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Research Article

Changes in Bat Abundance in Winter Roosts Close to the Polish-German Border in the Years 2000-2019: Are the Increasing Trends Continued in Central Europe?

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Abstract: Results of the study on bats wintering in underground objects of the Kostrzyn Fortress (Polish-German border zone) revealed the presence of at least 11 species (without distinguishing between *Myotis mystacinus* and *M. brandtii* and among species of the genus *Pipistrellus*). Analysis of long-term changes in the number of animals in regularly surveyed winter roosts showed a positive trend in *Myotis myotis* and a negative trend in *Plecotus auritus*. No statistically significant trends have been found in other species, which indicates that the rising numbers of many Central European bat populations have slowed down in the last two decades. Particular winter roosts differed in changes of bat numbers, which was a result of differentiated character of their micro-shelters and changes in microclimate. Similar patterns of changes during the study period were noted in pairs of thermophilic *Myotis nattereri* and *M. daubentonii* and in cryophilic *P. auritus* and *Barbastella barbastellus*. This indicates that the adopted strategy of wintering significantly affects species response to variable weather conditions during various periods of hibernation.

Key words: Chiroptera, hibernation, long-term changes, population trends, wintering strategies, Kostrzyn Fortress

Introduction

The extent strongholds in Poland and in Eastern Germany are often important wintering grounds for bats. Numerous wintering sites of these mammals were noted in many old military objects (Klawitter 1980, Fuszara & Fuszara 2002, Jurczyszyn et al. 2002, Kasprzyk et al. 2002, Lesiński & Kowalski 2002, Harder 2005, Bernard et al. 2019, Kokurewicz et al. 2019, Bator-Kocoł & Cichocki 2020). The Kostrzyn Fortress situated close to the Polish-German border belongs to such places. First data on bats present there have been acquired in the beginning of the 1990s (Gólski & Urbańczyk 1992).

Tracing changes in the number of bats hibernating in large winter roosts is one of commonly used methods to determine long-term population trends of particular species. Strong decline in the number of bats was an effect of the intensive application of toxic plant protection chemicals after the World War II (Jefferies 1972, Geluso et al. 1976, Thies & McBee 1994, O'Shea et al. 2016). Moreover, due

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to other unfavourable conditions such as disturbing bats in their roosts (Stebbings 1988), landscape changes like deforestation and/or forest fragmentation (Stebbings 1988, Lesiński et al. 2007), the effect of road infrastructure (Kiefer et al. 1994-1995, Lesiński 2007) or toxic wood preservatives (Leeuwangh & Voûte 1985, Mitchell-Jones et al. 1989), some European species in part of their range found themselves at the brink of extinction. That was the case of *Rhinolophus hipposideros* (Daan 1980, Bárta et al. 1981, Harmata 1981, Kokurewicz 1990) or *Rh. ferrumequinum* (Ransome 1989) among others.

After the abandonment or substantial reduction of the use of toxic pesticides, their content in bats' bodies decreased markedly (Bayat et al. 2014) and many European species started rebuilding their populations, which was well documented by long-term monitoring of bats' numbers carried out in various parts of the continent in both large winter roosts (Lesiński et al. 2005, Horáček 2010, Uhrin et al. 2010, Lesiński et al. 2011, Spitzenberger & Engelberger 2013, Van der Meij et al. 2015, Kokurewicz et al. 2019, Bator-Kocoł & Cichocki 2020, Toffoli & Calvini in press) and in reproduction colonies (Froidevaux et al. 2017, Toffoli & Calvini 2019). This process intensified strongly at the turn of the 20th and 21st centuries. The question is: could we still observe the increasing number of bats in the last two decades or rather bat populations started to stabilise to reach the limits determined by environment holding capacity?

Recently, it has been taken into account that climate warming may affect the results of monitoring of some bat species. Species that choose relatively cool places for hibernation may not find appropriate conditions in many underground roosts. Studies on *Barbastella barbastellus* wintering in underground objects in areas of different climate in Poland showed diverse long-term changes in the number of hibernating individuals (Gottfried et al. 2020). Similar effect of weather conditions on selection of places for bat hibernation in Western Poland was described by De Bruyn et al. (2021).

