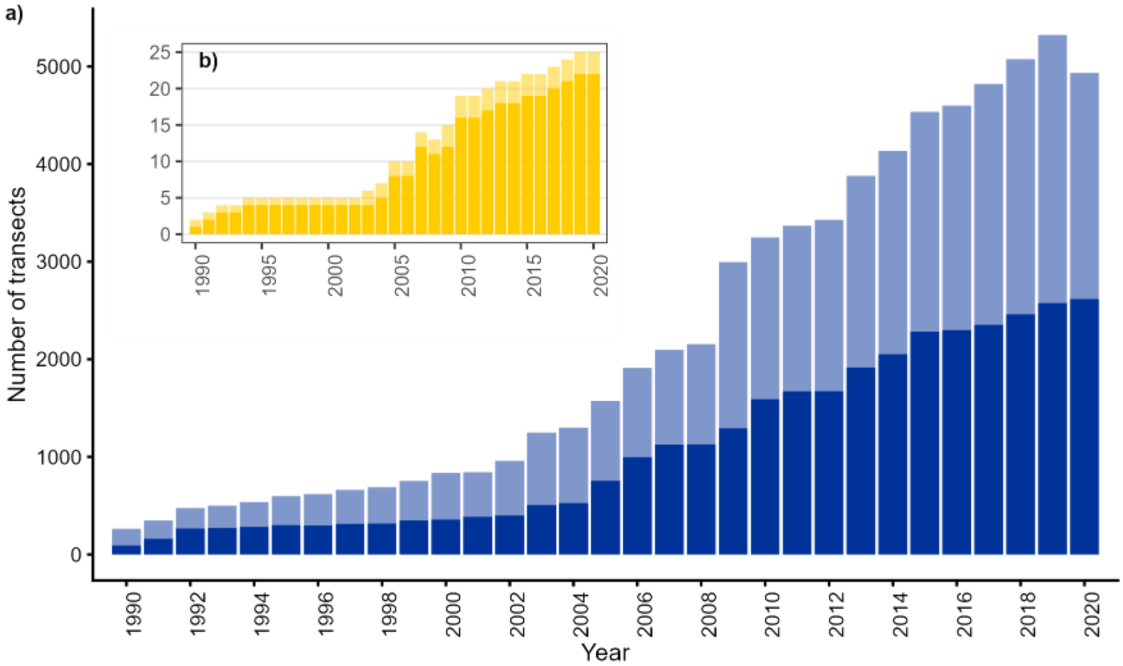


Figure 2: a) Number of transects that contributed to the Grassland Butterfly Indicator in Europe (pale blue) and EU27 (dark blue); b) number of Butterfly Monitoring Schemes (BMS) that contributed to the Grassland Butterfly Indicator in Europe (pale yellow) and EU27 (dark yellow). Only transects that have at least one record for at least one of the 17 selected species are included in the Grassland Butterfly Indicator.

Chapter 3 / From butterfly counts to indicators

Introduction

Butterflies can be found all over Europe and are one of the best-known groups of insects. Although popular, until recently little was known about their density and trends. In this chapter we will illustrate how counts are made and how they can be used to detect trends and to build indicators.

Fieldwork

Recording butterflies on a transect.

The butterfly indicators are based on the fieldwork of thousands of trained professional and volunteer recorders, counting butterflies on more than 10,000 transects scattered widely across Europe, with almost 5,000 visited in 2020. These counts are made under standardised conditions, providing high-quality data that are suitable to assess species status and trends. National co-ordinators collect the data and perform the first quality control.

All schemes apply the method initially developed for the UK Butterfly Monitoring Scheme (Pollard & Yates, 1993). The counts are conducted along fixed transects of 0.5 to 3 kilometres in length, divided into smaller sections for recording. The fieldworkers record all butterflies that are observed 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*. 2008). Butterfly counts are conducted between March-April to September-October, depending on the region. In some places (e.g., Andalucia, Canary Islands) there are places where monitoring takes place all year round, sometimes stopping in July-August during the hot and dry summer. Visits are only conducted when weather conditions meet specific criteria. The recommended number of visits varies from every week, e.g., in the UK, Catalonia and the Netherlands, to 3-5 visits annually in France. Austria and Switzerland BMS use a stratified sampling design with a subset of transects monitored every year. This protocol enables to maintain high frequency monitoring in areas where access present specific challenges (alpine sites). In this protocol, all sites are monitored at least once every four years.

