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# Analysis of the impacts of global warming on European bat species's range area in the 21st century using regional climate model simulation


**Júlia Anna Nagy**[1]*, **Judit Bartholy**[1], **Rita Pongrácz**[1], **Ildikó Pieczka**[1], **Hajnalka Breuer**[1], and **Levente Hufnagel**[2]

[1]*Department of Meteorology, Eötvös Loránd University,*
*Pázmány Péter sétány 1/A, H-1117 Budapest, Hungary*

[2]*Crop Production Institute, Szent István University,*
*Páter Károly u. 1, H-2100, Gödöllő, Hungary*

**Corresponding author E-mail: julcsi@nimbus.elte.hu*



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**Abstract**—Due to the projected climate change, the living territory of wild animals may be reshaped in the future, some of the species may even suffer extinction. The aim of this research is to make a comparative case study for the future predictions of the European terrestrial mammals' vulnerability to the climate change, by using their current range area maps (on the basis of The Atlas of the European Mammals). To characterize the climate indicators of the animals, we use the annual means and/or extremes of four climatic parameters (daily mean temperature, daily minimum temperature, daily maximum temperature, daily precipitation sum) based on the gridded E-OBS dataset for 1961–1990. Then, we determine specific percentiles of the climatic parameters for given species. The range area within the specific climatic intervals formed by the selected percentile pairs are mapped for the recent past (1961–1990), and also for the middle (2021–2050) and the end (2071–2100) of the 21st century using the RACMO (Regional Atmospheric Climate Model) simulation for the SRES A1B scenario. Our results suggest that, the optimal climatic requirements of the *Pipistrellus pipistrellus* may decrease and shift northward until the end of the 21st century. Moreover, this anaysis based on the climate indicator profile technique suggests a remarkable change in the habitats of all studied European bat species, and their northward migration in order to find their optimal conditions. As a result, from the recent past time period of 1961–1990, 63% of the studied European bat species will probably suffer habitat decrease, while 30% are likely to experience habitat increase, and 7% is projected to disappear by the end of the 21st century. Due to the projected regional climate change in Europe, habitat loss and degradation are the greatest threats to the studied bat species.



*Key-words*: mammals, bat species, temperature, precipitation, migration, ecology

## *1. Introduction*

The results of the ENSEMBLES project predictions concerning Europe suggest that under the A1B medium-high emission scenario (*Nakicenovic* and *Swart*, 2000) without mitigation, yearly mean temperature may rise by 1–2 °C by 2021–2050, and 1,5–4 °C by 2071–2100 relative to the baseline period 1961–1990 (*van der Linden* and *Mitchell*, 2009). The greatest warming in both periods is likely to occur in northeastern and southern parts of the continent. The projections indicate large differences across Europe for yearly precipitation sum and both the overall intensity and frequency of extreme precipitation events. In the northern areas, an overall increase in precipitation is projected, whereas drying trend is likely to occur in southern Europe (*van der Linden* and *Mitchell*, 2009).

Changing climate affects not only humans and, therefore, the urban environment, but also the living conditions of wild animals. One of the most important impacts of climate change may be that animals tend to occupy geographical regions with climatic conditions, which become suitable to the specific requirements of the given species. Therefore, local extinctions may arise and populations may suffer fragmentation (e.g., *Thomas et al*., 2004; *Peterson* and *Williams*, 2004; *Pounds et al*., 2006). The extinction and their survival in unconnected populations may cause reduction of genetic variability and high levels of inbreeding (*Ezard* and *Travis*, 2006).

The relationship between global warming and the response of the wildlife is obviously strong (*Williams et al*., 2003). The analysis of geographical impacts of climate change to wildlife is an increasingly popular research topic (*Thomas et al.*, 2004; *Diós et al*., 2009; *Drégelyi-Kiss* and *Hufnagel*, 2009*; Chen et al*., 2011; *Bartholy et al.,* 2012), however, the projections of future conditions are rarely investigated due to the lack of suitable model simulation outputs and the complex interdisciplinary methodology.

Climate is one of the abiotic factors, which controls primarily the range areas of the wildlife. If the climate significantly changes in a particular region, it may disturb the ecosystem and increase the chance of extinction. According to *Williams et al*. (2007), under the SRES A2 scenario (*Nakicenovic* and *Swart*, 2000) assumptions, 12–39% of the Earth's terrestrial surface is likely to experience significantly different climate conditions from the current climate.

Due to the anthropogenic activity, Europe is one of the most highly fragmented continents of the globe. Consequently, only about 1% of the surface area of the continent can be considered as wilderness, with the old-growth forests of Scandinavia, Poland, and Russia (*Jaeger et al*., 2011). Landscape fragmentations caused by roads, highways, and other artificial surfaces, have a number of detrimental effects, i.e., reduction in size and persistence of wildlife populations, and can provide great barriers to migrating animals (*Hanski*, 2005). Species' adaptation to current habitat fragmentation, and additionally to projected future climate change is an essential ecological problem. The key to this issue is providing increased connectivity, which could be the most significant aspect of mammal conservation in Europe (*Temple* and *Terry*, 2007).

Increasing temperature is estimated to cause significant loss of appropriate environment of all regionally endemic animals. On a European scale, roughly 25% of the wild terrestrial mammals are endemic to the continent (*Chen et al.,* 2011). The species that are affected the most negatively by climate change are the habitat specialists, and the species being less mobile. Species that live in fragmented landscapes may also struggle with the negative impacts of climate change, because they are not able to colonize the area (*Chen et al*., 2011).

According to *Temple* and *Terry* (2007), 15% of all wild European terrestrial and marine species are threatened, and 9% are listed near threatened, furthermore, 1.3% are already regionally or globally extinct. Nowadays, the rate of species extinctions worldwide is 100 to 1,000 times greater compared to the natural rate and is rapidly accelerating (*May et al.*, 1995). To moderate and delay the negative impacts of climate change on species' loss is both urgent and probably the most important issue for ecological researchers (*Bátori et al*., 2014).

In the regional ecosystems, bats are highly vulnerable to changing climate (*Burns et al*., 2003; Rebelo et al., 2010), that is why they can be considered as important indicator species, which may facilitate in identifying areas where conservation efforts should focus on. For instance, a few recent studies (e.g., *Rebelo et al*., 2010, *Prydatko et al*., 2011; *Sherwin et al*., 2013) demonstrate how the predicted climate change will affect the distribution of different bat species. According to *Petersen et al*. (2014), in the past three decades, there has been a significant increase in bat records in Iceland and the Faroes, which could probably be linked to climate change. It has also been reported that the analyzed time period of 2001–2010 was the warmest in the Faroes since 1890 (*Cappelen,* 2011). Additionally, climate change may result in many other impacts on bat species around the world. For example, a recent study by *Luo et al*. (2014) shows that global warming is likely to alter the prey detection ability of echolocating bats. This may affect the bat species' community structure and their distribution, as well as those of their insect prey.

