Mammalian Biology 80 (2015) 170–177

Contents lists available at ScienceDirect

Mammalian Biology

journal homepage: www.elsevier.com/locate/mambio

Original Investigation

Return of the bats? A prototype indicator of trends in European bat populations in underground hibernacula

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ARTICLE INFO

Article history:
Received 2 June 2014
Accepted 12 September 2014
Handled by Danilo Russo
Available online 2 October 2014

Keywords:
Bioindicator
Chiroptera
Monitoring
Methodology
TRIM

ABSTRACT

Monitoring data on hibernating bats were aggregated for the first time across a number of European countries. These supranational trends revealed that nine out of 16 bat species examined increased at their hibernation sites in Europe between 1993 and 2011, while only one is decreasing. This is reflected in the positive trend shown by a prototype multispecies bat indicator which combined the individual species trends. Our findings suggest that after a period of strong decline in the 20th century, populations of most of the investigated bat species are stabilising or recovering, although with profound differences between European bio-geographical regions and countries. Bat populations in the Continental region have a less positive tendency, compared to those in the Atlantic region. More data from more countries may reveal whether these differences are systematical. So far, the prototype indicator covers 9 countries and 16 of the 45 bat species found in Europe. The next steps will be to refine the methodology behind the indicator and to improve the indicator's representation of European bat populations and its capacity to compare trends among biogeographic regions. This should be achieved by participation of more countries and incorporating data from additional bat species, including data collected by other surveillance methods, such as summer roost counts. Robust information on trends in bat populations at a range of geographic scales is essential to the long-term conservation of bats. Further development of this indicator will make an important contribution to conservation of bats because it will stimulate international cooperation and capacity building for monitoring and research, thus exchanging and broadening knowledge of the status of bats and improving the identification of threats.

Introduction

In the latter half of the twentieth century dramatic declines of bat populations were reported throughout western Europe (Hutson et al., 2001; Racey and Stebbings 1972; Ransome, 1989; Stebbings 1988; Temple and Terry, 2007). Some species even became locally

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http://dx.doi.org/10.1016/j.mambio.2014.09.004

extinct (Bontadina et al. 2000; Haysom et al. 2010; Stebbings 1988). Declines were attributed to various causes, including widespread agricultural intensification and changes in landscape structure, disturbance and destruction of hibernacula and summer roost sites, degradation and fragmentation of feeding sites, pesticides used for remedial timber treatment and in agriculture, declines of insect prey, deliberate killing and water pollution (e.g., Bontadina et al. 2000; Brosset et al., 1985; Hutson et al., 2001; Jefferies, 1972; Leeuwangh and Voûte, 1985; Mitchell-Jones et al., 1989; Shore et al., 1990; Stebbings and Griffith, 1986; Wickramasinghe et al., 2003).

Concern about the state of bat populations stimulated research, species monitoring and conservation measures and eventually led to international agreements, in particular the Agreement on the Conservation of Populations of European Bats (EUROBATS, see Hutson, 2006) and the inclusion of bats in other protective conservation legislation, most notably their listing under Annexes II and IV of the EU Habitats Directive 92/43/CEE. The Habitats Directive is now one of the most powerful legal instruments for biodiversity conservation and an effective driving force for nature protection in the European Union. Member states are obliged to report regularly about the conservation status of those species listed on its Annexes, including all European bat species.

Worldwide concern about the rate and scale of loss of habitats and species also led to the Convention on Biodiversity (CBD) in 1992. Despite setting targets to reduce the rate of biodiversity loss significantly at the global, regional and national levels by 2010, biodiversity decline has continued. In 2010, the 10th Conference of Parties to the CBD adopted a new global Strategic Plan for Biodiversity 2011–2020. In response, the EU launched a new Biodiversity Strategy (2011/2307). This strategy aims to halt biodiversity loss and the degradation of ecosystem services by 2020, restore ecosystems, and make a contribution to addressing global biodiversity loss. To monitor progress in biodiversity conservation at the Pan-European level, a European Environment Agency (EEA) initiative called Streamlining European Biodiversity Indicators (SEBI) established a suite of indicators to provide summary information on environmental change for decision makers and the public. For SEBI indicator 01, “Trends in abundance and distribution of selected species”, indicators for birds and butterflies were developed since 2007 (Gregory et al., 2005, 2008; Van Strien et al., 2001; Van Swaay et al., 2010); however it was recognised that, where suitable data were available, the indicator set should be expanded to incorporate information on other taxa. Bats had been proposed previously as biodiversity indicators and in the UK, the official government biodiversity indicator statistics have included a measure of the UK bat population trends since 2008 (JNCC, 2008; Jones et al., 2009). In 2011, following an assessment of the rationale for developing a bat indicator and the availability of bat monitoring data throughout European countries (Haysom, 2008), the EEA funded a project to develop a prototype pan-European bat indicator (Haysom et al., 2014). The project was executed by the Bat Conservation Trust, the Dutch Mammal Society and Statistics Netherlands in cooperation with the coordinators of national or regional bat monitoring schemes in 9 countries. This paper describes the methodology used for constructing the indicator, provides the results of a prototype indicator based on bat trend data from 9 countries, examines the constituent national and regional trends and outlines suggestions for improvements and further development.

Material and methods

Monitoring data

Bat occurrence or abundance data are available in many European countries and from different types of monitoring programmes (Battersby, 2010; Haysom, 2008). Large-scale surveillance capable of delivering regional or national data usually relies on a large network of volunteer surveyors, who are organised by a body such as a Non-Governmental Organisation (NGO), often financially supported by local or national governments. Of these programmes, counts of overwintering bats in accessible hibernacula such as caves, mines or cellars, have the longest history and are the most common and widespread source of bat population data in Europe (Haysom, 2008). Many bat species are faithful to traditional hibernation sites in which they can be found as single animals or in small to very large cluster sizes. Although usually only part of all bats in a site can be counted, the proportion of counted bats is assumed to be stable over the years. Therefore hibernacula counts are considered a suitable method for determining relative population changes for 22 of the 45 European bat species (Battersby, 2010).