Apart from estimating species composition and domination structure of bats wintering in the Kostrzyn Fortress, the aim of this study was to determine long-term trends in the number of bats. We wanted to check whether bat populations from Central Europe still show increasing trends or rather stabilise their numbers and whether fluctuations in the number of individuals of species having diverse wintering strategies in different years have similar patterns.

Materials and Methods

Bats were studied in the Kostrzyn Fortress and in forts surrounding the town by the Odra River (Fig. 1). Monitoring was carried out in 16th to 19th century buildings situated in Old Kostrzyn: Bastion Król, Bastion Filip and Ravelin August. Bats were also studied within the Old Town (in cellars of ruined palace, post office and of some other buildings and in crypts of a ruined church). Cellars of the Old Town in further analyses were combined together. Most important and largest objects of Old Kostrzyn are: Bastion Filip of an area of about 770 m^2 (Anonymous 2021) and Bastion Król of an area of about 1600 m^2 (Wesołowski & Koławiecka 2014). Studies were also carried out in 19th century forts: Sarbinowo, Żabice, Czarnów and Gorgast situated within a ten-kilometre radius from Kostrzyn. Moreover, a concrete bunker near Fort Sarbinowo built in the 20th century was also controlled. Most visited objects are situated in Poland, only fort Gorgast is located in Germany. With the exception of four forts under study, the town was completely destroyed in the year 1945 and now remains in the form of preserved ruin. Now, the town Kostrzyn by Odra is situated near this area, on the other side of the Warta River at its outlet to the Odra River (Fig. 1).

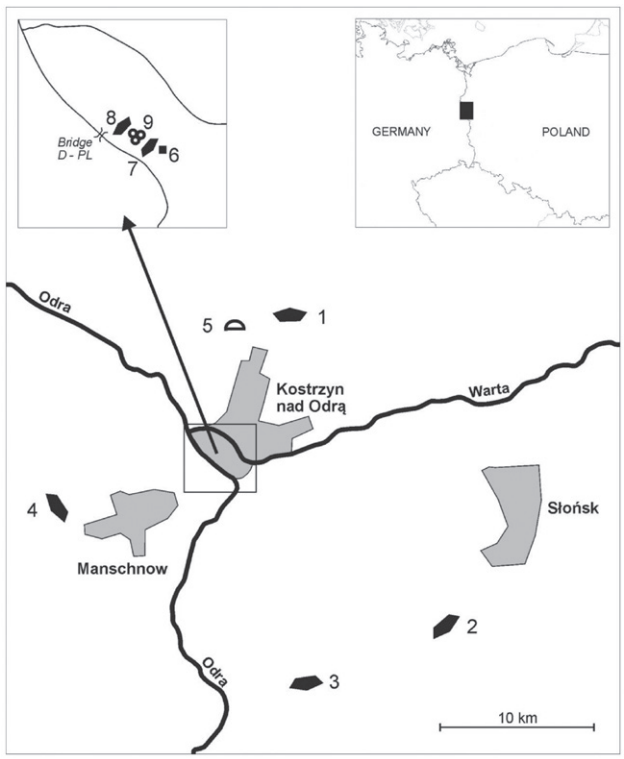

Fig. 1. Displacement of study objects of the Kostrzyn Fortress. 1 – Fort Sarbinowo, 2 – Fort Czarnów, 3 – Fort Żabice, 4 – Fort Gorgast, 5 – Shelter near Sarbinowo, 6 – Ravelin August, 7 – Bastion Filip, 8 – Bastion Król, 9 – Old Town