The above mentioned studies all highlight the importance of this global issue and the need for further research to understand the mechanisms of climate stress to ecosystems. Such detailed analysis may help to minimize the negative impacts of global warming to the wildife and ecosystems before it would be irreversible.

The aim of our research is to make a comparative study for the future predictions of the European terrestrial mammals' vulnerability to the climate change. In the current study, fine (25 km) resolution, bias-corrected outputs of the RACMO (Regional Atmospheric Climate Model) simulation taking into account the SRES A1B intermediate emission scenario are analyzed for the entire 21st century. First, the data describing climatic conditions are identified for each mammal species. Then, the values of the four climate variables are presented on maps for the past (1961–1990), the middle (2021–2050), and the end (2071–2100) of the 21st century. Finally, changes in the future potential spatial status and size of given species' habitat are calculated.

## *2. Materials and methods*

### *2.1. Data used in the analysis*

Our analyses are based on the following databases: (1) The Atlas of European Mammals (available from Societas Europaea Mammalogica) is used for defining the range area of species. This database was compiled in 1999 (*Mitchell-Jones et al.*, 1999) and has been widely used as reference dataset. It separately contains data for the pre-1970 and post-1970 presence of mammal species in Europe. (2) To characterize the climate indicators of the animals, we use the 30 years means of four climatic variables (daily mean temperature, daily minimum temperature, daily maximum temperature, daily precipitation sum) based on the gridded E-OBS dataset (*Haylock et al.*, 2008) using 25 km horizontal resolution. This database was compiled from quality controlled daily data of national meteorological station networks. (3) For the future, predictions of the temperature and precipitation for time periods 2021–2050 and 2071–2100 considering SRES A1B (Nakicenovic and Swart, 2000) scenario, we use the bias-corrected outputs of RACMO simulation (*van Meijgaard et al.*, 2008), which was completed by KNMI (Royal Netherlands Meteorological Institute) in the framework of the ENSEMBLES project (*van der Linden* and *Mitchell*, 2009). Bias correction of daily data was completed on the basis of monthly quantile matching technique (*Pongrácz et al.*, 2014) for the time period of 1961–2100.

### *2.2. Species' climate indicator profile*

According to *Vaughan et al.* (2000) estimations, every endotherm has a thermal neutral zone (TNZ), which covers the temperature tolerance range. Within the species' TNZ the organisms do not need to produce extra energy to keep itself warm, neither cooling themselves. Therefore, minimum, maximum, and mean temperatures were used as species' climate indicator variables. In addition, precipitation sum also influences the wild mammals by controlling their resource availability (*Hooper et al.*, 2005), that is why precipitation is also considered as climate indicator variable.

Each European bat species was characterized by specific percentile pairs related to the four climate describing variables (mean temperature, precipitation sum, minimum temperature, maximum temperature) and the climatic values that mostly cover the current spread of the species in Europe. The specific percentiles were determined on the basis of the E-OBS datasets representing the observations (*Haylock et al.,* 2008), and using combined analysis of digitalized distribution maps by The Atlas of European Mammals (*Mitchell-Jones et al.*, 1999). We have evaluated the bat species in Europe by their climatic requirements. During this process, on the basis of all the values of the climatic variables where the Atlas shows the presence of the species, the empirical distribution is determined. From this distribution, a „lower” and an „upper” percentile can be selected using the step value of 0.01 in the empirical cumulative relative frequency; i.e., the minimum value is paired to the 1st, 2nd, ..., 100th percentiles; the 1st percentile is paired to the 2nd, 3rd, ..., 100th percentiles; ..., the 99th percentile is paired to the 100th percentile. Thus, altogether 5050 ($101 \cdot 100/2$) possible pairs are evaluated for each climatic variable. For this purpose, specific percentile pairs were determined from the following gridcell-based values of the climatic variables:

- annual mean values of the daily mean temperature data averaged for 30 years;
- annual maximum values of the daily maximum temperature data averaged for 30 years;
- annual minimum values of the daily minimum temperature data averaged for 30 years;
- annual sum values of the daily precipitation data averaged for 30 years.

Two percentiles were selected to form an interval, which were used to calculate the number of gridcells according to the following criteria:

- $A$ indicates the number of gridcells where particular species could live under temperature and precipitation conditions, and it actually lives (located in the area between the two percentile values, and it actually is included in the Atlas).
- $B$ indicates the number of gridcells where particular species could live under the temperature and precipitation conditions, but does not live (located in the area between the two percentile values, but there is no recorded presence according to the Atlas).
- $C$ indicates the number of gridcells, where particular species could not live under the actual temperature and precipitation conditions, but it actually lives (the climatic value is not between the two percentiles, but there is a recorded presence in the Atlas).

These criteria were analyzed for all possible pairwise selection of the "lower" and "upper" percentiles (5050 percentile pairs), then, the value of $Q$ was calculated using the following formula:

$$Q = A / (A + B + C) \tag{1}$$

The final "lower" and "upper" percentiles were determined for each climatic variable (mean temperature, precipitation sum, minimum temperature, maximum temperature), where the procedure leads to the regional maximum value of Q. The interval between these "lower" and "upper" percentiles describes the climatic requirements of a given species.

We prepared the index graphs for all the mammal species including the bat species analyzed in this paper. The values of the four climatic variables (mean temperature, precipitation sum, minimum temperature, maximum temperature) were mapped for the recent past (1961–1990) and for two future time periods (2021–2050, 2071–2100) based on the simulation outputs. Moreover, the projected changes of the size and spatial status of the area (range) were also mapped for the mid- and late-century.

### *2.3. Spatial scale of the analysis*

The applied study area was limited by the simulation domain of RACMO, which extends from 34°N to 74°N latitude, and from 11°W to 41°E longitude, this includes western Europe, with the eastern borders of Finland, the Baltic states, Poland, Slovakia, Hungary, Romania, Bulgaria, and European Turkey (Thrace) forming the eastern border. Moreover, from the Atlantic, the Faroe Islands were included, as were the Portuguese and Spanish islands of Macaronesia. In the south, Malta was included. The range area maps were scaled to a fine (25 km) horizontal resolution of the E-OBS climate data and the RACMO simulated data.

## *3. Results*

This analysis based on the climate indicator profile technique enables us to estimate the possible regional impacts of the projected climate change to the living territory and conditions of the European bat species. These species have been selected, because recent studies suggest that bat species are affected negatively by climate change (*Burns et al*., 2003; *Rebelo et al*., 2010), and their responses have been rarely studied.