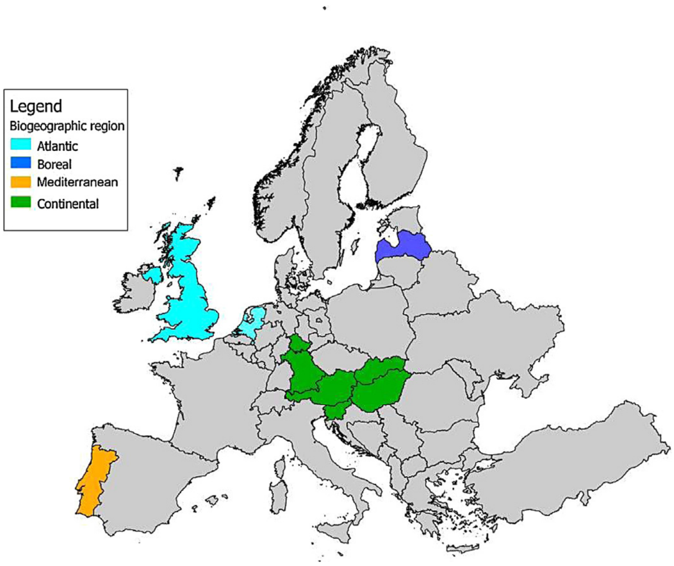


Fig. 1. Bio-geographical grouping of countries contributing to the prototype European hibernating bat indicator. For this project the Alpine and Pannonian regions were merged with the Continental region.

Hibernacula counts were the most extensive and readily available source of data from existing surveillance schemes. Therefore we decided to use these for the development of the prototype pan-European bat indicator. For species that overwinter in tree holes or wall cavities count data are scarce and data from other surveillance schemes are also limited.

Hibernation count data for this study came from underground sites, mines, cellars and other man-made structures such as ice-houses in 9 countries: Austria, Germany (Federal States Bavaria and Thuringia), Hungary, Latvia, the Netherlands, Portugal, Slovakia, Slovenia and the United Kingdom (Fig. 1). Between them the 10 monitoring schemes covered 27 species and represent a total of around 6000 sites, approximately 2300 of which are monitored annually through a network of more than 760 surveyors (Table 1). Full details of the protocols and results for some of these individual monitoring schemes are published elsewhere (e.g., Barlow et al., in press; Dijkstra and Korsten, 2005; Meschede and Rudolph, 2010; Presetnik et al., 2011; Tress et al., 2012; Uhrin et al. 2010). From these countries data were extracted for 16 species and two cryptic species groups (see Table 2), covering a period of 19 years (Haysom et al., 2014), although the length of time series available for individual species varied among countries, ranging between six and 26 years (Table 1, 2). The data were gathered, entered into databases and validated and error-checked by each partner.

During counts at hibernation sites, surveyors identify bats at the species level. Some bat sibling species cannot be separated reliably

Table 1
Summary of data made available by participating countries (1993 = winter 1993/1994).

Country	Approximate no. of sites	Approximate no. of sites counted each year	Time series
Austria (AT)	200	100	1993–2011
Germany – Bavaria (DE-B)	2300	350	1993–2010
Germany – Thüringia (DE-T)	1500	177	1993–2011
Hungary (HU)	850	49	2005–2009
Latvia (LV)	120	120	1993–2011
Netherlands (NL)	1100	600	1986–2011
Portugal (PT)	38	21	1988–2011
Slovakia (SK)	50	50	1998–2007
Slovenia (SI)	65	20–50	2003–2011
United Kingdom (UK)	617	361	1997–2011

where they occur together in hibernacula, because their identification by morphological characteristics is difficult without close examination, a practice that is avoided to minimise disturbance during hibernation. This is true for *Myotis mystacinus* and *Myotis brandtii* and for *Myotis myotis* and *Myotis blythii*. For these species trends were produced for the combined species, e.g. *M. mystacinus*/*M. brandtii*. Furthermore, in some countries, *Plecotus austriacus* was not distinguished from *Plecotus auritus* when there were only a few *P. austriacus* relative to the number of *P. auritus*. In these cases, we treated these records as representing the brown long-eared bat alone.

Statistical analysis

The procedure to calculate the pan-European bat indicator was similar to the methods applied to the pan-European indicators developed previously for birds and butterflies (Gregory et al., 2005, 2008; Van Strien et al., 2001; Van Swaay et al., 2010). The procedure consist of a hierarchical schedule of combining analysis results of the computer programme TRIM (i.e., time totals, covariants and standard errors) on a lower level to produce yearly indices and average yearly change per species on a higher level and finally combining the results per species into a single multi-species indicator.

