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Long-term increase in hibernating bats in Swedish mines — effect of global warming?

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We present the result of bat winter censuses in three old mines in southern Sweden from 1980 until present (2017). The Taberg and Kleva mines, each with about 1.5 km of accessible passages, have winter populations of 517 and 132 bats, respectively (maximum counts) belonging to six species, the highest numbers known in underground sites in Sweden. Ädelfors is less extensive and has fewer individuals (maximum 22). The two former sites were protected and gated in the 1980's while the third site still has no formal protection and is subject to disturbance. Generally Daubenton's bat *Myotis daubentonii* and the brown long-eared bat *Plecotus auritus* are common species and the numbers are stable. The whiskered and Brandt's bats *M. mystacinus*/*brandtii* and Natterer's bat *M. nattereri* have increased significantly, while the northern bat *Eptesicus nilssonii*, which is relatively rare in mines generally, has shown a slight but significant decline. At the species level the population trends conform well to those of the respective species in continental Europe and the British Isles. This suggests that there is a common factor behind the population changes across Europe. Although our data are very limited, the results question some previous explanations for the observed trends, but are in line with theoretical predictions based on global warming scenarios.

Key words: climate change, bat conservation, hibernation, population change, roost survey

Introduction

The European Environmental Agency presented a report on recent population trends among European bats (Haysom *et al*., 2014), based on hundreds of surveillance efforts across seven countries (Latvia, Germany, the Netherlands, Great Britain, Slovakia, Slovenia and Portugal) over the last 20 years. Sweden and the other Nordic countries were not included in the compilation, however, and it may be of interest to see if the trend observed by Haysom *et al*. (2014) also applies to this area.

Due to the prevalence of Precambrian rocks, mostly granite and gneiss, in Fennoscandia (defined as the Scandinavian Peninsula, Finland and Russian Karelia), caves are rare and of marginal importance to bats in this area. No underground mass hibernation sites e.g. like the limestone mines in Denmark (Egsbaek and Jensen, 1963) or fortifications and caves in continental Europe (e.g., Daan, 1980; Urbańczyk, 1989), with thousands of bats in winter are known. Instead, underground hibernation sites mostly consist of old mine tunnels, cellars and fortifications, and, with few exceptions, each site harbors only between a few and ca. 50 bats (Ryberg, 1947; Rydell, 1989; Rigstad *et al*., 1996; Rydell *et al*., 1999; Isaksen, 2007; Siivonen and Vermundsen, 2008; Michaelsen *et al.*, 2013; Belkin *et al*., 2014).

Although there are hundreds of old and disused mines in Sweden and the rest of Fennoscandia, most of them are more or less water-filled and only a few are safe enough to be surveyed for bats. Even fewer have been visited regularly and over sufficiently long periods. We present the result of winter bat counts in three mines in southern Sweden. The surveys began in 1980 and at two of the mines they have been carried out more or less regularly since then. We compare the resulting trends with those in the rest of Europe, as presented in the European Environmental Agency report (Haysom *et al*., 2014).

Materials and Methods

Study Sites

The locations of the mines included in this study are shown in Fig. 1 and features of the sites are given in Table 1. The mines are used by bats during the hibernation period in winter (October–April — Rydell *et al*., 1999) but there is also considerable late summer swarming activity (August–September — Karlsson *et al*., 2002). The mines are located in the central part of the province of Småland, southern Sweden, which is dominated by Precambrian rocks and moraines at 100–300 m a.s.l. The plant communities mostly consist of boreal or hemi-boreal coniferous forests, dominated by spruce *Pices abies* and pine *Pinus silvestris*, interspersed with extensive peat bogs in elevated areas with high precipitation, oligotrophic lakes and small scale farmland. Småland is sparsely populated by European standards (ca. 25 inhabitants per km^2) and with extensive areas of relatively intact forests remaining until recently.