European Butterfly Monitoring Scheme database

The European Butterfly Monitoring Scheme (eBMS) database collates standardised butterfly counts recorded along Pollard walks repeated in time (since 1976 in the UK). Since 1990, volunteers and professionals have recorded more than 5.5 million butterfly count events documented at the species level in the eBMS database. These counts have been recorded over more than 991,000 monitoring events (e.g., BMS transect visits). In terms of sampling effort, these visits took place in over 12,000 transects (Figure 1), distributed across 25 monitoring schemes and 23 countries (Figure 2b), with nearly 7,000 monitoring sites located in EU27 Member States.

The eBMS database is updated on an annual cycle, each update being released as a major version (e.g., v4.0), with subsequent corrections, additions and bug fix being identified and released as minor version updates (e.g., v4.2). Source data files are sent by national Butterfly Monitoring Schemes and processed programmatically to ensure adequate standardisation and formatting of the data before being integrated into the eBMS database.

Transect selection

To be able to draw proper inferences on the temporal population trends at the national or regional level, transects should ideally best be selected in a grid, random or stratified random manner (Sutherland, 2006). Several recent schemes, e.g., in Switzerland, France and in parts of Austria, have been designed in this manner (Henry *et al*. 2008). If a scheme aims to monitor rare species, scheme co-ordinators preferentially locate transects in areas where rare species occur, leading to an over-representation of special and protected areas. In most schemes transects were selected by free choice of observers, which in some cases has led to the overrepresentation of protected sites in natural areas and the under-sampling of the wider countryside and urban areas (Pollard & Yates, 1993). However, this is not the case in all countries (e.g., Germany, Kühn *et al.* 2008).

Lysandra bellargus is one of the 'Blues' listed on the species list of the European Grassland Butterfly Indicator.

Calculating population trends

Population trends can be calculated at different levels by combining observations at the site level, the monitoring scheme level or across schemes in each region. For the European Grassland Butterfly Indicator and the EU27 Member States Grassland Butterfly Indicator, we combined the abundance indices calculated at the site level to produce scheme-level indices, which we then combined to produce European and EU27 population trends for each species.

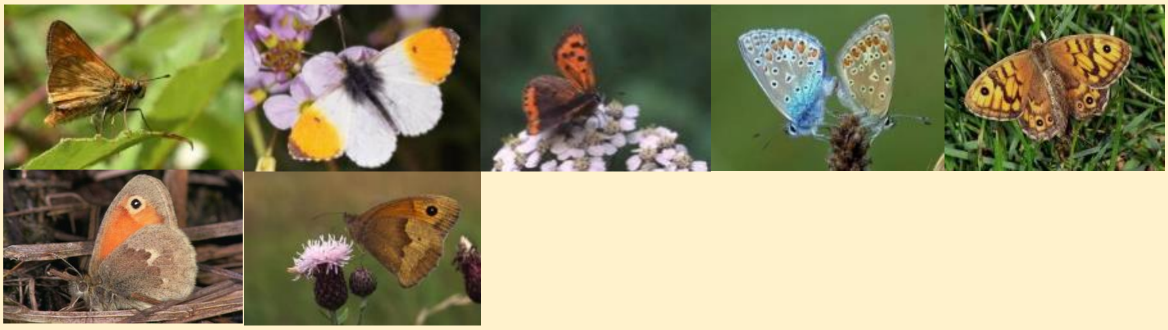
In a first step, we calculated annual abundance indices for each species at the site level. For each species and year, we estimated flight periods (Dennis *et al.* 2016) based on counts recorded, daily accumulated growing degree days (GDD) and latitude of each monitoring site. We estimated species annual flight curves using generalised additive models (GAM) fitted independently for seven major geographical units (i.e., United Kingdom and Republic of Ireland, Mediterranean, Continental West, Continental East, Alps, Northern Baltic, and Eastern Baltic). Using the local annual flight curves, we imputed the expected values for each missing weekly count to calculate standardised annual abundance indices at the site level. These abundance indices are species-specific and estimate the total annual adult butterfly density expected along a 1 km transect at a given site. Estimates of transect density were only calculated on transects with at least 3 years of monitoring history.

For each species and monitoring scheme (BMS), local densities were then integrated into an annual summary index that represents an estimate of the total number of adult butterflies expected along a 1 km transect in each BMS. Such annual collated species abundance indices were calculated for each species and year where at least three transect estimates were available. We calculated these collated indices at the BMS level by fitting a generalised linear Poisson model (GLM) with site and year effects and using the proportion of the flight period covered as a weighting factor. The inclusion of such weighting allows us to reduce the influence of site indices derived from fewer visits which are potentially more biased. To exclude unreliable estimates derived from counts for only a minimal number of years and sites, multiple filters (see details in Annexe I) were applied. For each BMS, the time series of species collated indices were then transformed to the log10 scale and standardised to a value of 2 for the first year (Figure 1).