The successive steps in this procedure were:

1. **Calculating national trends**. National trends, expressed as average yearly increase or decrease and annual indices of species, expressed as percentage of count numbers in the first year, were computed using the computer programme TRIM, which is an efficient implementation of log-linear regression developed by Statistics Netherlands (Pannekoek and Van Strien, 2001). This programme was developed specifically for the analysis of wildlife count data and offers solutions for several statistical problems encountered in animal monitoring by volunteer field workers: missing data and under- or oversampling of certain habitats or regions. Missing values occur when sites are not counted each year, e.g. because no volunteers could be recruited to count particular sites. Under- or oversampling leads to poor representativeness and occurs, e.g. because volunteers are more easily recruited in some regions then in others. If not taken into account properly, both phenomena may lead to biased trend estimates. TRIM estimates missing values, based on the changes in other sites (Braak et al., 1994). TRIM also allows the use of weighting factors to give certain sets of sites higher or lower weight in order to dampen the effects of oversampling and undersampling. National data and results were assumed to be representative for the involved species and countries.
2. **Calculating regional trends**. The national data were then combined into trends for bio-geographical regions (Fig. 1). We did not combine the raw data, but we instead aggregated the estimated total numbers per year as produced in the first step. Combining total numbers across countries is straightforward in cases where we restricted the analysis to a time period for which data were available for all countries. The obvious method is to add the estimated totals for each country. Since the estimates of the year totals are independent between countries, the variance of each combined total is the sum of the variances of the corresponding country totals. This procedure is equivalent to applying TRIM to the raw data for all sites from all countries with an interaction term country × year, i.e., allowing annual indices to differ

Table 2
Slopes of individual species trends calculated for each country and for two bio-geographical regions. Trends are characterised by slope and standard error as significant decrease (slope ±1.96 * SE <1), significant increase (slope ±1.96 * SE >1), stable (slope −1.96 * SE >0.95 and slope +1.96 * SE <1.05) or uncertain (all others). Significant decrease and increase are underlined, stable trends are in normal font and uncertain trends are in italics. Hibern.: +hibernating predominantly in underground sites, o also in other structures, e.g. trees, wall-cavities. Region: A – Atlantic, B – Boreal, C – Continental, M – Mediterranean; Country – for abbreviations see Table 1).

Biogeographical region		A			M	C							B
Country		UK	NL	Combined	PT	DE -B	DE -T	AT	HU	SK	SI	Combined	LV
Period	Hibern.	’97–’11	’86–’11	’93–’11	’88–’11	’93–’10	’93–’11	’93–’11	’05–’09	’98–’07	’03–’11	’93–’11	’93–’11
Rhinolophus euryale	+				1.06				*1.31*	*0.98*		*0.94*[a]	
Rhinolophus ferrumequinum	+	1.04		1.04[a]	0.98	1.08		*1.02*	*1.03*	1.03	0.98	1.05	
Rhinolophus hipposideros	+	1.05		1.05[a]	*1.04*	*1.04*	1.16	1.07	1.10	1.07	1.05	1.07	
Myotis myotis/blythii	+		1.05	1.07	*1.07*	1.03	1.06	0.99	*5.61*	0.99	*1.01*	1.01	
Myotis bechsteinii	o					0.99	1.00	*0.81*	*1.02*	*0.97*		*0.96*	
Myotis nattereri	+	1.06	1.12	1.10		1.03	1.01	*1.00*	*1.11*	*0.99*		1.02	1.02
Myotis mystacinus/brandtii	+	1.03	1.06	1.05		1.05	1.08	*1.30*	*0.99*	1.00		1.06	1.08
Myotis emarginatus	+		1.13	1.13				*0.92*	*1.99*	1.08		1.00[a]	
Myotis dasycneme	+		1.05	1.04					*0.91*	1.11		0.99[a]	0.98
Myotis daubentonii	o	1.01	1.03	1.02		1.04	1.00	*0.97*	*1.12*	*0.98*		1.02	1.05
Eptesicus nilssonii	o					0.99	1.03	*1.11*		1.12		*1.04*	1.00
Eptesicus serotinus	o					1.01		*1.03*	*1.04*	*0.91*		1.0	
Plecotus auritus	o	1.00	1.03	1.00		0.99	0.98	*0.97*	*1.21*	*0.95*		0.98	0.97
Plecotus austriacus	o						0.96	0.88	*1.32*	0.83		0.92	
Barbastella barbastellus	o					1.04	1.03	1.05	*1.09*	0.95	*0.94*	1.04	
Miniopterus schreibersii	+				0.99			*0.95*		*1.54*		*0.97*	

[a] Based on a shorter period because of data availability: Continental *M. dasycneme* and *R. euryale* 1998–2009; Continental *M. emarginatus* 1998–2011; Atlantic *R. ferrumequinum* and *R. hipposideros* 1997–2011

between countries. Combing the estimated total numbers per country therefore produces exactly the same estimates of combined year totals as analysing the raw data and their standard errors are also equal.

Unfortunately, the monitoring schemes differ in years covered and the missing year totals for certain countries make combination of year totals more complicated. The missing year totals were estimated by TRIM in a way equivalent to imputing missing counts for particular sites, but the estimation procedure was slightly different and incorporated the standard errors and covariances of the year totals per country (Van Strien et al., 2001).

This procedure has the advantage that national coordinators do not need to share their raw data but only the results of applying TRIM. In addition to the benefit of generating national results in the first step, this circumvents any concerns about the use of raw data by anyone other than the owners in the country of origin. Hibernacula sites are sensitive and so sometimes locations and number of species are kept secret.

Due to natural variation in species distribution and surveillance history, not all nations have data for each species for the same time period. So estimation of missing data is also needed to generate complete time totals for each country, species and year within the bio-geographic regions. These missing values were again imputed by TRIM, but to avoid imputing values based on data from too few countries, the time period for calculation of supranational trends was shortened to 1993–2011. For every year in this period data from at least 5 countries and 14 species were available (Fig. 2).