Among the results, a methodological case study based on the simultaneous analysis of the current range map from The Atlas of European Mammals and the E-OBS observations database for 1961–1990 is analyzed here, through the example of the common pipistrelle (*Pipistrellus pipistrellus, Temminck, 1840*). The climate indicator maps for the mid-century (2021–2050) and the end of the 21st century (2071–2100) characterize the sensitivity of the estimated changes in the habitat of species *Pipistrellus pipistrellus*, due to the projected regional climate change in Europe. Then, using the current range maps from the Atlas of European Mammals, changes in the future potential spatial status and size of 30 European bat species' habitat were calculated. Moreover, we have determined the most endangered wild European mammals for the entire 21st century, to be focused for future action plans and protect these species. Such detailed analysis may help to minimize these negative impacts of global warming.

Based on the current range map of the common pipistrelle, this species is present in 4,216 grid cells in Europe (*Fig. 1*). Its conservation status is 'least concern' (*Temple* and *Terry*, 2007), nevertheless, it is protected in Hungary. The species is listed in Appendix III of the Bern Convention – i.e., Convention on the Conservation of European Wildlife and Natural Habitats, 1979 –, and Appendix II of the Bonn Convention – i.e., Convention on the Conservation of Migratory Species of Wild Animals, 1979 (*Battersby,* 2005).

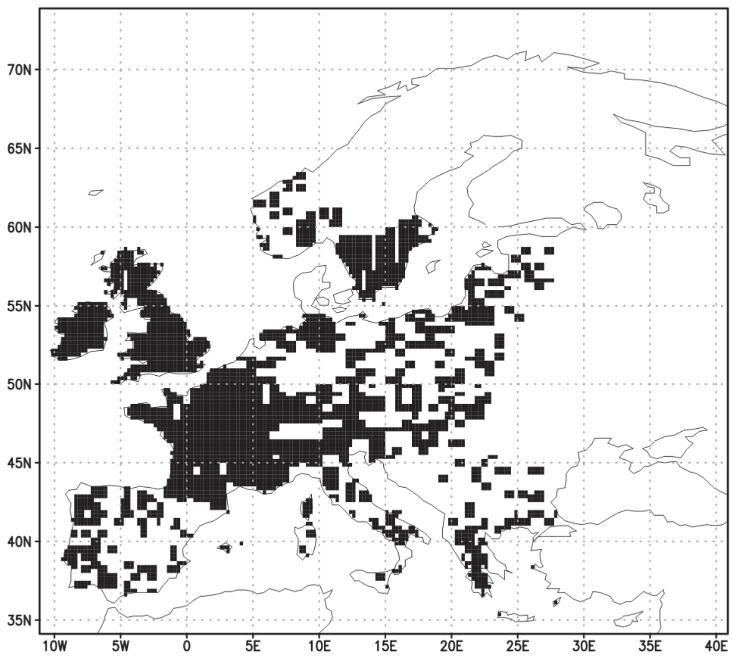


*Fig. 1*. The range map of *Pipistrellus pipistrellus* on the base of the Atlas of European Mammals. Shaded area indicates the occurrence of the species.

*Fig. 2* represents how the procedure leads to the regional maximum value of the *Q*, based on the systematic estimation process using the percentile pairs. The four climate indicator variables together describe the optimal climatic requirements of the *Pipistrellus pipistrellus* species. It can be seen from *Fig. 2a* that the maximum *Q* value in case of the mean temperature climate variable is 28.5% (which is reached in case of using the 48th and 86th percentiles). The maximum *Q* value in case of the precipitation sum presented in *Fig. 2b* is 38.3% (when using the 82nd and 100th percentiles). *Fig. 2c* shows the maximum *Q* value in case of the minimum temperature, which is 33.9% (when using the 61st and 86th percentiles). Finally, the maximum *Q* value in case of the maximum temperature is 15.9% (when using the 1st and 77th percentiles) as shown in *Fig. 2d*.

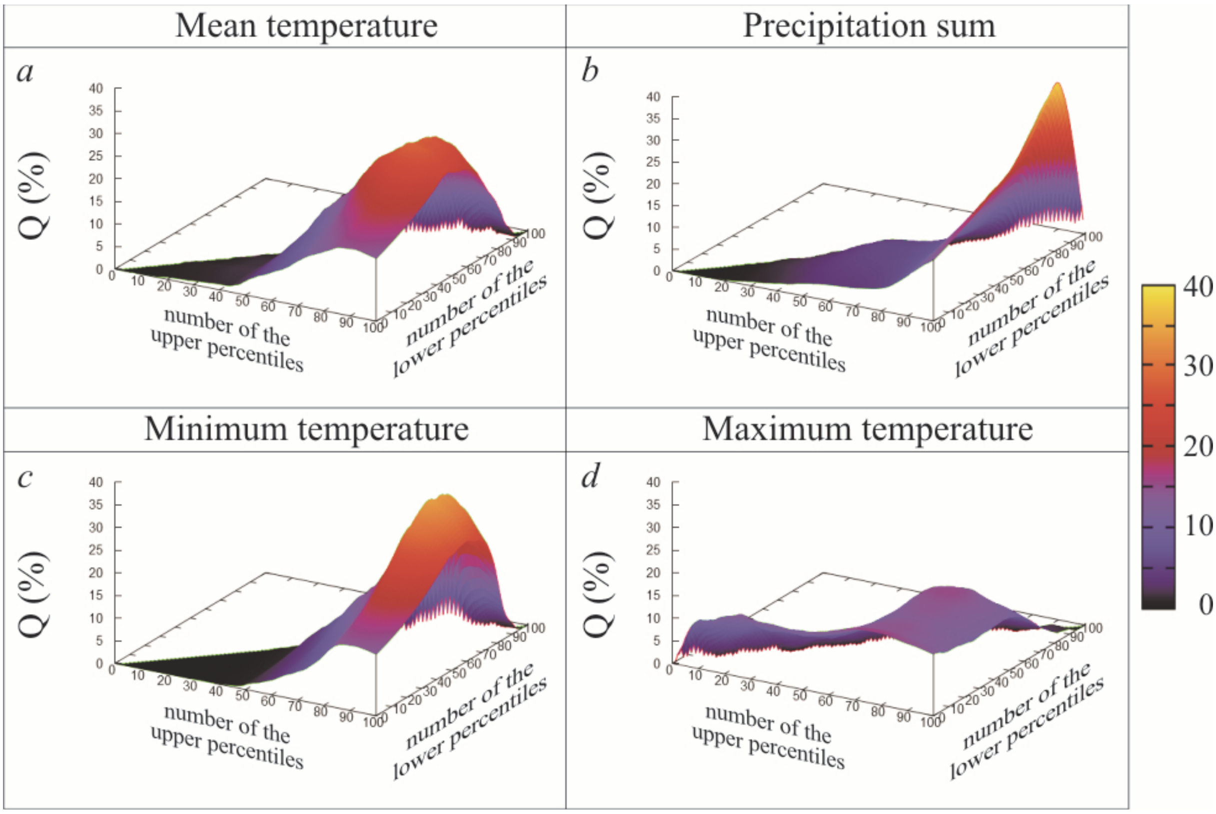


*Fig. 2.* Graphs of *Pipistrellus pipistrellus'* climate indicators, based on the observed annual mean values of the four climate describing variables. The graphs refer to the upper and lower percentiles on the horizontal axes. The values of *Q* (expressed in %) are shown on the vertical axis.