The Taberg mine consists of two sections with separate entrances. In the period 1980–1986 only the northern section was surveyed, but since 1987, when most of mine was made safe and accessible, bats have been counted annually in both sections. The oldest parts of the mine consists of open pits with few or no bats but there are also regular shafts, tunnels and chambers that were constructed more recently (until WW2) by the use of dynamite (Table 1). In these parts there are abundant drill holes, which provide relatively constant temperatures and relative humidity and well protected hiding places for bats. The accessible and regularly surveyed tunnels are about 1.5 km, which is about 3/5 of the underground parts of the mine. The remaining 2/5 consists of more or less inaccessible shafts and large chambers, which have not been surveyed. The Taberg mine is a nature reserve since 1985. It is used for ecotourism in daytime in summer but is closed to visitors from 1 October to 30 April, with the exception of the annual bat counts.

The Kleva mine has been known as a locality for Natterer's bat in Sweden for a long time (Ryberg, 1947). However, winter visits to Kleva mine with the purpose of counting bats did not start until 1980 and were made more or less irregularly with respect to the timing and the area covered until 1988, when the mine was gated and made safe (Rydell *et al*., 1999). The Kleva mine is in private ownership. It is used for ecotourism in summer but maintained as a bat reserve between 1 October and 30 April, when it is closed to visitors. Deeper parts of the mine are water-filled, but passages and shafts in the upper part remain dry and accessible. Most of the Kleva mine is very old and constructed by fire-setting, which means that it's topography is irregular, although, like in the Taberg mine, there are also some adits and galleries made in the early 1900's by the use of dynamite (Table 1). The length of the accessible parts is similar to that of the Taberg mine, ca. 1.5 km.

The Ädelfors mine is relatively small and the accessible part consists of a rather narrow ca. 300 m long horizontal adit that ends in a shaft and a large chamber, mostly made long ago by fire-setting. It has not been visited regularly and no bat counts were carried out until 1980. It is not protected or gated at present and the disturbance in winter has probably been considerable and still occurs. However, the mine has a potential to harbor many bats, provided it receives proper protection, and is therefore included here.