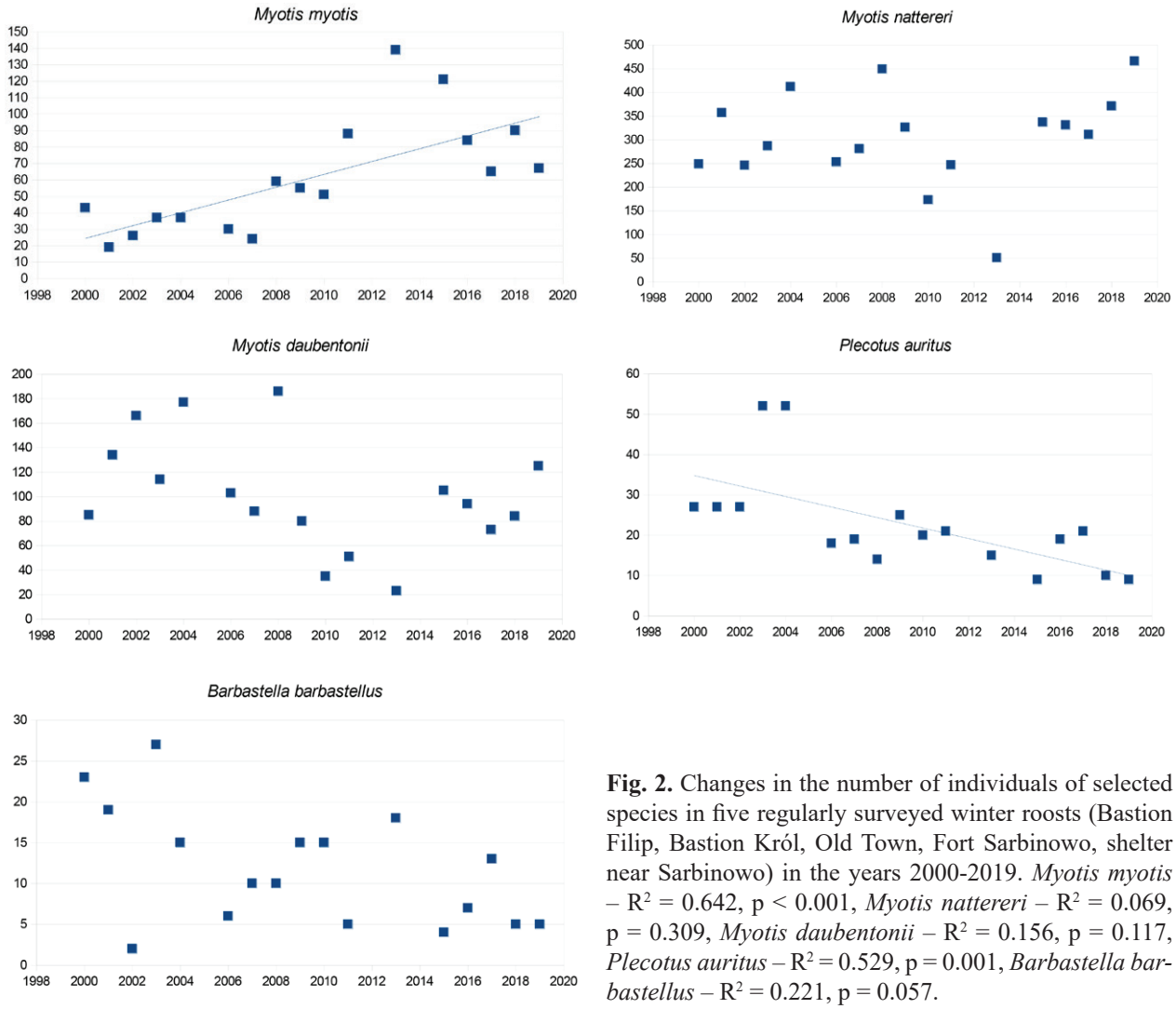

Fig. 2. Changes in the number of individuals of selected species in five regularly surveyed winter roosts (Bastion Filip, Bastion Król, Old Town, Fort Sarbinowo, shelter near Sarbinowo) in the years 2000-2019. *Myotis myotis* – $R^2 = 0.642$, $p < 0.001$, *Myotis nattereri* – $R^2 = 0.069$, $p = 0.309$, *Myotis daubentonii* – $R^2 = 0.156$, $p = 0.117$, *Plecotus auritus* – $R^2 = 0.529$, $p = 0.001$, *Barbastella barbastellus* – $R^2 = 0.221$, $p = 0.057$.