The maps based on the observed values of mean temperature (*Fig. 3a*), minimum temperature (*Fig. 3c*), maximum temperature (*Fig. 3d*), and precipitation sum (*Fig. 3b*) together explain the current boundaries of the European *Pipistrellus pipistrellus.* Colored areas show the following intervals of the variables' values on the maps:

- a) for mean temperature: 5.7 °C – 13.5 °C (48th–86th percentiles),
- b) for precipitation sum: 626 mm – 3347 mm (82nd–100th percentiles),
- c) for minimum temperature: –17.5 °C – –4.9 °C (61st–86th percentiles),
- d) for maximum temperature: 18.5 °C – 35.0 °C (1st–77th percentiles).

The map based on the observed values of the maximum temperature shows (*Fig. 3d*) the almost full optimal coverage in Europe for this species, because of the wide interval of the values. Thus, analyzing the maps of all the four variables provides an estimate of the animal's current spread within Europe.

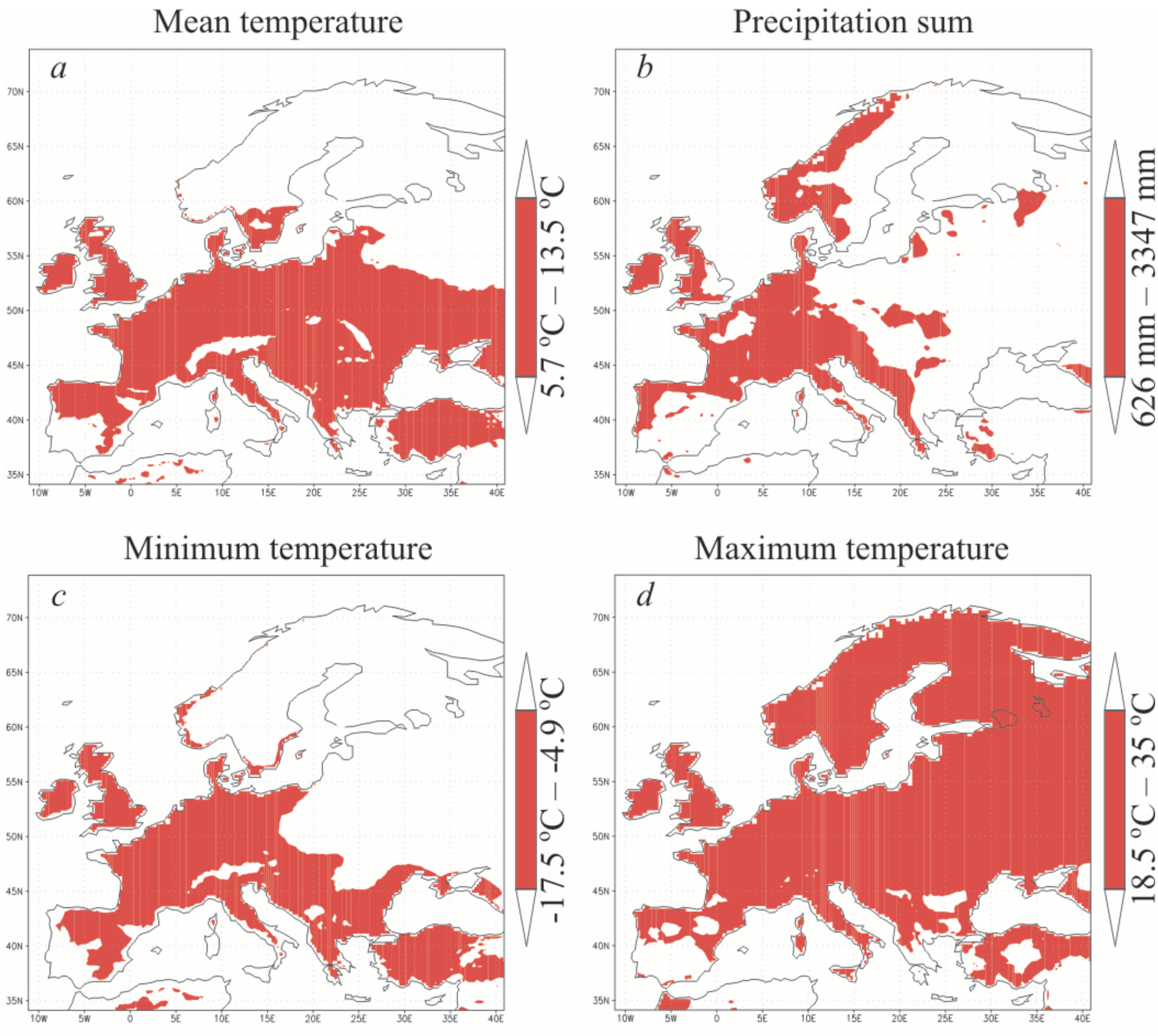


*Fig. 3*. Individual maps of the climate indicators for *Pipistrellus pipistrellus*, based on the observed annual values of the four climatic variables.

The model simulations for the periods 2021–2050 and 2071–2100 show a northward shift of the optimal climatic conditions of the *Pipistresllus pipistrellus* species, which is very likely due to global warming (*Fig. 4*).