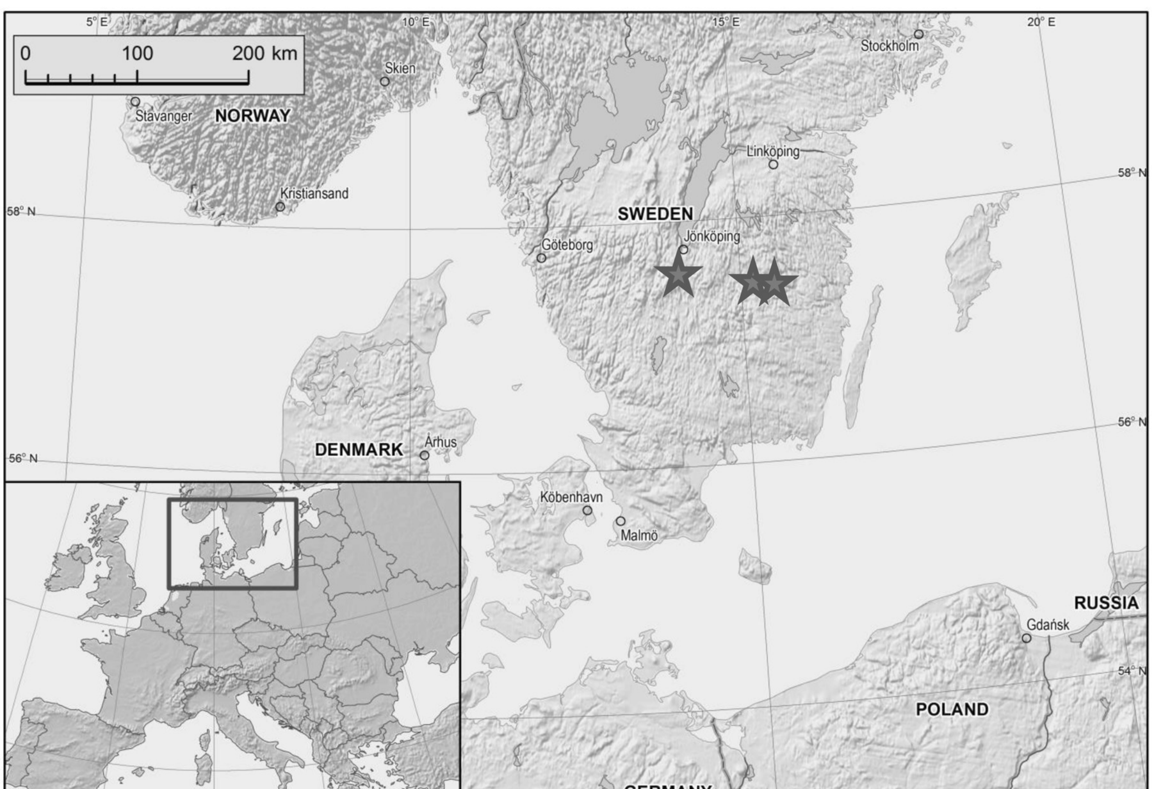

Fig. 1. The location of the three mines surveyed, from left to right Taberg, Kleva and Ädelfors. Source map kindly provided by W. Bogdanowicz

TABLE 1. Characteristics of the mines considered in this survey

Mine	Location (WPS84)	Length of accessible passages (km)	Metals mined	Active mining periods
Taberg	57.678, 14.082	1.5	Fe	1621–1880, WW2
Kleva	57.450, 15.279	1.5	Cu, Ni	1691–1889, WW1
Ädelfors	57.425, 15.353	0.3	Au	1738–1824, 1915–16

The Taberg and Kleva mines show considerable vertical gradients (ca. 50 m) and therefore also a more or less predictable variation in temperature and humidity between the various parts. In midwinter (January–early March) the temperature span is usually from about -2ºC in the lowest parts to about +9ºC, in the uppermost sections, but the mine is generally a few degrees warmer early and late in the season. The history and geology of the mines as well as illustrative horizontal and vertical maps can be found in Tegengren (1924).

Methods

Bats were counted using torches and binoculars. The censuses were usually made by a small group (3–5) of people each time, at least some of which were experienced with bat winter surveys, except in Ädelfors, which was visited by only one or two of us at a time. The counts normally took place during one day in January or February, or, in a few cases, in early March. For Kleva the *Myotis* species were pooled before this presentation because of uncertainties in the species identification in some years. The *M. mystacinus* and *M. brandtii* species pair have been treated together at all sites, mostly because we have not found any means to distinguish them easily and confidently in situ.

We netted and identified some bats outside the Taberg mine during swarming on a few occasions in the 1990's, which showed that both *M. brandtii* and *M. mystacinus* are present, with the former being most common. This is probably also the case in the Kleva and Ädelfors mines, but we have no capture data to confirm this. Capture of bats inside the mines has been avoided consistently in order to minimize the interference, and consequently we have no information on the sex and age of the hibernating individuals. To test if the observed trends in the number of bats in the mines were statistically significant, we employed non-parametric tests of serial randomness (Zar, 1984).

RESULTS

The increasing trends for Natterer's bat *Myotis nattereri* and *M. mystacinus*/*brandtii* at Taberg are significant ($P < 0.01$ — Fig. 2) and this is also true for *Myotis* spp. combined at Kleva ($P < 0.05$ — Fig. 3). The declining trend in the northern bat *Eptesicus nilssonii* in Taberg is also significant ($P < 0.01$), although the sample size is very small in this case. Daubenton's bat *Myotis daubentonii* and the brown long-eared bat *Plecotus auritus* do not show any significant trends and thus appear to be stable locally.

The Ädelfors mine was surveyed only four times, starting in 1980 when we found five *E. nilssonii* and eight *P. auritus*. In 1992 we found 15 *Myotis* spp., in 2011 no bats and in 2015 we found 13 *Myotis* spp., five *E. nilssonii* and four *P. auritus*. Hence the total annual count varied between zero and 22 bats belonging to at least four species. The low and variable counts in Ädelfors were almost certainly an effect of disturbance, as human activities sometimes occurred inside the mine in winter.