To combine species trends across multiple schemes (BMSs), we combined the annual collated indices by calculating the weighted geometric mean of the exponentiated index, where the first year is set to 100 (i.e., $10^2 = 100$, where 2 is the standardised pooled index for the reference year). For each year, the geometric mean was weighted by the area of the species' range sampled in each BMS and included in the mean for a given year. Starting from a standardised value of 100 in the first year, the indices of BMS included in the dataset after that year were set to the value of the weighted geometric mean of the year in which they entered the dataset. This approach allows new schemes to contribute to the compiled index without affecting the index of their entry year and the trend of previous years. If a BMS has some missing years after it has started contributing to the collated index, the missing values are replaced and kept constant with the last non-missing value. In this way, missing values are informed by their own scheme and only for the years following their first contribution. For more details on the methods used to calculate population trends, see Annexe I.

Producing European and EU27 Grassland Butterfly Indicators

The Grassland Butterfly Indicator is the combined population trend of 17 selected grassland species monitored across Europe (Figure 3). The indicator can be calculated from population trends estimated for the whole European region or restricted to the 27 EU Member States. Species' trends are combined by calculating the geometric mean of the species' collated annual indices described above. Following the same approach that we used to combine species-specific population indices across monitoring schemes (BMS) and accounting for species that start late in the time series, we set the first year (1990) as the base year and gave each species the same weighting. By averaging the relative rather than absolute abundance indices of species and giving each species equal weight in the resulting indicators, this indicator provides a consistent measure of biodiversity like the bird indicators described by Gregory *et al.* (2005). If positive and negative changes in the indices balance each other out, we assume that their mean value remains stable. On the other hand, if more species decrease than increase, the mean should decrease and vice versa. The trend in the geometric mean is therefore considered a measure of biodiversity change. For more details on the indicator method used, see Annexe I.



Widespread species: *Ochlodes sylvanus, Anthocharis cardamines, Lycaena phlaeas, Polyommatus icarus, Lasiommata megera, Coenonympha pamphilus and Maniola jurtina*

Specialist species: *Erynnis tages, Thymelicus acteon, Spialia sertorius, Cupido minimus, Phengaris arion, Phengaris nausithous, Polyommatus bellargus, Cyaniris semiargus, Polyommatus coridon and Euphydryas aurinia*

Figure 3: Seventeen butterflies were used to build the European Grassland Butterfly Indicator, comprising seven widespread and ten specialist species.

Chapter 3 / Grassland Butterfly Trends

Introduction

The European Grassland Butterfly Indicator is built from European species trends. In this chapter, we give an overview of the trends of grassland butterflies in the EU27 and Europe. These trends are calculated for each of the 17 species by a weighted combination of all trends by Butterfly Monitoring Scheme (BMS).

Species trends in EU27

From the 17 indicator species, one shows a significant moderate increase (the Orange Tip, *Anthocharis cardamines*), three are stable, five show a significant moderate decline and for six species no significant trend could be established in the participating EU27 countries (Figure 4). For two species (*Phengaris arion* and *P. nausithous*) there was not enough data to calculate a trend.

Numbers of the Orange Tip* (Anthocharis cardamines) *are increasing in the EU27.