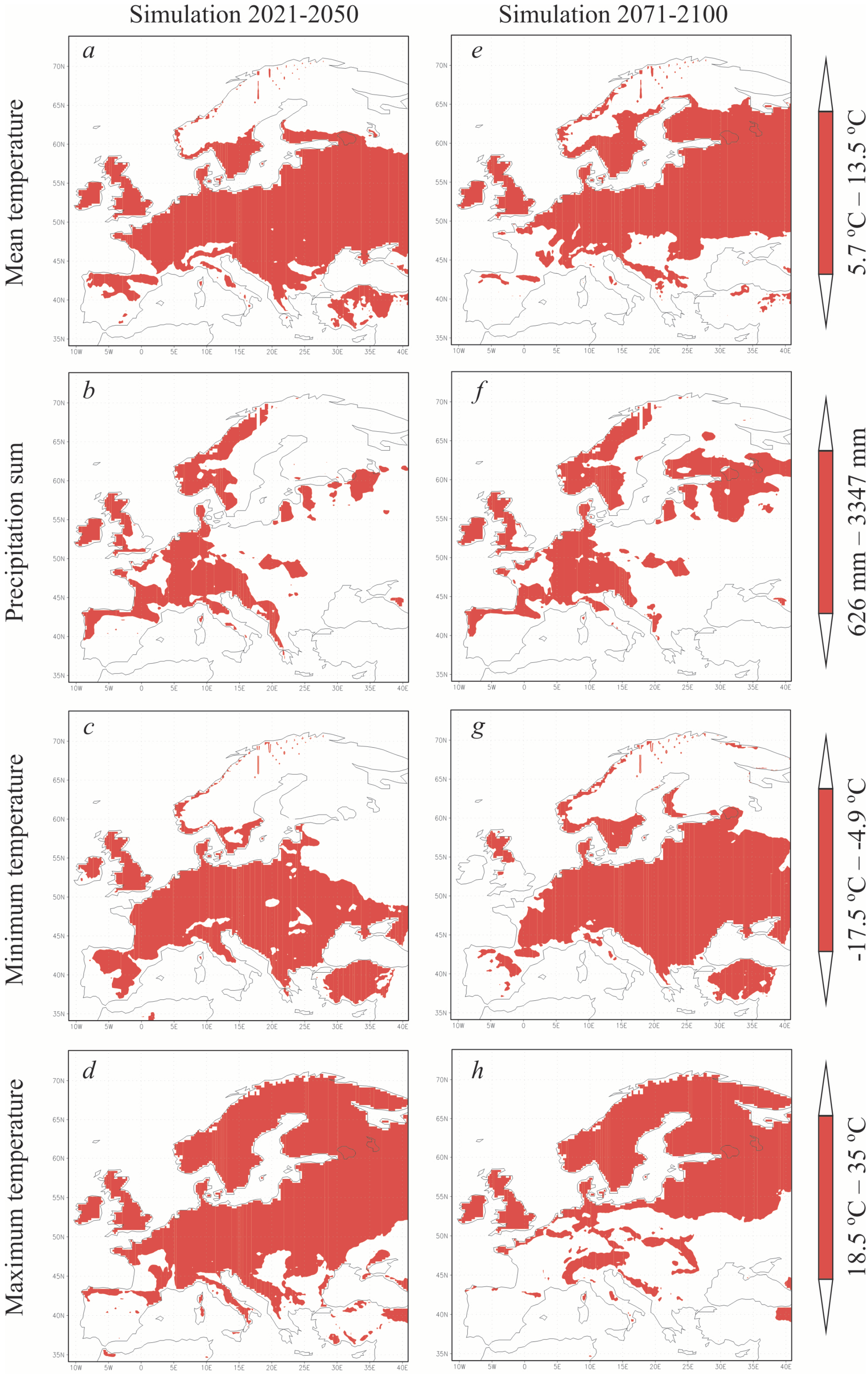


*Fig. 4.* Individual maps of the climate indicators for *Pipistrellus pipistrellus*, based on the annual values of the four climatic variables for the simulated periods of 2021–2050 (a-d) and 2071–2100 (e-h).

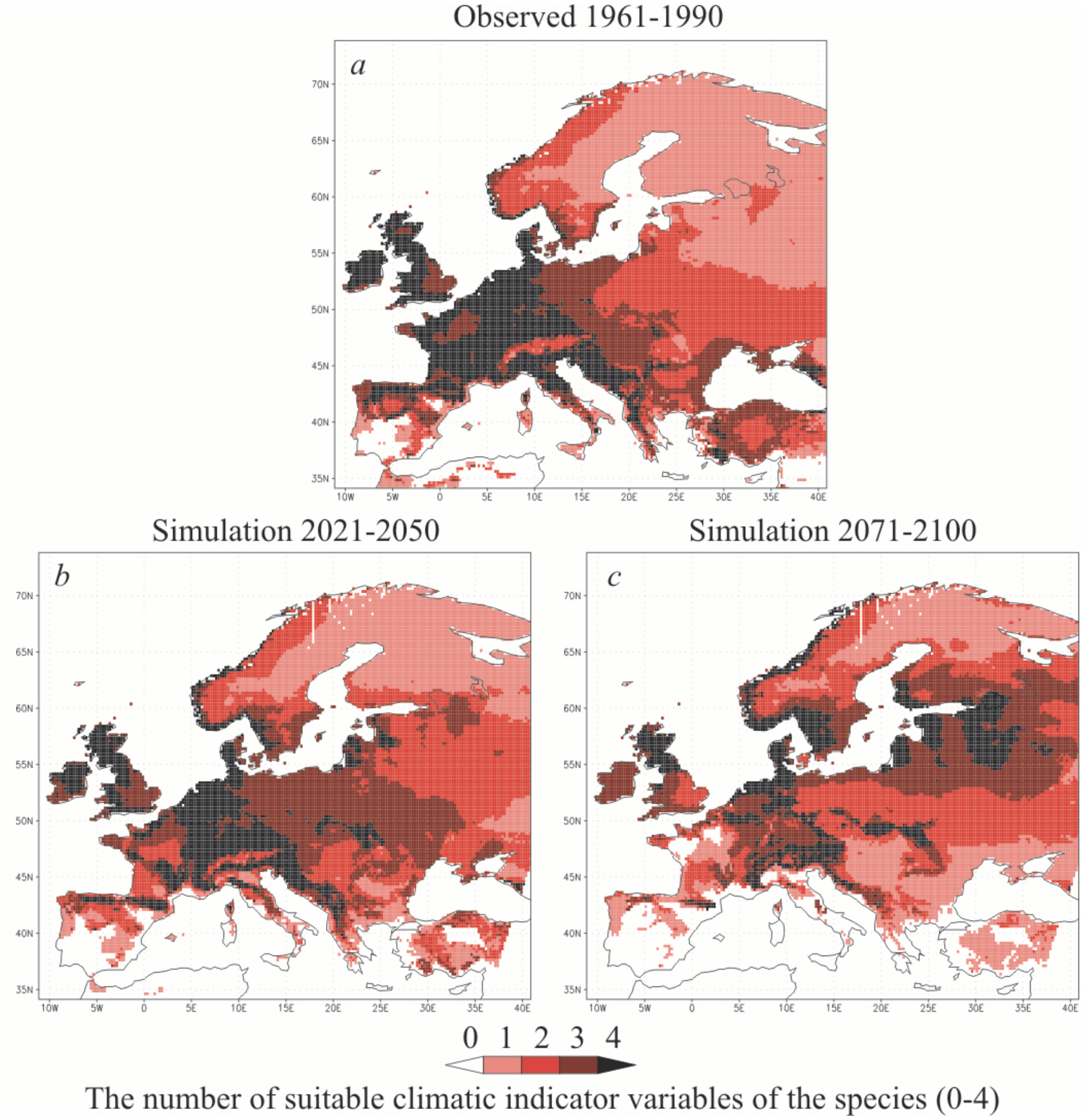


*Fig. 5.* Composite maps of *Pipistrellus pipistrellus'* climate indicators, based on the annual values of the four climatic variables for the observation period of 1961–1990 (a), and for simulated periods of 2021–2050 (b) and 2071–2100 (c).