3. **Calculating European species trends**. The output of those regions was used as input for equivalent calculations at a pan-European level. Again estimation is needed to generate complete time totals. In this case for every bio-geographic region, species and year at a European scale.
4. **Constructing the indicator**. Finally a single pan-European indicator for bats was calculated by taking the geometric means of the European indices of individual species as described by Gregory et al. (2005) and Van Strien et al. (2011). We also calculated combined species indicators for the Atlantic and Continental region in the same way (Fig. 1). Combined indicators for the Boreal and Mediterranean region were not calculated because both regions are represented by one country only. Biogeographic regions were taken according to European Environment Agency (http://www.eea.europa.eu/data-and-maps/figures/biogeographical-regions-in-europe-1), and each country was assigned only to one region, even though some actually lie in more than one (e.g., Slovenia, Austria). This was done because we started with national trends and could not split these in trends for regions within countries.

Weighting factors

Differences in methodology and/or sampling strategy per country ensure that in every country a different proportion of the total population is counted. An intensive monitoring scheme may result in relatively high count numbers in countries with a small population. The contribution to the pan-European trend of a species of a country with a large population of this species should be bigger than the contribution of countries with a small population. Rather than giving each country an equal influence on the overall trend we wanted to correct count results per country by weighting factors in such a way that they reflected differences in the population sizes of each country. Weighting factors are needed both for combining national trends to generate bio-geographical region trends and for combining regional trends to pan-European trends. Weighting factors to correct for over- or under-sampling within a country may also be needed, but fall beyond the scope of our study.

Using weighting factors based on exact or relative population sizes would be ideal, but unfortunately reliable estimates of population sizes of bat species in each country are rarely available. As a suitable alternative for calculating the weighting factors based on population sizes we used the range of each bat species as compiled in the IUCN Red List of Threatened Species (IUCN, 2010). These ranges are drawn from various sources and reviewed by bat experts, and these data are in the public domain. Further information on the methodology for compiling these data is available at http://www.iucnredlist.org online. For political boundaries, we used Vector Map VMAP0 (NIMA, 2010). This is a vector-based collection of geographic data developed by the National Imagery and Mapping Agency from the United States, which is also available in the public domain. The weighting factor for each species–country combination was defined as the proportion of the range of that species in that country.

In combining the pan-European trends of each species into a single indicator no weighting was applied; each species counted equally. Selecting a group of species or giving more weight to certain species may be considered if for instance special attention is needed for red list species or typical forest dwelling species.

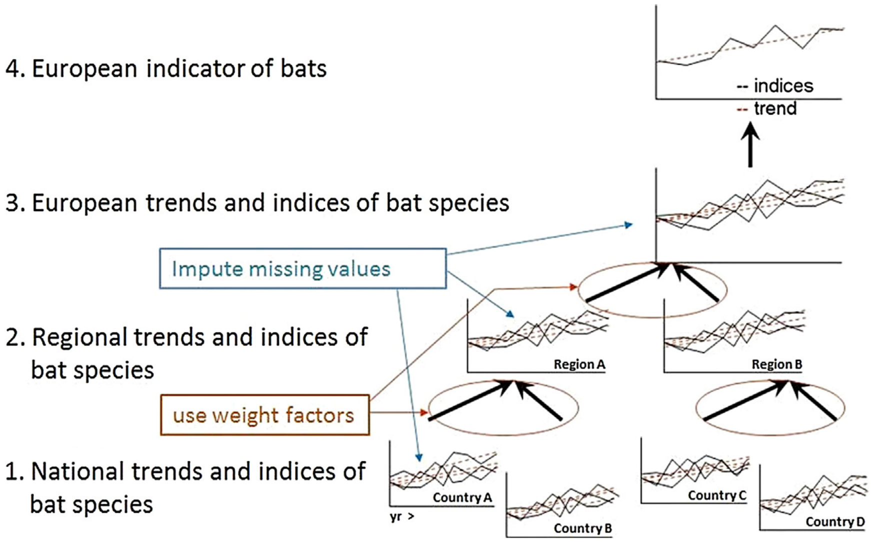


Fig. 2. Schematic representation of European indicator construction.

Table 3
Slope, number of hibernation sites in which the species was observed, and trend of species for the combined countries (see Table 2 for definition of trends).

Species	Slope	Trend	Error of slope	Number of sites
Rhinolophus euryale	1.08	Increase	0.03	37
Rhinolophus ferrumequinum	1.04	Increase	0.01	272
Rhinolophus hipposideros	1.06	Increase	0.01	619
Myotis myotis/blythii (*oxygnathus*)	1.02	Increase	0.00	1748
Myotis bechsteinii	0.96	Uncertain	0.04	500
Myotis nattereri	1.05	Increase	0.01	2066
Myotis mystacinus/brandtii	1.06	Increase	0.00	1506
Myotis emarginatus	1.08	Increase	0.02	111
Myotis dasycneme	1.00	Stable	0.01	230
Myotis daubentonii	1.02	Increase	0.00	2125
Eptesicus nilssonii	1.03	Uncertain	0.02	309
Eptesicus serotinus	1.02	Stable	0.01	201
Plecotus auritus	0.99	Stable	0.01	3655
Plecotus austriacus	0.91	Decline	0.03	399
Barbastella barbastellus	1.04	Increase	0.01	973
Miniopterus schreibersi	1.00	Stable	0.01	44

Results

National trends

Results of trends for individual species do not show striking differences between countries (see Table 2). Most species show an increasing population trend in more than one country and do not show the opposite trend in other countries. For one species, *P. austriacus*, significant trends are only declining. Only three species have opposing trends: *Barbastella barbastellus*, *P. auritus* and *Rhinolophus ferrumequinum*. Remarkably all but one declining trends of species are found in continental countries.

The number of species with uncertain trends showed much variation between countries. Whereas the United Kingdom, the Netherlands, Thuringia and Latvia had no uncertain trends at all, Austria, Hungary and Slovakia had uncertain trends for at least seven species. Differences between trends of individual species are large in the countries in the Continental region. While Hungary has the highest – but uncertain – average trend of all countries, its neighbours Slovenia and Austria have the lowest.