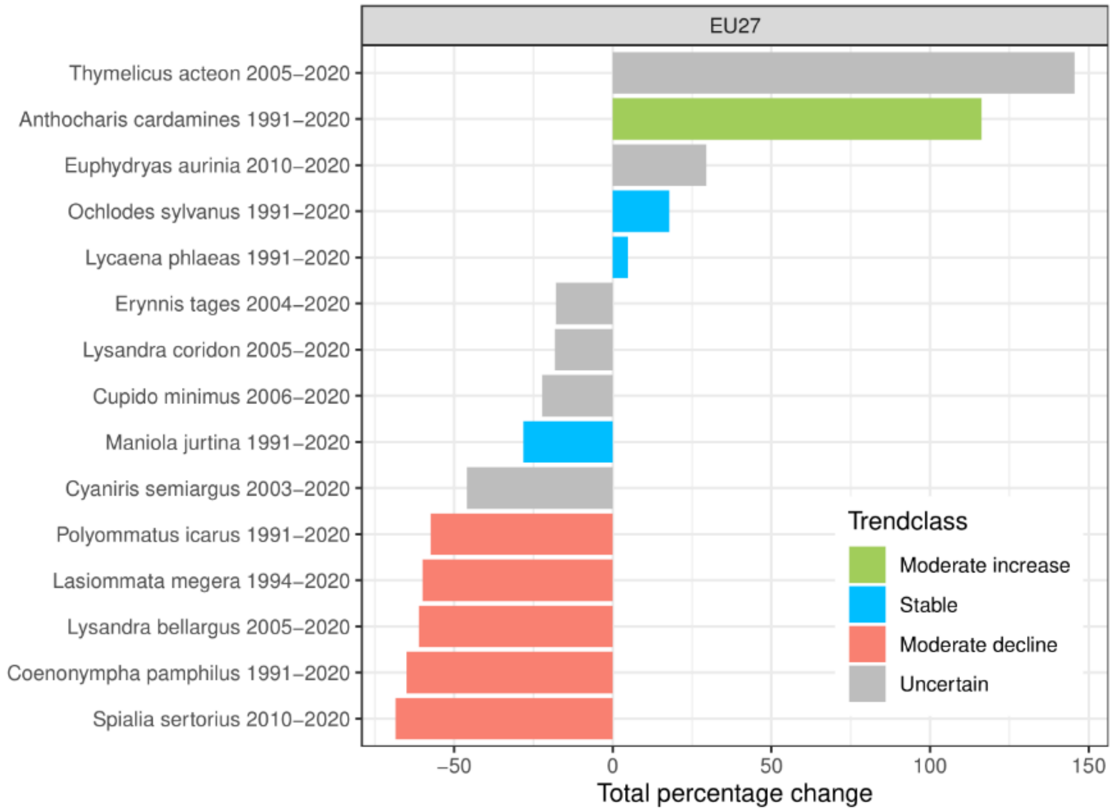


Figure 4: Total percentage change of the 15 species of the Grassland Butterfly Indicator in the EU27. Note that the time period for the trend varies among species due to variation in data quantity.

Species trends in Europe

From the 17 indicator species, three are stable, six show a significant moderate decline, one a significant strong decline (Large Blue, *Phengaris arion*) and for six species no significant trend could be established in the participating European countries (Figure 5). For one species (*Phengaris nausithous*) there was not enough data to calculate a trend.