Several shades are used on the composite maps (*Fig. 5*) of the *Pipistrellus pipistrellus* species' climate indicator areas, corresponding to how many variables are within the optimal ranges in the given grid cells (0–4). The darkest shade indicates the composite area, where each analyzed variables can be found within the optimal range of the *Pipistrellus pipistrellus* in the given grid cell. Our estimation, based on the composite maps of the *Pipistrellus pipistrellus* species illustrates a fitting similarity of 81% between the current range area and the composite climate indicator variables.

The composite maps present a major northward shift and an overall decline of the composite climate indicator area of the *Pipistrellus pipistrellus* species (*Fig. 5d*). As can be seen in *Table 1*, the composite climate indicator range will probably decrease from 1,498,350 km$^2$ to 948,761 km$^2$ until the end of the 21st century, which means 37% area decline, compared to the observed time period of 1961–1990.

*Table 1.* Comparison of the size of the composite range area of *Pipistrellus pipistrellus*, based on the climate indicator values in different time slices

| Climatic indicator variable | Observed 1961–1990 (km$^2$) | Simulation 2021–2050 (km$^2$) | Simulation 2071–2100 (km$^2$) |
|---|---|---|---|
| Mean temperature | 4,667,650 | 4,891,376 | 4,275,980 |
| Minimum temperature | 3,414,878 | 4,112,801 | 4,625,866 |
| Maximum temperature | 6,844,172 | 5,495,416 | 3,493,743 |
| Precipitation sum | 2,409,654 | 2,040,029 | 2,428,300 |
| Composite area | 1,498,350 | 1,154,040 | 948,767 |

All the studied bat species have 8,551 grid cells together (shaded area in *Fig. 6*), summarized from their current range maps. The greatest bat biodiversity is located in western Europe and in the mountainous regions of Mediterranean and temperate Europe (*Fig. 6*).

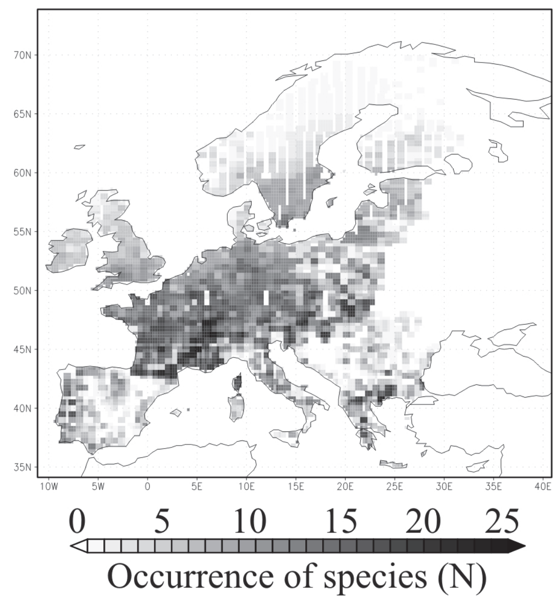


*Fig. 6.* The current composite range map considering all the 28 studied bat species, based on the Atlas of European Mammals.

The composite maps for the projected time periods 2021–2050 and 2071–2100 indicate remarkable change in the spatial status and size of the studied European bat species climate indicators. The composite range area will probably shift to the Baltic region and to the mountainous regions of eastern Europe and western Russia, considerably by the end of the 21st century (*Fig. 7c*).

Our estimations suggest that, compared to the recent past time period of 1961–1990, 93% (N=26, where N is the number of the bat spices) of the studied European bat species will suffer habitat decrease (*Table 2*), while 7% (N=2) are likely to experience habitat increase till the mid-century (2021–2050). Furthermore, compared to the recent past time period of 1961–1990, 96% (N=27) of the studied European bat species are projected to suffer habitat decrease, while 4% (N=1) may disapear till the end of the 21st century (2071–2100).