Studies were carried out between 2000 and 2019. No inventory in any object was made in the year 2005. In part of the buildings, no studies were carried in some years for various reasons (object not accessible, a lack of agreement for carrying studies from building administrators, etc.). In Fort Gorgast, studies were made since 2008 with the break in 2012-2014. Fort Żabice was controlled for the first time in 2004; earlier a dumping site for outdated herbicides was located there.

The number of bats in particular objects was counted during census performed daily in the first half of February. Species of wintering bats were determined based on their external features without awaking of bats. Bats that could not be reliably attributed to species (e.g. animals hidden deep in crevices) were determined as Chiroptera indet. The species of *Pipistrellus* were identified at the generic level only since hibernating individuals were not taken in hands. *Myotis mystacinus* and *M. brandtii* were not distinguished and counted together. The study area is out of the northern range of *Myotis alcathoe* in Poland (Kmiecik et al. 2020).

Spearman's rank correlation coefficients was used to estimate population trends (Gauthier 2001) and the relationships of the numbers of individuals in the pairs of species. Obtained data were statistically processed with the use of Statistic 13.3 software adopting significance level at $p = 0.05$.

Results

At least 11 bat species were found wintering in the controlled underground roosts (Table 1). The most numerous was *Myotis nattereri* (more than half of bats) and quite frequent were also *Myotis myotis* and *M. daubentonii*. These three species together constituted almost 90% of all recorded bats. Apart from the three listed above, *Plecotus auritus* and *B. barbastellus* were found most often (Table 1).

Long-term trends in the number of bats were analysed in five selected objects, which were regu-

Table 1. Domination (%) of particular bat species in the Kostrzyn Fortress in the years 2000-2019 (N – the number of individuals without bats not determined to species)

Species	N	%
Myotis myotis	1292	12.8
Myotis bechsteinii	10	0.1
Myotis nattereri	5886	58.2
Myotis mystacinus / Myotis brandtii	8	0.1
Myotis dasycneme	1	0.0
Myotis daubentonii	1840	18.2
Eptesicus serotinus	89	0.9
Pipistrellus spp.	145	1.4
Plecotus auritus	505	5.0
Plecotus austriacus	44	0.4
Barbastella barbastellus	295	2.9
Total	10115	100.0

Table 2. Spearman correlation coefficients in the number of individuals between pairs of species in five regularly controlled winter roosts (Bastion Filip, Bastion Król, Old Town, Fort Sarbinowo, shelter near Sarbinowo) in the years 2000–2019. Statistically significant relationships are given in bold.

Species vs. species	*Myotis myotis*	*Myotis nattereri*	*Myotis daubentonii*	*Plecotus auritus*
Myotis myotis	---------- -----	–	–	–
Myotis nattereri	0.077 p = 0.768	---------- -----	–	–
Myotis daubentonii	– 0.456 p = 0.066	**0.608 p = 0.010**	---------- -----	–
Plecotus auritus	**– 0.617 p = 0.008**	– 0.255 p = 0.323	0.135 p = 0.604	---------- -----
Barbastella barbastellus	– 0.302 p = 0.239	0.154 p = 0.555	– 0.149 p = 0.568	**0.559 p = 0.020**

larly controlled during the study period. Statistically significant relationships were found in only two species: an increasing trend in *M. myotis* and a decreasing trend in *P. auritus*. A weaker (insignificant p = 0.057) declining tendency was found in *B. barbastellus* (Fig. 2).