Biogeographic trends

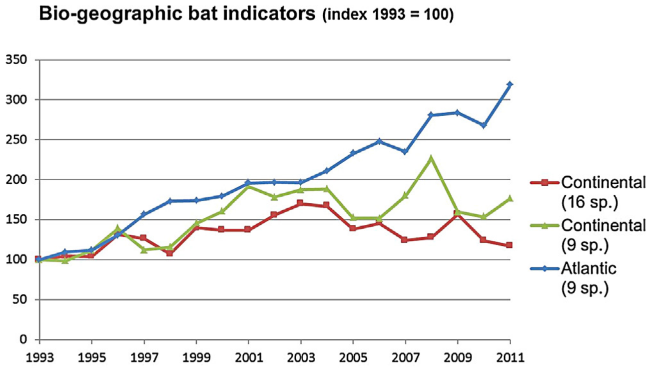
In the Atlantic region eight out of nine species had increasing population trends at their hibernation sites while none were observed to decline. In contrast, only six of 16 species in the Continental region increased while one species, *P. austriacus*, declined. Tests for differences in slope for the nine species for which both Continental and Atlantic region trends were produced suggested smaller increases in the Continental region ($n = 9$; paired t-test; $p = 0.09$). The difference was greatest for *Myotis* and *Plecotus* species ($n = 7$; paired t-test; $p = 0.04$) but there was no significant difference between the regions for the two *Rhinolophus* species.

Yearly combined species indicators for these regions, calculated as geometric averages of the indices for each species in each year, show the differences between the Atlantic and Continental region (Fig. 3). The most remarkable difference is the opposite trends in 2003–2011, where the Atlantic region has an ongoing increase while in the Continental region the increase of the first ten years is entirely offset by a decrease after 2003.

European trends and indicator

The final combination of trends at the European level resulted in nine species with a significant positive trend. Only *P. austriacus* showed a moderate decline (Table 3). For two species, *Myotis bechsteinii* and *Eptesicus nilssonii*, no European trend could be determined, probably due to high between-year variation. Four species appeared to be stable (Haysom et al., 2013).

The prototype of the European bat indicator, calculated by taking the geometric means of the indices for all 16 species, showed a positive trend for bats as a group in the time period 1993–2011 (Fig. 3). Since 2000 the trend seems rather stable, but has a marked dip in 2007 (Fig. 4).



BatLife Europe / Statistics Netherlands

Fig. 3. Combined species population trends for two bio-geographic regions. Continental (9 species) is based on a subset of 9 Continental species, matching the 9 species in the Atlantic region (slopes: Atlantic: 1.05; Continental: 1.00; Continental, 9 species: 1.02).

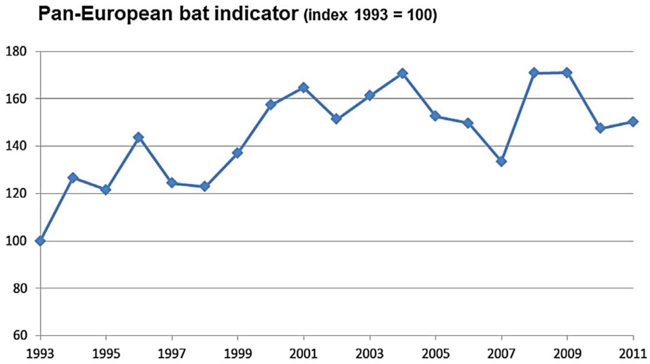


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Fig. 4. The prototype of the European indicator of trends in bat populations, based on hibernacula counts in 9 countries (slope: 1.02).

Conclusions and discussion

The pan-European indicator shows that bat populations on average have increased at hibernation sites between 1993 and 2011. Although not all species and regions show an equally positive trend, and more recently the trend is flattening, this result suggests that bats may have recovered partly from the massive decline reported during the latter half of the twentieth century. This therefore also suggests that targeted conservation policies may have been successful. There are some caveats in our study however, so the conclusion that bat populations are increasing should be treated with some caution.

In the first place, we should note that the indicator does not include data from all European countries and bio-geographic regions, nor does it represent the majority of European bat species. The robustness of the indicator would be much improved by expanding it to cover a greater proportion of Europe, so that it can become more representative of both Europe and its component regions. Although we know of up to 20 countries with potentially suitable survey data, time and budget restrictions during the project limited the number of participation countries to 9. The process of grouping countries into bio-geographic ranges was rather constrained, with Portugal being the only Mediterranean country, Latvia the only Boreal country and countries with parts in Continental, Alpine and Pannonian regions classified together as one Continental region. But the differences in the trends between only two bio-geographic regions – Atlantic and Continental – which are not yet understood – indicate the potential of our data to detect conservation issues at the regional scale.

Although incorporating data from more countries is definitely required, the impact on the combined European trends of each species and the combined indicator may not be substantial. If the trends in newly added countries were found to diverge as little as those that have already been incorporated, we would expect the expanded overall indicator to remain positive. Since it is unsatisfactory to speculate, recruiting additional countries would contribute to the robustness of the indicator and is therefore a major goal for the next update.

Although trends and indices for species generally indicate that bat populations have increased and national species population trends generally point in the same direction, species trends in the Continental region show more variability and are often uncertain. The uncertainty is probably caused when national species trends are calculated from relatively few data, from a limited number of sites and a limited number of years (e.g., Hungary, Slovenia), in combination with a high variance in counts and site characteristics. This may lead to outliers such as the slope value of 5.61 (Table 2) for *M. myotis*/*blythii* in Hungary. Such outliers may potentially have a large influence on overall trends, but the fact that this is based on a small sample of European bat populations data largely prevents this. The Continental trend for *M. myotis*/*blythii* (slope value 1.01, Table 2) would only have been 0.0045 lower without the input of Hungary, changing it from a mild increase to a stable trend.