DISCUSSION

According to the compilation of survey data from underground hibernation sites in continental Europe and Great Britain (Hayson *et al*., 2014), the overall trend for bats seems to be positive at present, and, for the species that also occur in our study area, this is particularly noticeable for *M. mystacinus*/*brandtii* and *M. nattereri*. Other species, e.g., *M. daubentonii*, *E. nilssonii* and *P. auritus*, appeared to be more stable. Hence the trend that we observed in the Swedish mines is very similar to that in the rest of Europe (Haysom *et al*., 2014), and, although our data is very limited, it applies generally as well as for each individual species with the possible exception of *E. nilssonii*. Increases in hibernating bat populations, sometimes involving the same species as in our study, have been observed in other hibernacula in areas with similar winter climate further south in Europe, e.g., in Poland (Fuszara *et al*., 2010; Lesiński *et al*., 2011), the Czech Republic (Řehák and Gaisler, 1999) and Slovakia (Uhrin *et al*., 2010) but, although *Myotis* spp. seem to be increasing at some sites, the results are not clear-cut.

The present increase in some European bat species or populations, including several *Myotis* spp. is believed to be a response to improved environmental conditions and better protection, compared to some decades ago. According to Haysom *et al*. (2014: 7), "Bat populations … have undergone significant declines throughout Europe, particularly during the second half of the 20th century […] attributed to agricultural intensification, deliberate persecution, killing and destruction of roosts, habitat loss, fragmentation and degradation and impact of persistent timber-treatment toxic chemicals […]. The apparent population increase of some species