Long-term trends in the number of individuals of the studied species were not the same among particular winter roosts. Statistically significant declines were noted in Bastion Filip and Fort Czarnów while an increase in the number of bats was recorded in Fort Sarbinowo. Close to the limit of significance was an increasing trend in Fort Żabice (Fig. 3). In five regularly surveyed roosts combined there was no statistically important trend in the number of hibernating bats ($R^2 = 0.030$, p = 0.477).

Correlations between the numbers of individuals were analysed in pairs of species wintering in regularly controlled roosts. Positive correlations were found between *M. nattereri* and *M. daubentonii* as well as between *P. auritus* and *B. barbastellus*. Negative correlation was found in the number of individuals of *M. myotis* and *P. auritus* (Table 2).

Discussion

No clear trends in the number of individuals were found for most species in the study area during the last two decades. This may indicate stabilisation of some populations after significant increases observed since 1980s in Central Europe (Horáček 2010, Lesiński 2010, Uhrin et al. 2010, Lesiński et al. 2011). Similar stabilisation or a slight decline in the number of bats after constant increase since 1985 was observed in *Rh. hipposideros* in Austrian winter roost after 2005 (Spitzenberger & Engelberger 2013). Increasing number of some bat species was also inhibited in Slovakia in the end of the 20th century (Uhrin et al. 2010).

The only species which has shown a distinct increase in the number of wintering individuals in the study area is *M. myotis*, which coincides with findings from recent years in a large winter roost in the Nature Reserve Nietoperek situated several tens of kilometres south-east from the study area. The number of individuals of this species wintering there increased almost twofold during the last two decades (Bator-Kocoł & Cichocki 2020). Increasing trends have been found in Poland recently also in *M. nattereri* while at the same time *M. daubentonii* showed declining trends (Fuszara et al. 2010, Bernard et al. 2019); this was, however, not confirmed in winter roosts near Kostrzyn.

Interpretation of obtained results may be significantly affected by climate warming manifesting itself (also in western Poland) in the recent decades by frequent mild winters. Species presenting various wintering strategies may differently use underground roosts respective to weather conditions. This may be confirmed by positive correlations between the number of wintering individuals in species which choose warmer sites for hibernation (*M. nattereri* and *M. daubentonii*) and those selecting colder sites (*P. auritus* and *B. barbastellus*). It was shown that temperatures preferred by the two groups of bat species in Central Poland differ by several degrees Celsius (Lesiński 1986).