A response to the uncertainty of some national species trends could be to exclude these from the overall European Indicator. However, on the European level the inclusion of more data leads to smaller standard errors and a more reliable outcome, hence the decision to include data of species with uncertain trends on a national level. High standard errors and uncertain trends on a national level are of course undesirable for the countries concerned and should be a stimulus to improve monitoring schemes and/or gaining more data.

The reasons behind the larger differences between national trends (e.g., *B. barbastellus*, Table 2) in the Continental region are unknown. Due to the inclusion of Alpine and Pannonian regions, the Continental region is likely to be more heterogeneous than the other regions while especially Alpine hibernacula are difficult to monitor because of the inaccessibility of many sites. Differences in habitat management, landscape, agricultural practices or other potential drivers may also be important, but more investigation is required to understand the mechanisms behind these differences.

One of the weaknesses of this study is the rather crude weighting procedure, based on distribution area alone. Hibernacula are often located at different and sometimes distant locations from summer colonies so migration and seasonal differences in distribution and density are common phenomena among bats. The methodology does not take these differences into account and could certainly be improved with a weighting procedure that is better equipped to take these differences into account.

Despite that, we would not expect a refinement of the weighting procedure to affect the overall conclusion that populations of some species studied within this area have increased, because trends in different countries generally point in the same direction. Different weighting factors can change the relative influence of trends from a country, but they do not change the direction of trends.

The prototype indicator only uses data from counts in hibernacula that are accessible to people. The species observed represent approximately 40% of the European bat fauna and 64% of the species that Battersby (2010) considered generally suited to surveillance in this kind of hibernacula. Nine of the 16 species used in the indicator hibernate predominantly in underground sites. The other seven species also hibernate in other much less accessible structures such as trees and wall cavities that cannot generally be surveyed (Dietz et al., 2009). However, only anecdotal evidence is available as regards the proportions of animals hibernating in overground (hard to count) sites and in underground (easier to survey) sites, let alone how stable these proportions are. On top of that, hibernation behaviour is also influenced by climate and weather conditions. The resulting indicator is therefore biased towards trends for species that predominantly hibernate in man-accessible hibernacula. Species that use other types of hibernacula, have different ecology or behaviour and may be subject to other influences. As a consequence, they may show different population trends. The best way of addressing this potential bias would be to incorporate data from other monitoring approaches such as summer roosts counts or bat detector surveys. Since methods of surveillance vary in their suitability for each species and since all methods bring potential biases (Battersby, 2010), integrating different types of data may increase certainty in the European species trends and the overall indicator. Incorporation of data from different methods within the framework of the indicator is not a technical problem and data from such surveys are already available (Battersby, 2010; Haysom, 2008). But including these data requires careful selection of suitable monitoring methods for each species and country and may require different weight factors for each method. For instance one of the challenging aspects of combining summer and winter counts is whether and how to combine those for migrating bats. Can summer counts of a species be combined with winter counts of the same species if we only have summer counts in one country and winter counts in another? Incorporating data for more species and from other methods is another major goal for the next version of the indicator.

In the next update of the indicator special attention is needed regarding the treatment of data on rare species or species recorded at small numbers of sites with a high variability in number of bats counted (e.g., *Rhinolophus euryale*, *Miniopterus schreibersi*). For such species, the indices may be heavily affected by artefacts in survey methodology or occasional outliers. For example, some peaks in the trend of *R. euryale* may be due to recent discoveries of new chambers in a large hibernaculum. Such species-specific peaks in the data do not have a great impact on the indicator trend, unless this occurs for a species that has a limited range or when very few hibernacula are counted. As the indicator develops, this issue should be addressed further, through the incorporation of data from larger numbers of sites and/or from other monitoring methods and also through the improvement of rules regarding species inclusion.

The work to establish European bird and butterfly indicators provided conservation benefits by helping to build the capacity of many countries to undertake species monitoring and subsequently analyse national population trends (Gregory et al., 2008). It is hoped that the work to develop a pan-European bat indicator will have the same effect. The need for such capacity building, both for monitoring and data analysis has already been identified by EUROBATS. Closer collaboration between national monitoring schemes, including the sharing of skills and data will broaden our knowledge regarding the status of bats and bring many other benefits for conservation, because it will stimulate international cooperation and capacity building for monitoring and research including stimulating wider research on the drivers of change in bat populations and how these may vary in different regions.

Bats have a slow rate of reproduction, so if environmental or human pressures cause a large or rapid population decline, bat species tend to recover slowly. Whether bats are in fact returning to European landscapes in numbers seen more than half a century ago cannot be answered at this point. While our findings of increase are encouraging, conservationists consider that current populations are still likely to be smaller than they were before they declined. And while former threats such as large-scale habitat destruction, deliberate persecution, toxic timber treatment chemicals and water pollution may have become less influential because of the effectiveness of EU wide nature conservation and environmental protection measures, there are significant new threats from roads and intensifying traffic, wind turbines, climate change and light pollution (e.g., Berthinussen and Altringham, 2012; Haensel and Rackow, 1996; Hötker et al., 2006; Kiefer et al., 1995; Kuijper et al., 2008; Rebelo et al. 2010; Stone et al., 2009; Voigt et al., 2012). For these reasons bats should still be considered vulnerable and changes in their population sizes should continue to be monitored closely. The decreasing trend of *P. austriacus* clearly underlines this.