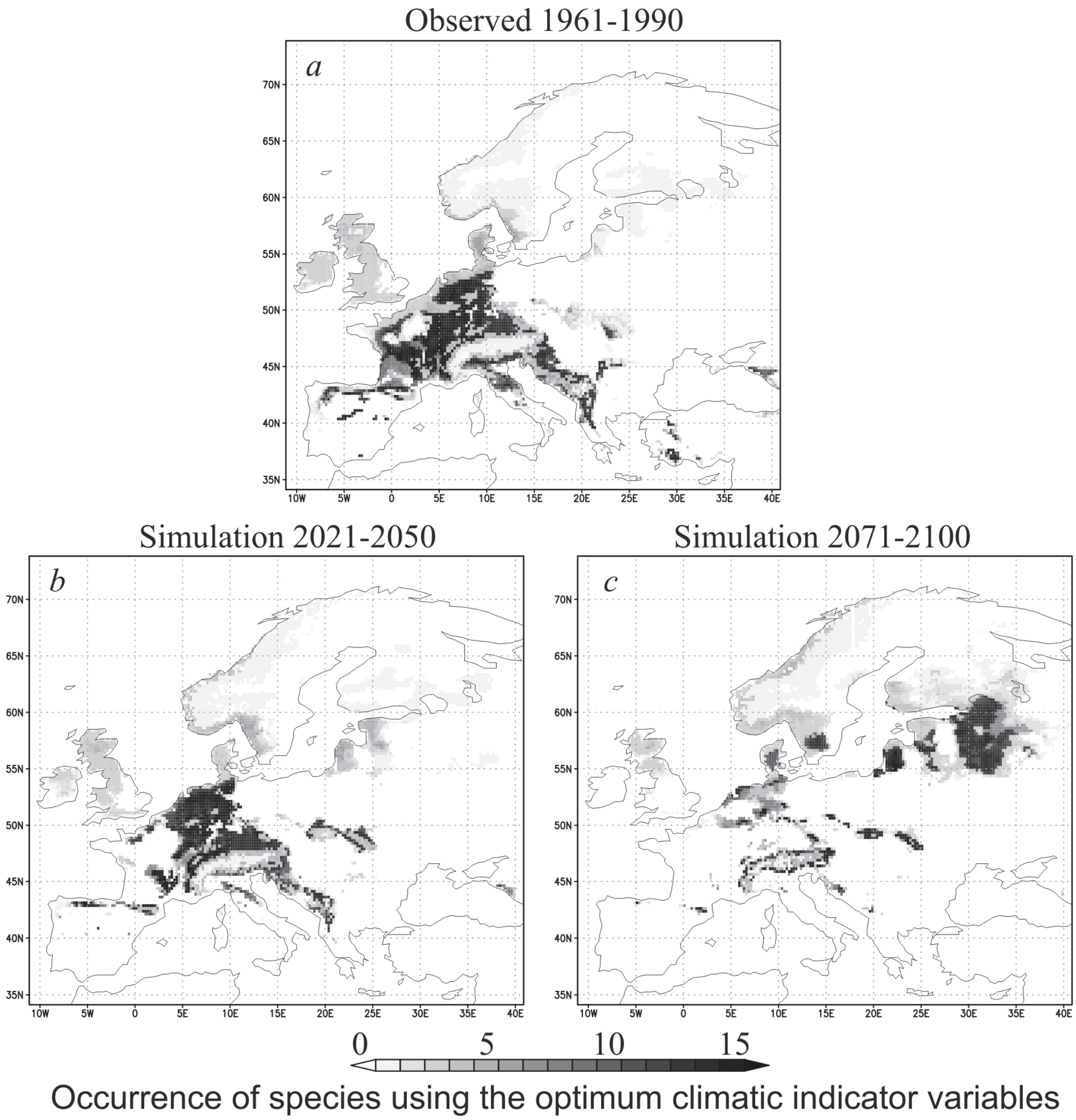


*Fig. 7.* Size of the composite range area of all studied European bat species, based on the climate indicator values for the past and future time slices.

We have determined the most endangered European bat species by the middle and also by the end of the 21st century to be focused for future action plans and protecting these species. The results suggest that, from the studied 30 bat species, *Rhinolophus mehelyi*'s optimal climatic conditions are projected to disappear by 2071–2100. This species is narrowly distributed on the continent nowadays, and is also present in relatively few grid cells. Consequently, it might have narrower climatic niche.

*Table 2.* English and Latin name of all studied bat species and the projected habitat change by the middle and the end of the 21st century (relative to the 1961–1990 reference period)

| **English name** | **Latin name** | **by 2021–2050** | **by 2071–2100** |
|---|---|---|---|
| Barbastelle | *Barbastella barbastellus* | decrease | decrease |
| Northern bat | *Eptesicus nilssonii* | decrease | decrease |
| Serotine | *Eptesicus serotinus* | decrease | decrease |
| Schreibers' bat | *Miniopterus schreibersii* | decrease | decrease |
| Bechstein's bat | *Myotis bechsteinii* | decrease | decrease |
| Lesser mouse-eared bat | *Myotis blythii* | decrease | decrease |
| Brandt's bat | *Myotis brandti* | increase | decrease |
| Long-fingered bat | *Myotis capaccinii* | decrease | decrease |
| Pond bat | *Myotis dasycneme* | decrease | decrease |
| Daubenton's bat | *Myotis daubentonii* | decrease | decrease |
| Geoffroy's bat | *Myotis emarginatus* | increase | decrease |
| Greater mouse-eared bat | *Myotis myotis* | decrease | decrease |
| Whiskered bat | *Myotis mystacinus* | decrease | decrease |
| Natterer's bat | *Myotis nattereri* | decrease | decrease |
| Leisler's bat | *Nyctalus leisleri* | decrease | decrease |
| Noctule | *Nyctalus noctula* | decrease | decrease |
| Kuhl's pipistrelle | *Pipistrellus kuhlii* | decrease | decrease |
| Nathusius' pipistrelle | *Pipistrellus nathusii* | decrease | decrease |
| Common pipistrelle | *Pipistrellus pipistrellus* | decrease | decrease |
| Savi's pipistrelle | *Pipistrellus savii* | decrease | decrease |
| Brown long-eared bat | *Plecotus auritus* | decrease | decrease |
| Grey long-eared bat | *Plecotus austriacus* | decrease | decrease |
| Mediterranean horseshoe bat | *Rhinolophus euryale* | decrease | decrease |
| Greater horseshoe bat | *Rhinolophus ferrumequinum* | decrease | decrease |
| Lesser horseshoe bat | *Rhinolophus hipposideros* | decrease | decrease |
| Mehely's horseshoe bat | *Rhinolophus mehelyi* | decrease | disapear |
| European free-tailed bat | *Tadarida teniotis* | decrease | decrease |
| Parti-coloured bat | *Vespertilio murinus* | decrease | decrease |

## *4. Discussion and conclusions*

The purpose of this reasearch was to analyze the possible regional impacts of the global warming to the living territory and conditions of the European bat species. Our predictions, based on the climate indicator profile technique of the 30 studied European bat species are consistent with the analysis of *Rebelo et al.* (2010) about these species' rapid potential northward migration due to the projected regional climate change during the 21st century. Furthermore, these species may suffer decrease in their size of habitats and disappearance from their current range areas. Estimations of *Rebelo et al.* (2010) were based on SRES A1FI, A2, B1, and B2 scenarios (*Nakicenovic* and *Swart*, 2000), our results conclude similar projections even though they consider a different (A1B) scenario. Consequently, all future scenarios predict reduction in European bat species richness in Europe, compared to the current conditions. The northward shift of the daily mean, minimum, and maximum temperature could imply a significant change in habitats. Meanwhile, the projected precipitation change is not likely to affect the possible migration of bat species in Europe. Other studies mention signs about European bats having already suffered from the impacts of regional climate change. For instance, due to response to warmer temperature conditions in the past 15 years, the species *Pipistrellus kuhlii*'s range area has expanded northwards (*Sachanowicz et al*., 2006), whereas in southern regions of Spain, the parturition in *Myotis myotis* has occurred up to 6 months before the expected birth period (*Ibanez*, 1997). As an overall result, habitat conditions are likely to decrease in continental climate regions during the 21st century. Due to the projected regional climate change in Europe, habitat loss and degradation is the greatest threat to the studied bat species.

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## *References*

*Bartholy J., Pongracz R., Nagy J., Pieczka I.,* and *Hufnagel L*., 2012: Regional climate change impacts on wild animals' living territory in central Europe. *Appl. Ecol. Environ. Res. 10*, 107–120.

*Bátori, Z., Lengyel, A., Maróti, M., Körmöczi, L., Tölgyesi, C., Biró, A., Tóth, M., Kincses, Z.,* and *Erdős, L.,* 2014: Microclimate-vegetation relationships in natural habitat islands: species preservation and conservation perspectives, *Időjárás 118*, 257–281.

*Battersby, J*. 2005: UK Mammals: Species Status and Population Trends. First Report by the Tracking Mammals Partnership. JNCC / The Tracking Mammals Partnership.