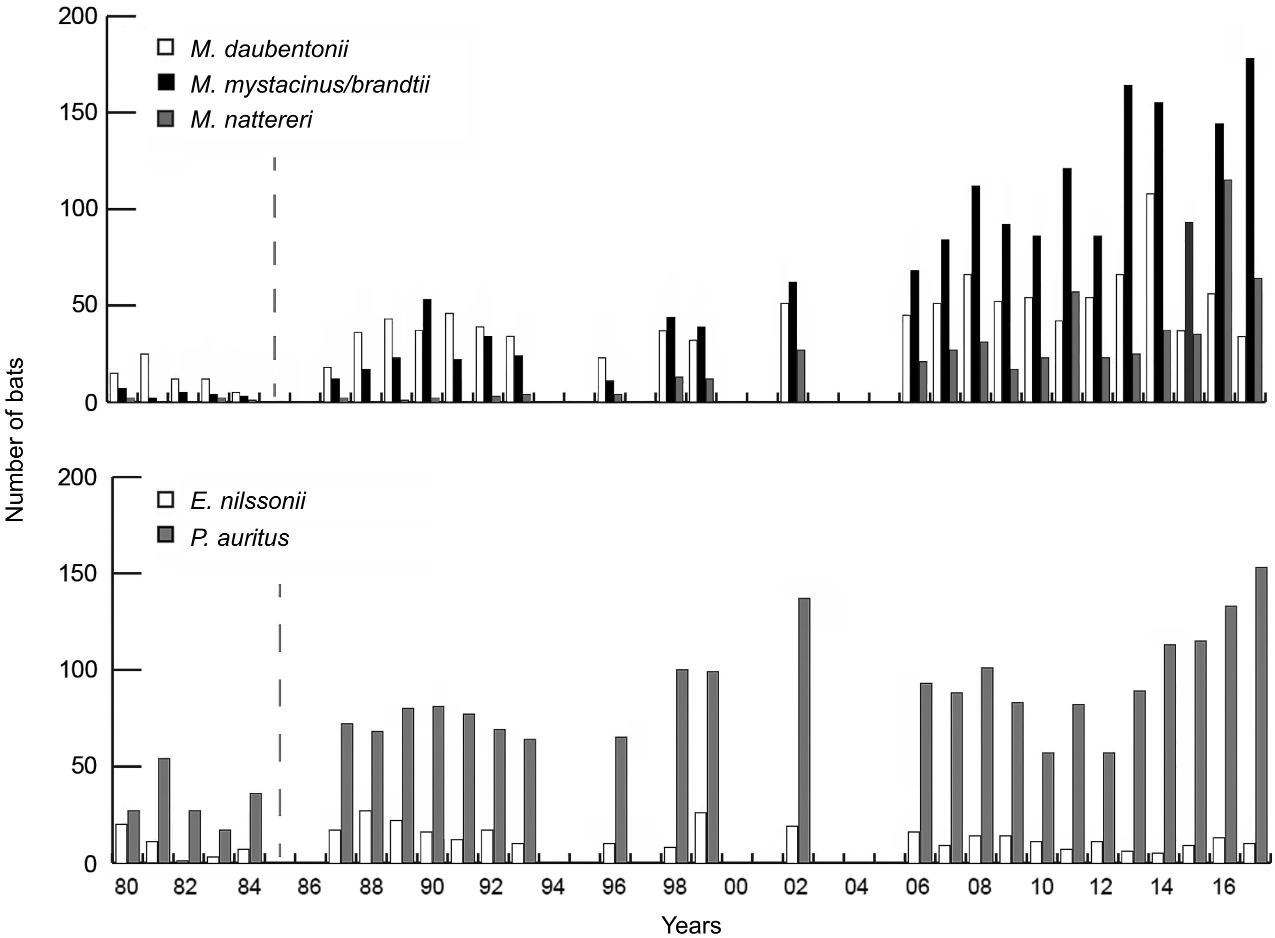

FIG. 2. Counts of bats hibernating in Taberg mine 1980–2017. Years without bars indicate that no counts were made. Only the northern part of the mine was surveyed before 1985, indicated by a hatched vertical line

[…] may reflect the impact of national and European conservation legislation, species and site protection, targeted conservation measures and widespread awareness-raising towards the European public and professional sectors, particularly under the EUROBATS agreement".

Gating of the mines in the 1980's has presumably provided much better protection and this effort may be part of the reason behind the general increase observed in the mines in our study, although this cannot explain the differences between the species involved. Indeed, the species showing the most noticeable increase in Sweden as well in the rest of Europe are *M. mystacinus/brandtii* and *M. nattereri*, which in Scandinavia are typical inhabitants of the forest, and as such would seem unlikely to have suffered seriously from any of the threats mentioned by Haysom *et al.* (2014) in the past. Consequently, a 'recovery' would not be expected in these particular species. If anything, we would expect the opposite, namely that they may have thrived in the past, when the northern forest was relatively intact, but suffer from the recent intensification of the forestry that currently transforms these forests into tree plantations on a large scale. Our results suggest that the increase in *Myotis* populations in Sweden cannot be understood in the terms mentioned by Haysom *et al*. (2014) except as a local response to the protection of the mines.

The northern bat, which also is a forest species, shows a slight but significant negative trend in our survey, but although it is very common in Småland, it is represented by very few individuals in the mines, so the data do not permit any conclusion. However, for this particular species, which often feeds at streetlights, a declining population trend may actually be expected, following the recent replacement of mercury vapor and high-pressure sodium lamps by LED and halogen lights, resulting in diminished availability of food (Lewanzik and Voigt, 2017) compared to the situation before the shift (Rydell, 1992).