Acknowledgements

European Environment Agency Grant number EEA/NSV/11/005 funded the development of this prototype indicator. All the co-author organisations that coordinate the ten monitoring schemes that contributed data acknowledge many sources of funding, cooperation and data sharing and are grateful for the help of many hundreds of volunteer surveyors. It is not possible to thank all individuals and organisations here by name, but further details are available in Haysom et al. (2013) and in the various national monitoring reports and websites. Especial thanks are due to the following data contributors and funders of national or regional bat monitoring schemes: Austria – The 'Artenschutzprojekt Fledermäuse' projects in Carinthia, Salzburg, Styria, Tyrol, Upper Austria and Vorarlberg which were funded by the respective local governments, Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW) and the European Union; Netherlands – the Nature Data Authority, Statistics Netherlands, provincial bat groups and Ministry of Economic Affairs, Agriculture and Innovation; Germany (Bavaria) Bernd Ulrich Rudolph of the Bavarian Environment Agency (Bayerisches Landesamt für Umwelt), Matthias Hammer of the Coordination Centre for Bat Conservation in Northern Bavaria, and Dr Andreas Zahn of the Coordination Centre for Bat Conservation in Southern Bavaria; Germany (Thuringia) – the Thuringian environment authorities Thüringer Ministerium für Landwirtschaft, Forsten, Umwelt und Naturschutz and Thüringer Landesanstalt für Umwelt und Geologie; Portugal – Faculdade de Ciências de Lisboa, Universidade do Porto and Federação Portuguesa de Espeleologia; Slovakia – members of the Slovak Bat Conservation Society and other bat workers; Slovenia – the Republic of Slovenia Ministry of the Environment and Spatial Planning; United Kingdom – the Joint Nature Conservation Committee (JNCC), Department of Environment, Food and Rural Affairs (Defra), Natural Resources Wales (NRW), Natural England, Bat Conservation Ireland, Republic of Ireland National Parks and Wildlife Service (NPWS) and Northern Ireland Environment Agency (NIEA).

References

Barlow, K., Briggs, P., Catto, C., Haysom, K.A., Hutson, T., Lechiara, N., Racey, P.A., Richardson, P., Walsh, A., Langton, S., in press. Citizen science reveals trends in bat populations: the National Bat Monitoring Programme in Great Britain. Biol. Conserv.

Battersby, J., 2010. Guidelines for Surveillance and Monitoring of European Bats. EUROBATS Publication Series, vol. 5. UNEP/EUROBATS Secretariat, Bonn, Germany.

Berthinussen, A., Altringham, J., 2012. The effect of a major road on bat activity and diversity. J. Appl. Ecol. 49, 82–89.

Bontadina, F., Arlettaz, R., Fankhauser, T., Lutz, M., Muhlethaler, E., Theiler, A., Zingg, P., 2000. The lesser horseshoe bat *Rhinolophus hipposideros* in Switzerland: present status and research recommendations. Le Rhinolophe 14, 69–83.

Braak, C.J.F.ter., Van Strien, A.J., Meijer, R., 1994. Analysis of monitoring data with many missing values: which method? Proc. Bird Numbers, 1992.

Brosset, A., Barbe, E., Beaucournu, J.-C., Faugier, C., Salvayre, H., Tupinier, Y., 1985. La rarefaction du rhinolophe euryale (*Rhinolophus euryale*) en France. Recherche d'une explication. Mammalia 52, 101–122.

Dijkstra, V., Korsten, E., 2005. Handleiding voor het monitoren van vleermuizen in de winter. Zoogdiervereniging VZZ, Arnhem.

Dietz, C., von Helversen, O., Nill, D., 2009. Bats of Britain, Europe and Northwest Africa. A&C Black, London.

Gregory, R.D., Van Strien, A.J., Vorisek, P., Gmelig Meyling, A.W., Noble, D.G., Foppen, R.P.B., Gibbons, D.W., 2005. Developing indicators for European birds. Philos. Trans. R. Soc. B 360, 269–288.

Gregory, R.D., Vorisek, P., Noble, D.G., Van Strien, A.J., Klvanova, A., Eaton, M., Meyling, A.W., Joys, A., Foppen, R.P.B., Burfield, I.J., 2008. The generation and use of bird population indicators in Europe. Bird Conserv. Int. 18, S223–S244, http://dx.doi.org/10.1017/S0959270908000312.

Haensel, J., Rackow, W., 1996. Fledermäuse als Verkehropfer – ein neuer report. Nyctalus (N.F.) 6, 29–47.

Haysom, K.A., 2008. Streamlining European 2010 Biodiversity Indicators (SEBI 2010): Developing a Methodology for Using Bats as Indicator Species and Testing the Usability of GBIF Data for Use in 2010 Biodiversity Indicators. Report to European Environment Agency.

Haysom, K.A., Jones, G., Merrett, D., Racey, P.A., 2010. Bats. In: Maclean, N. (Ed.), Silent Summer. The State of Wildlife in Britain and Ireland. Cambridge University Press, pp. 259–280.

Haysom, K.A., Dekker, J., Russ, J., Van der Meij, T., Van Strien, A., 2014. European Bat Population Trends. A Prototype Biodiversity Indicator. EEA Technical Report No. 19/2013.

Hötker, H., Thomsen, K.-M., Jeromin, H., 2006. Impacts on Biodiversity of Exploitation of Renewable Energy Sources: The Example of Birds and Bats. Books on Demand, Norderstedt.

Hutson, A.M., 2006. EUROBATS – the early years. In: Jones, M., Classen, O., Krueger, D. (Eds.), 1991–2006 EUROBATS Celebrates Its 15th Anniversary. Eurobats Publ Series, vol. 1. UNEP/EUROBATS Secretariat, Bonn, Germany.