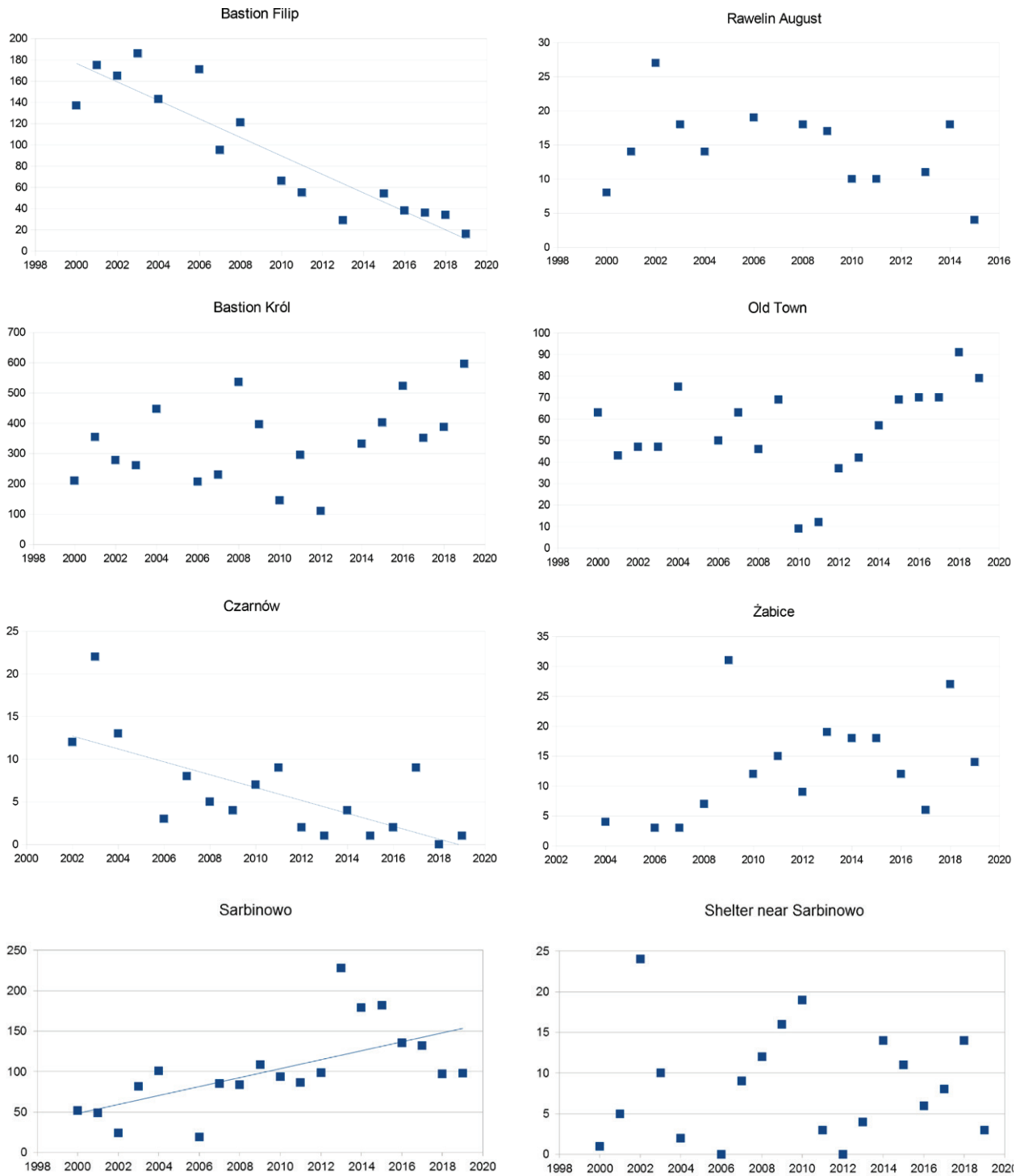

Fig. 3. Changes in the number of bats wintering in eight regularly surveyed winter roosts in the years 2000-2019. Bastion Filip – $R^2 = 0.815$, $p < 0.001$, Ravelin August – $R^2 = 0.077$, $p = 0.360$, Bastion Król – $R^2 = 0.151$, $p = 0.111$, Old Town – $R^2 = 0.151$, $p = 0.100$, Fort Czarnów – $R^2 = 0.501$, $p = 0.001$, Fort Żabice – $R^2 = 0.251$, $p = 0.057$, Fort Sarbinowo – $R^2 = 0.510$, $p < 0.001$, Shelter near Sarbinowo – $R^2 = 0.009$, $p = 0.699$.

It is conceivable that the rebuilding of bat populations observed in the last decades was affected not only by limitation of strongly toxic pesticides but also by other factors. Among the latter, most often indicated is the effect of climate warming (Piksa & Nowak 2013, Froidevaux et al. 2017). It is possible that the increase in the numbers of *M. myotis* noted in the last two decades in Western Poland (Bator-Kocoł & Cichocki 2020, this study) is somehow associated with this phenomenon.

Results presented here may indicate that at least some bat species hibernating in underground

objects in this part of Central Europe ended the process of intensive rebuilding of their populations. Results of long-term studies in a hibernaculum located ca. 140 km NE from Kostrzyn (Bernard et al. 2019) lead to the similar conclusion. Changes in the number of bats in winter roosts and their translation onto changes in the number of individuals in local populations should be, however, interpreted with caution. To obtain more reliable data one should continue monitoring and studies for several decades in order to eliminate the effect of weather conditions in particular years on the number of observed bats.

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