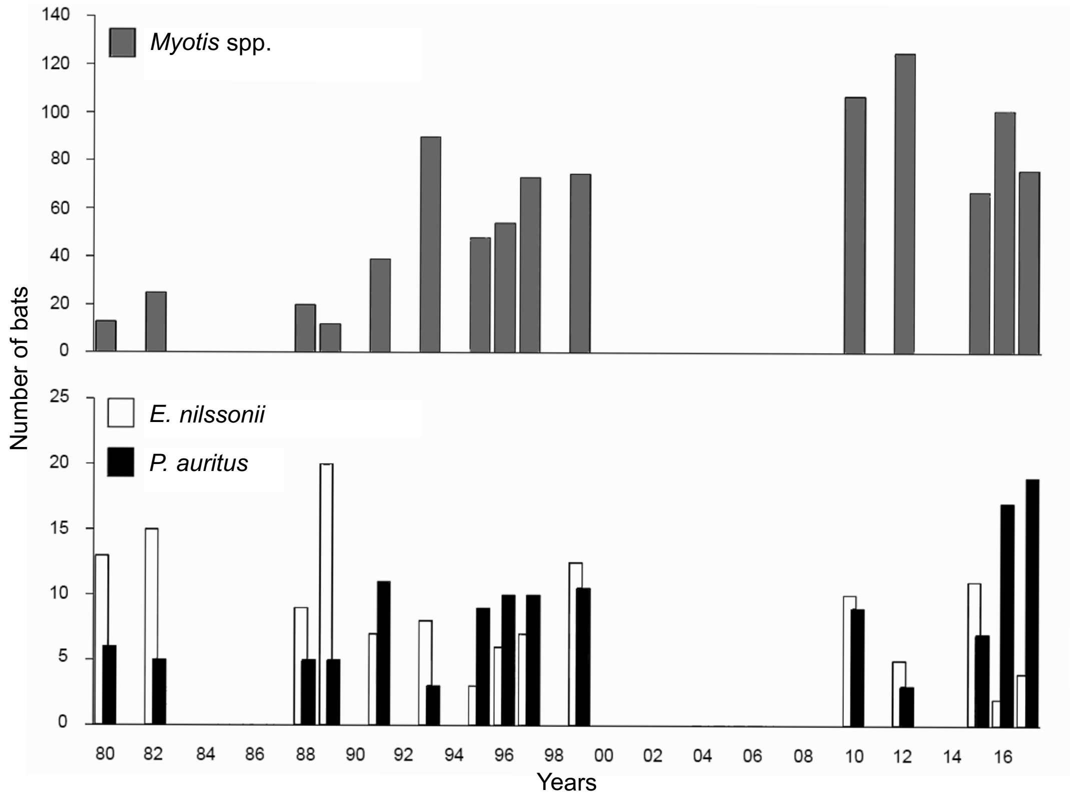

FIG. 3. Counts of bats hibernating in Kleva mine 1980–2017. Years without bars indicate that no counts were made

Changing numbers of bats in a particular hibernaculum could be related to the availability of other suitable roosts so that destruction of some hibernacula may result in more bats in those that remain intact. In Sweden and neighboring countries *E. nilssonii* and *P. auritus* typically hibernate alone or in small groups in houses, cellars and similar places (Rydell, 1989; Vintulis and Petersons, 2014), which are unlikely to be in short supply. The individuals found in mines represent only a small fraction of the populations. However, for the *Myotis* species, few hibernacula are known in Sweden with the exception of the mines and, hence, we cannot evaluate the possibility that the increase in Taberg and Kleva mines are related to loss of other hibernacula nearby. However, we have no indication that this is the case and we find it unlikely.

The winter temperature, based on the daily mean for December to February in Småland, specifically in the Jönköping Region, where the three mines are located, has increased by 0.8ºC (-2.8 to -2.0) between 1980 and 2017, i.e. over the course of this study and the winters have become shorter by ca 10 days on average during the same period (Ohlsson *et al.*, 2015). Temperature has not been measured consistently inside the mines, but we can probably assume that the climate inside has changed in a similar way as outside. However, caution is needed, because there is considerable air flow through the mines, and this may affect the temperature considerably, particularly in exposed parts.

Bats with a northern distribution in Europe, particularly those that are adapted to a cold climate, are expected to show a stronger negative response to the ongoing climate change than bats further south (Rebelo *et al.*, 2010; Sherwin *et al.*, 2013). There are also cases where bats clearly expand rapidly towards the north at present (Lundy *et al.*, 2010). We find it possible, at least intuitively, that a shortening of the winter by 10 days may compensate for the increased energy consumption during hibernation due to rising temperature by 0.8°C (as in our case). Furthermore, bats can probably easily compensate for the increased temperature by using sites that stay colder, as sufficient variation is always available within each of the mines. Nevertheless, we cannot exclude the possibility that the increasing trend in some *Myotis* species is an effect of climate change (Humphries *et al.*, 2002). Better protection locally may also have a positive effect.

Finally, it is interesting but somewhat puzzling that the two species that have the northernmost distributions of all bats, namely *E. nilssonii* and *M. brandtii* (recall that most M. *mystacinus/brandtii* in our counts were *M. brandtii*) showed opposite trends. While the former showed a slightly negative trend, the latter showed the most dramatic increase of all the species. This discrepancy casts some doubt over the generality in the prediction mentioned earlier (Rebelo *et al*., 2010), namely that bats adapted to a cool climate will suffer most seriously from global warming.

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