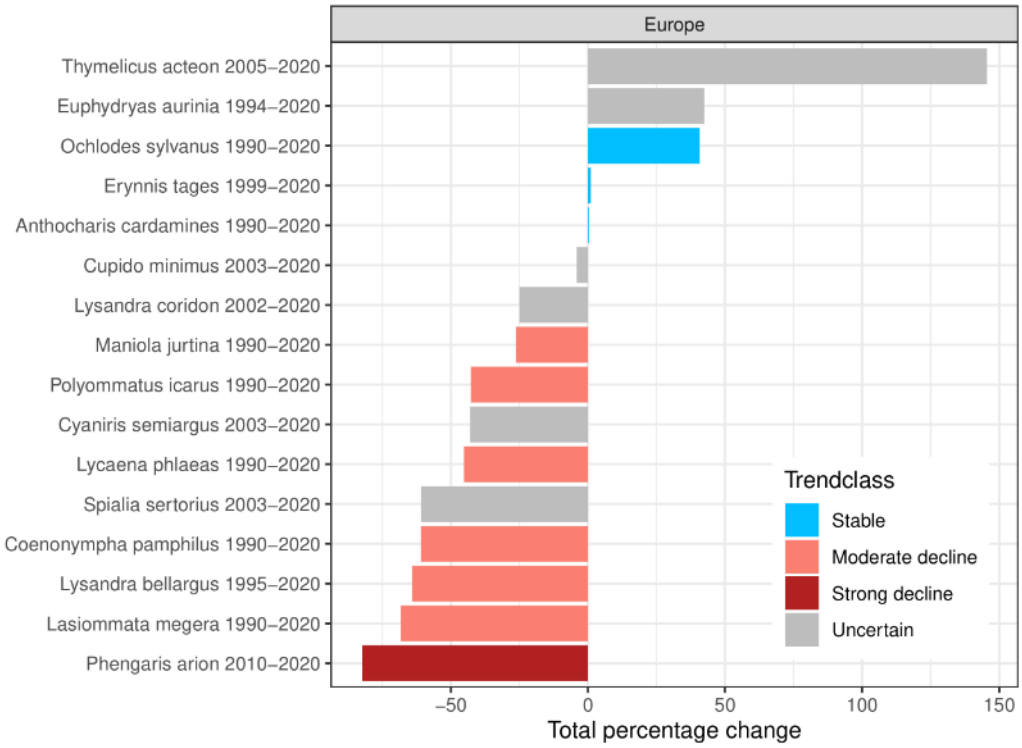
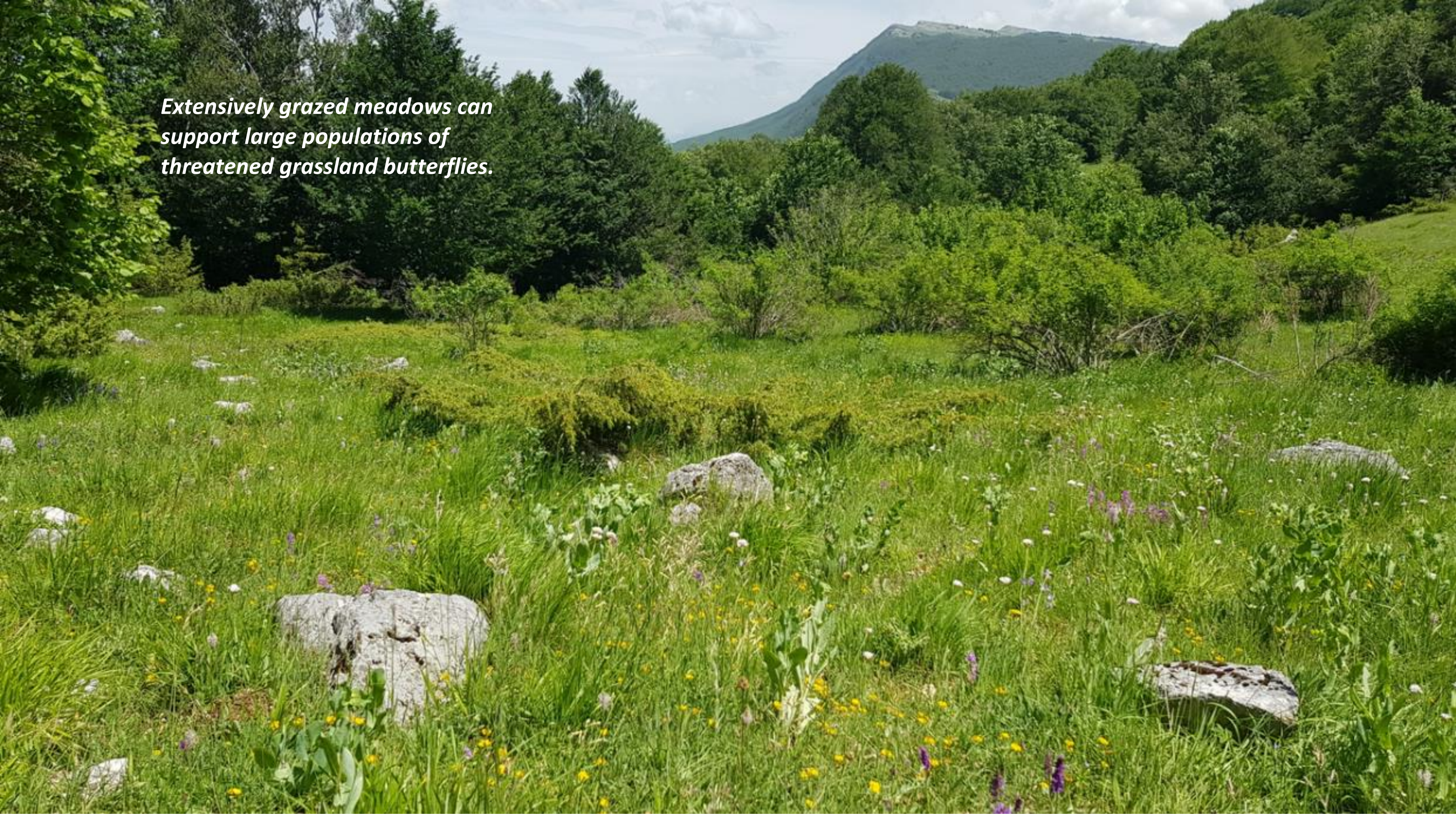


Figure 5: Total percentage change of the 16 species of the Grassland Butterfly Indicator in Europe. For Euphydryas aurinia there is a non-significant (uncertain) positive change of 2395%. Note that the time period for the trend varies among species due to variation in data quantity.

Numbers of the Common Blue (**Polyommatus icarus**) show a decline in Europe.



Extensively grazed meadows can support large populations of threatened grassland butterflies.