Hutson, A.M., Mickleburgh, S.P., Racey, P.A., 2001. Microchiropteran Bats – Global Status Survey and Conservation Action Plan. IUCN, Gland.

IUCN, 2010. IUCN Red List of Threatened Species. Version 2010.4. http://www.iucnredlist.org (accessed 27.10.10).

Jefferies, D.J., 1972. Organochlorine insecticide residues in British bats and their significance. J. Zool. Soc. Lond. 166, 245–263.

JNCC, 2008. JNCC—UK Biodiversity Indicators in Your Pocket (BIYP). Joint Nature Conservation Committee, http://www.jncc.gov.uk/page-4229 (accessed 03.06.13).

Jones, G., Jacobs, D.S., Kunz, T.H., Willig, M.R., Racey, P.A., 2009. Carpe noctem: the importance of bats as bioindicators. Endanger. Species Res. 8, 93–115.

Kiefer, A., Merz, H., Rackow, W., Roer, H., Schlegel, D., 1995. Bats as traffic casualties in Germany. Myotis 32/33, 215–220.

Kuijper, P.J., Schut, J., Dullemen, D.van., Toorman, H., Goossens, N., Ouwehand, J., Limpens, J.G.A., 2008. Experimental evidence of light disturbance along the commuting routes of pond bats (*Myotis dasycneme*). Lutra 51, 37–49.

Leeuwangh, P., Voûte, A.M., 1985. Bats and wood preservatives. Pesticide residues in the Dutch pond bat (*Myotis dasycneme*) and its implications. Mammalia 49, 517–524.

Meschede, A., Rudolph, B.-U., 2010. 1985–2009: 25 Jahre Fledermausmonitoring in Bayern (1985–2009: 25 Years of Bat Monitoring in Bavaria). Bayerisches Landesamt für Umwelt, Augsburg (in German) www.bestellen.bayern.de/shoplink/lfu_nat_00174.htm

Mitchell-Jones, A.J., Cooke, A.S., Boyd, I.L., Stebbings, R.E., 1989. Bats and remedial timber treatment chemicals – a review. Mammal Rev. 19, 93–110.

NIMA, 2010. Vector-based Geographic Data for Europe. National Imagery and Mapping Agency, US, Available from http://geo.lib.umn.edu/gisdata/vmap0/File eurnasia.zip (accessed 20.09.10).

Pannekoek, J., Van Strien, A.J., 2001. TRIM3 Manual. Trends and Indices for Monitoring Data. Research Paper No. 0102. Statistics Netherlands Voorburg, The Netherlands.

Presetnik, P., Podgorelec, M., Grobelnik, V., Šalamun, A., 2011. Monitoring populacij izbranih ciljnih vrst netopirjev v letih 2010 in 2011 (Končno poročilo), Naročnik. Ministrstvo za okolje in prostor, Ljubljana (in Slovenian).

Racey, P.A., Stebbings, R.E., 1972. Bats in Britain – a status report. Oryx 11, 319–327.

Ransome, R.D., 1989. Population changes of greater horseshoe bats studied near Bristol over the past twenty-six years. Biol. J. Linn. Soc. 38, 71–82.

Rebelo, H., Tarroso, P., Jones, G., 2010. Predicted impact of climate change on European bats in relation to their biogeographic patterns. Glob. Change Biol. 16, 561–576.

Shore, R.F., Boyd, I.L., Leach, D.V., Stebbings, R.E., Myhill, D.G., 1990. Organochlorine residues in roof timber treatments and possible implications for bats. Environ. Pollut. 64, 179–188.

Stebbings, R.E., 1988. Conservation of European Bats. Christopher Helm, London.

Stebbings, R.E., Griffith, F., 1986. Distribution and Status of Bats in Europe. Natural Environment Research Council, Institute of Terrestrial Ecology, 599.4 OL737. C5.

Stone, E.L., Jones, G., Harris, S., 2009. Street lighting disturbs commuting bats. Curr. Biol. 19 (13), 1123–1127.

Temple, H.J., Terry, A., 2007. The Status and Distribution of European Mammals. Office for Official Publications of the European Communities, Luxembourg.

Tress, J., Biedermann, M., Geiger, H., Prüger, J., Schorcht, W., Tress, C., Welsch, K.-P., 2012. Fledermäuse in Thüringen (Bats of Thuringia. Naturschutzreport 27) (in German with English Summary).

Uhrin, M., Benda, P., Obuch, J., Urban, P., 2010. Changes in abundance of hibernating bats in central Slovakia (1992–2009). Biologia (Bratisl.) 65 (2), 349–361.

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

Van Strien, A.J., Soldaat, L.L., Gregory, R.D., 2011. Desirable mathematical properties of indicators for biodiversity change. Ecol. Indic. 14, 202–208.

Van Swaay, C.A.M., Van Strien, A.J., Harpke, A., Fontaine, B., Stefanescu, C., Roy, D., Maes, D., Kühn, E., Õunap, E., Regan, E., Švitra, G., Heliölä, J., 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., 2010. The European Butterfly Indicator for Grassland Species 1990–2009. Report VS2010.010. De Vlinderstichting, Wageningen.

Voigt, C.C., Popa-Lisseanu, A.G., Niermann, I., Kramer-Schadt, S., 2012. The catchment area of wind farms for European bats: a plea for international regulations. Biol. Conserv. 153, 80–86.

Wickramasinghe, L.P., Harris, S., Jones, G., Vaughan, N., 2003. Bat activity and species richness on organic and conventional farms: impact of agricultural intensification. J. Appl. Ecol. 40, 984–993, http://dx.doi.org/10.1111/j.1365-2664.2003.00856.x.