*Burns C.E., Johnston K.M.,* and *Schmitz O.J.,* 2003: Global climate change and mammalian species diversity in U.S. national parks. *Proc. Nat. Acad. Sci. 100*, 11474–11477.

*Chen, I.C., Hill, J.K., Ohlermüller, R., Roy, D.B.,* and *Thomas, C.D.,* 2011: Rapid range shifts of species associated with high levels of climate warming. *Science 333*, 1024–1026.

*Cappelen, J.,* 2011: Denmark's climate 2010 in Torshavn, Faroe islands and Nuuk, Greenland. Technical report 11–01. Danmarks Meteorologiske Institut, Kobenhavn. Available at www.dmi.dk/dmi/tr11-01. 72p. (in Danish, with English summary).

*Diós, N., Szenteleki, K., Ferenczy, A., Petrányi, G.,* and *Hufnagel, L.* 2009: A climate profile indicator based comparative analysis of climate change scenarios with regard to maize (zea mays l.) Cultures. *Appl. Ecol. Environ. Res. 7*, 199–214.

*Drégelyi-Kiss, Á.,* and *Hufnagel, L.*, 2009: Simulations of Theoretical Ecosystem Growth Model (TEGM) during various climate conditions. *Appl. Ecol. Environ.Res. 7,* 71–78.

*Ezard T.H.G.,* and *Travis J.M.J.,* 2006: The impact of habitat loss and fragmentation on genetic drift and fixation time. *Oikos 114*, 367–375.

*Haylock, M.R., Hofstra, N., Klein Tank, A.M.G., Klok, E.J., Jones, P.D.,* and *New, M.,* 2008: A European daily high-resolution gridded dataset of surface temperature and precipitation. *J. Geophys. Res. (Atmospheres) 113*, D20119.

*Hanski, I.,* 2005: Landscape fragmentation, biodiversity loss and the societal response. *EMBO reports* 6, 388–392.

*Hooper, D.U., Chapin, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S., Schmid, B., Setälä, H., Symstad, A.J., Vandermeer, J.,* and *Wardle, D.A.,* 2005: Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. *Ecol.Monogr. 75*, 3–35.

*Ibanez, C.* 1997: Winter reproduction in the greater mouse-eared bat (Myotis myotis) in South Iberia. J. *Zoology 243*, 836–840.

*Jaeger, J.A.G., Soukup, T., Madriñán, L.F., Schwick, C.,* and *Kienast, F.*, 2011: Landscape fragmentation in Europe. *EEA Report* No 2/2011.

*van der Linden, P.* and *Mitchell, J.F.B.*, (Eds.), 2009: ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre, UK.

*Luo J., Koselj K., Zsebők, S., Siemers B.,* and *Goerlitz, H.R.,* 2014: Global warming alters sound transmission: differential impact on the prey detection ability of echolocating bats. *J. R. Soc. Interface 11*, 20130961.

*May, R.M., Lawton, J.H.,* and *Stork, N.E.,* 1995: Assessing extinction rates. In: (Eds. *Lawton, J.H., May R.M.*) Extinction rates. Oxford University Press, New York, NY, USA. 1–24.

*van Meijgaard, E., van Ulft, L.H., van de Berg, W.J., Bosveld, F.C., van den Hurk, B.J.J.M., Lenderink, G.,* and *Siebesma, A.P.,* 2008: The KNMI regional atmospheric climate model RACMO version 2.1, Technical Report.

*Mitchell-Jones, A.J., Amori, G., Bogdanowicz, W., Krystufek, B., Reijnders, P.J.H., Spitzenberger, F., Stubbe, M., Thissen, J.B.M., Vohlarik, V.,* and *Zima, J.,* 1999: The Atlas of European Mammals. T A & D Poyser.

*Nakicenovic, N.* and *Swart, R.,* (Eds), 2000: Emissions Scenarios. A special reports of IPCC Working Group III. Cambridge University Press, UK., 570p.

*Petersen, A., Jens-Kjeld, J., Paulina, J., Bloch D.,* and *Finnur, I.,* 2014: A review of the occurrence of bats (Chiroptera) on islands in the North East Atlantic and on North Sea installations. *Acta Chiropterologica 16*, 169–195.

*Peterson O., Phillips L.* and *Williams S.E.*, 2004: Extinction risk from climate change. *Nature 427*, 145–148.

*Pongrácz R, Bartholy J,* and *Kis A.,* 2014: Estimation of future precipitation conditions for Hungary with special focus on dry periods. *Időjárás 118*, 305–321.

*Pounds, J.A., Bustamante, M.R., Coloma, L.A., Consuegra, J.A., Fogden, M.P.L., Foster, P.N., La Marca, E., Masters, K.L., Merino-Viteri, A., Puschendorf, R., Ron, S.R., Sanchez-Azofeifa, G.A., Still, C.J.,* and *Young, B.E.,* 2006: Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature 439*, 161–167.

*Prydatko, V., Makarenko, V.,* and *Kolomytsev, G.,* 2011: Lesser Noctule (Nyctalus leisleri) habitats change modelling in EEBIO Region in scope of the IMAGE climate change data: GLM scenario by 2050. Biomodel. Vefsíđa. Available at: http://bio model.info/species/lesser-noctule-nyctalus-leisleri/.

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

*Sachanowicz, K., Wower, A.,* and *Bashta A-T.,* 2006: Further range extension of Pipistrellus kuhlii (Kuhl, 1817) in central and eastern Europe. *Acta Chiropterologica 8*, 543–548.

*Sherwin, H. A., Montgomery, W. I.,* and *Lundy, M.G.,* (2013): The impact and implications of climate change for bats. *Mammal Rev. 43*, 171–182.

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

*Thomas C.D., Cameron A., Green R.E., Bakkenes M., Beaumont L.J., Collingham Y.C., Erasmus B.F.N., Ferreira de Siquera M., Grainger A., Hannah L., Hughes L., Huntley B., van Jaarsveld A. S., Midgley G.F., Miles L., Ortega-Huerta M.A., Townsend ,A., Peterson O., Phillips L.* and *Williams S.E.*, 2004: Extinction risk from climate change. *Nature 427*, 145–148.

*Vaughan, T.A., Ryan, J.M.,* and *Czaplewski N.J.*, 2000: Mammalogy. 4th ed. Saunders College Publishing, Fort Worth, Texas

*Williams, J.W., Jackson, S.T.,* and *Kutzbach, J.E.,* 2007: Projected distributions of novel and disapearing climates by 2100 AD. *Proc. Nat. Acad. Sci. 104*, 5738–5742.

*Williams, S.E., Bolitho, E.E.,* and *Fox, S.,* 2003: Climate change in Australian tropical rainforests: An impending environmental catastrophe. *Proc. Biol. Sci. 270*, 1887–1892.