When interpreting the species trends, it is important to realise that:

- The coverage of the species' populations and thus the representativeness of the data is lower at the beginning of the time series (see also figure 1). As more countries join in later, the indices improve in accuracy each year.
- Large year-to-year fluctuations or a low number of transects, can cause large confidence intervals, leading to uncertain trends.
- Because of the filters we had to apply (see Annexe I) there was not enough data for some species, notably in the EU27, as important countries with a strong butterfly monitoring scheme, such as Switzerland and the United Kingdom had to be excluded.
- Not all EU27 member states have a Butterfly Monitoring Scheme. The trends shown only represent the countries in map 1, which means they are based on a wide range of countries, including the larger ones such as France, Germany and Spain. However, extra data from the countries in the eastern part of the EU27 would make the results more representative. Although this expansion is foreseen in the SPRING project, it will take some years before enough data become available and contribute to the indicators.
- Apart from the schemes included in the EU27 indicator, the European trend is determined by the data collected in the United Kingdom, Norway, Andorra and Switzerland. For many species, these non-EU27 countries in the analysis represent only a minor part (sometimes less than 10%) of the distribution as compared to the EU27 countries. This means that the European trends in this report are dominated by the trend in the EU27. However for some species (e.g. the Large Blue *Phengaris arion*) the butterfly monitoring data from Switzerland makes it possible to generate a significant trend, where the EU27 countries did not have enough transects to calculate a reliable trend.
- As new countries and schemes join in and new data become available, trends can change and differ from previous versions of the indicator. For some species, this can even result in a change in the direction of the trend.

Chapter 4 / Grassland Butterfly Indicator

Introduction

The European Grassland Butterfly Indicator has been updated for the EU27 countries and Europe as a whole. In this chapter both indicators are presented.

Grassland Butterfly Indicator

For both indicators the 2020 value is significantly lower than the start value of the indicator. In the last ten years the indicator shows a linear decline of 32% in the EU27 and 36% in Europe. Due to the filtering by the minimum number of Butterfly Monitoring Schemes (BMS), the Grassland Butterfly Indicator for the EU27 starts one year later than the European one (Figure 6). For the EU27 there is a greater uncertainly in the yearly estimates for this indicator due to less data included. Compared to previous Grassland Butterfly Indicators the United Kingdom is now not represented in the EU27 indicator anymore, resulting in large confidence intervals.

The main reasons for the decline are intensification of agricultural grasslands, and nitrogen deposition in nature reserves (WallisDeVries & Van Swaay, 2017), especially in NW Europe. Furthermore, substantial decreases probably already happened before the start of the indicator calculation in 1990 (Van Strien *et al.* 2019). In some parts of Europe climate warming led to an increase in the numbers of some of the widespread generalist butterflies. However the recent accumulation of extremely hot and dry summers has reversed this trend leading to new declines. As new BMSs are starting up, inclusion of their recent data means the rate of decline of the overall European and EU27 indicators changes as compared with previous calculations.

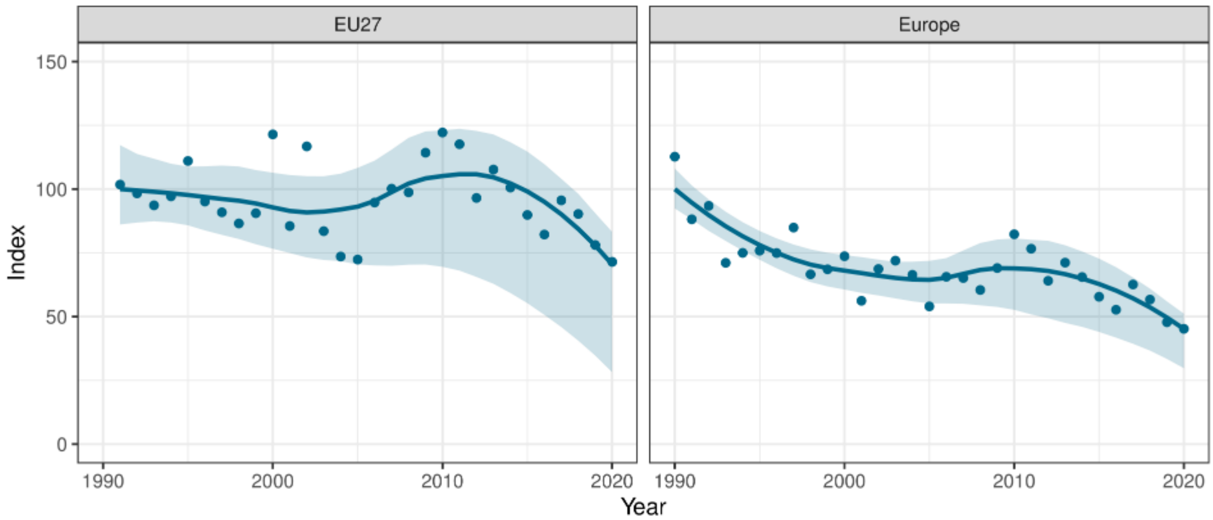


Figure 6: Grassland butterfly indicators for EU27 and Europe. Shaded areas represent 95% confidence intervals.

Chapter 5 / Conclusions

- This report gives an update of an indicator for Grassland Butterflies, which gives the trend of a selection of butterflies characteristic of European grasslands.
- The indicator is based on national Butterfly Monitoring Schemes from across Europe, most of them members of the European Union (see Figure 1).
- This report shows the Grassland Butterfly Indicator has especially declined in the last ten years by 36% since 1990 across Europe and by 32% across the EU Member States with schemes in the EU27 (Figure 6).
- In North-western Europe, intensification of farming is the most important threat to grassland butterflies. Protecting remaining semi natural-grasslands in these areas and reversing fragmentation is essential to halt further losses.
- In many parts of the rest of Europe, abandonment is the key factor in the decline of grassland butterflies. Only if young farmers see a future for their families, while at the same time respecting long established farming traditions, grassland butterflies can be saved. Redirection of CAP funding to support sustainable farming of HNV areas is vital.
- The increase in the duration, frequency and intensity of heatwaves and droughts as a consequence of climate change has also contributed to the declines of grassland butterflies in the last ten years. More research would be needed to establish the exact size of the impact. However stopping further climate warming would certainly help most grassland butterflies.
- The completion of the Natura 2000 network across Europe is an important way to help these butterflies. In addition, restoration or creation of mosaics of habitats at a landscape scale, both inside and outside Natura 2000 areas, are needed.
- This Grassland Butterfly Indicator will become one of the components to monitor for Member States in the upcoming Nature Restoration Law.

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Annexe I / Statistical method

Data collection
All data was first collected at a regional or national level, and after validation added to the eBMS database (version 4.2). This is a standardised database containing the following tables:

1. Butterfly count data table
2. Monitoring visit table
3. Site geographical information table
4. Habitat type table
5. Habitat type description table
6. Species name table

Grassland butterfly indicator

Step 1 – produce species site indices

For each species and year, flight periods were estimated based on the combined effect of latitude and local climate condition (Schmucki et al., 2016). In our model, we used the local records of daily accumulated growing degree days (GDD) and the site latitude as covariates and the spline formulation of the generalised abundance index approach (GAI, Dennis et al., 2016). The GDD and the latitude variable were modelled as interactions, smoothing on the main and a tensor product interaction. For all smoothed terms, we used penalised spline (P-spline) as basis. All flight curves were computed with the R package rbms (Schmucki et al., 2022) that fits GAMs using the gam function implemented in the R package mgcv v1.8-4 (Wood, S.N. 2017).
The daily accumulation of growing degree day was calculated with the R package climateExtract (Schmucki, R. 2022), using the daily grided temperature data available from the E-OBS climate dataset v.25. This dataset, developed by the ECA&D project and available from Copernicus Climate, provides European climate data on a 0.11° grid (i.e., *ca.* 10 km resolution). For better model fitting, we further stratify our dataset into seven large geographic regions (i.e., United Kingdom and Republic of Ireland, Mediterranean, Continental West, Continental East, Alps, Northern Baltic, and Eastern Baltic). This stratification was sufficiently broad to include a large number of sites while allowing for wide geographical variation in butterfly phenology. By including the daily accumulated GDD and site-specific latitude in our model, we were able to derive reliable estimates of local flight period curves. These flight curves were then used to produce local estimates for the weekly butterfly counts that we used to input the missing counts.
Estimates of weekly counts were derived from a negative binomial GLM fitted on the observed counts, including site parameters and the shape of flight curve as offset. When combined with the observed counts, these estimates allow us to generate complete time-series of weekly butterfly counts for each site and species. These time-series were then used to calculate annual site-level abundance indices for each species. We use these inputted time-series to compute local annual site indices. The site-level species abundance index was computed by summing the weekly counts of adult butterflies over the entire monitoring season. This standardised abundance index represents the total number of adult butterflies that are expected to be counted over a monitoring season at a given site. This abundance index was standardised to 1 km transect to provide a comparable proxy of butterfly density. To avoid including highly unreliable site index estimates, we excluded all site indices that had weekly predictions larger than 10 times the largest observed count – this threshold was set to avoid extreme values, most likely due to unreliable flight curves or GLM model. We also exclude all sites with less than 3 years of monitoring history.
To be able to produce suitable estimates of precision of the subsequent indices, indicators and trends, a bootstrapping approach was taken, as is typical for these modelling approaches, to account for sources of uncertainty from multiple model stages (Dennis et al. 2013). Hence the site indices were randomly resampled 1000 times while keeping the number of transects sampled per year the

same as in the original data. The subsequent stages of analysis (steps 2-4) were then applied to each bootstrap, which could then be combined to produce confidence intervals.

Step 2 - species collated indices per BMS

Species site-level indices were combined per monitoring scheme (BMS) to produce a collated species index (density estimates) for each species and BMS. Annual collated abundance indices were calculated for each species where estimate of local abundance index were available for at least three sites (transects) in the given year. We derived the scheme-level species indices by fitting a Poisson generalised linear model (GLM) with site and year effects on site-level indices. In this GLM, we also included the proportion of the flight period surveyed as a weighting (Brereton et al., 2018) on all the site indices. This model allows us to derive annual scheme-level estimates of butterfly densities (total number of butterflies expected) per 1 km transect for each species recorded in each BMS. Using a bootstrap resampling approach, we generated the empirical distribution of the collated indices from which we can derive confidence intervals and account for uncertainty. For each species and BMS, we computed the collated index from 1000 bootstrap samples (with replacement) of the sites monitored in the original dataset. The collated indices and magnitude of confidence intervals were then checked for reliability, in consultation with National BMS coordinators. Species scheme-level collated indices were filtered to the first year beyond which the species was observed on at least 3 sites per year, and very short time series (less than 3 years) were excluded.

Step 3 - species collated indices for EU27 and Europe

For each BMS, the time series of species collated indices were then transformed into the log10 scale and standardised to a value of 2 for the first year. This standardisation enables us to calculate, compare and integrate the relative change over time of a given species across monitoring schemes (BMS). For each of the 17 selected species, we combined time series of the standardised collated indices across the BMS located in the region of interest (i.e., Europe or EU27 Member States). For each species, collated indices were filtered to the first year beyond which at least two BMS were monitored each year. Annual collated indices were combined by calculating the weighted geometric mean of the exponentiated index, where the first year is 100 (i.e., $10^2 = 100$, where 2 is the standardised collated index). For each year, the geometric mean was weighted by the area of the species' range sampled in each BMS. Species’ range (distribution area in hectares) was estimated per BMS as the overlap between the species distribution map (from www.iucnredlist.org) and the convex hull of the monitoring sites in the BMS. The weighted geometric mean was then used as the species collated index for Europe or EU27.
Starting from a standardised value of 100 in the first year, the first year of every time series of scheme-level collated indices that entered the dataset after the first year was set to the value of the weighted geometric mean of the year they entered the dataset. This approach aligns the trend of new schemes with the older schemes and contribute to the compiled index without affecting the trend of previous years. If a time series of a BMS has some missing values in years after it has started contributing to the collated index, the missing values are replaced and kept constant with the last non-missing value. Thereby, missing values are informed by their own scheme and only for the years following their first contribution. This follows the approach already used for combining species indices to produce multi-species indicators (step 4).

Step 4 - producing EU27/European Grassland Butterfly Indicator

The European or EU27 indices were combined by taking the geometric mean of the indices. We applied the same approach as the one implemented in the BRCindicators R package (August et al., 2017), with equal weight being given to each species. This approach accounts for missing values and integrates species with late entry in the dataset. A smoothed indicator was produced using a loess smooth with span=0.75 and degree=2 (as in Soldaat et al., 2017). The same approach was applied to produce multi-species indices and smoothed indicators for each of 1000 bootstraps, from which

quantiles were taken to produce 95% confidence intervals around the indicators. All values were rescaled such that the smoothed indicator started at 100.
Trends were estimated by applying linear regression to the smoothed indicator (and similarly to unsmoothed species-level European/EU27 indices). Trends were estimated for each bootstrap, from which 95% confidence intervals around the actual trend were produced and used to assess significance. Trends were classified based on the multiplicative slope estimate, as in TRIM (Pannekoek & van Strien, 2005).

Annexe II / Glossary

- ABLE: Assessing ButterfLies in Europe: an EU project aiming at capacity building for butterfly monitoring, collecting butterfly monitoring data into the eBMS, producing tools for analysis of the data and produce trends and indicators.
- BGR: Biogeographical Region
- BMS: Butterfly Monitoring Scheme
- CBD: Convention on Biological Diversity
- eBMS: European Butterfly Monitoring Scheme, the database that holds all butterfly monitoring data.
- SPRING: Strengthening Pollinator Recovery through INdicators and monitorinG