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Physical parameters beneficial for grouping of western barbastelle bats into clusters during hibernation.

Grzegorz Kłys*[1]. Zbigniew Ziembik[2]. Joanna Makuchowska-Fryc[3]

[1]Institute of Biology. University of Opole. Oleska Street 22. 45-052 Opole. Poland

[2., 3]Institute of Environmental Engineering and Biotechnology. University of Opole Kardynała B. KominkaStreet 6. 6a. 45-032 Opole. Poland

[1]gklys@uni.opole.pl

[2]ziembik@uni.opole.pl

[3]amak@uni.opole.pl

[*] Corresponding author. E-mail address: gklys@uni.opole.pl

Abstract

Social hibernation of animals is one of the most important physiological and ecological behaviours. The purpose of the study was the investigation of the influence of the roostsite climate parameters: temperature (T), humidity (Rh) and air flow velocity (v) on the clustering of the *Barbastella barbastellus* (western barbastelle) during hibernation. The research was carried out in the underground systems of Poland (Central Europe) over a period of 6 years. The range of air parameters changes ranged for T from 6.0 to 12.4 °C, for Rh from 56.4 to 91.8% and for v from 0.01 to 1.17 m/s. The quantile linear regression method was used for the statistical analysis of the results. The study indicated that the increase in the number of individuals in the hibernaculum occurs with an increase in the

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product (correlation result) T and v, while a decrease in the size of the group occurs with an increase in the products T and Rh, v and Rh as well as T, v and Rh.

ORCID

G. Kłys https://orcid.org/0000-0003-3117-7813

J. Makuchowska-Fryc https://orcid.org/0000-0002-2221-673X

Z. Ziembikhttps://orcid.org/0000-0003-0251-5035

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1. Introduction

The phenomenon of grouping among bats is one of the important physiological and ecological behaviours (Boyles et al. 2008). Although clustering aims mainly at minimizing heat loss into the environment, it can also serve as protection against predators or to maintain emotional and family ties, hierarchy in the herd, etc.

The hibernation process is precisely regulated and controlled (Thomas, 1995, Janicki et al., 2006). The parameters characterizing metabolic changes in the state of energy equilibrium during hibernation depend on constant factors (species, size, weight,

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gender, age of the individual) and variables (values of physical parameters of the environment).

The process is characterized by a drastic reduction in body temperature and other physiological functions, which can reduce energy consumption by up to 95% compared to the cost of staying active during winter (Geiser, 2004). This state can last from several hours to several months (Hoffman, 1964; Nelson, 1980; Lyman et al., 1982; Wang, 1987; French, 1988; Storey and Storey, 1990; Geiser and Ruf, 1995). In particular, the bats can decrease their body temperature almost to the ambient one (McNab, 1982) or in a short time increase it significantly above this value (even up to 40°C at the air temperature of only a few degrees) (Davydow, 2004).

It is widely known that in order to reduce energy consumption during hibernation, in addition to the euthermic process, animals also use various behaviours, e.g. they form dense clusters (aggregations). As it was noted by Ransome (1990), social thermoregulation is of great importance during hibernation. The grouping of individuals during wintering is variable both within the species and between species (Kłys, 2013). Some bat species winter separately, some form small, "rare" clusters, while others gather in dense groups (Смирнов et al. 1999; Томиленко, 2002; Kłys, 2013), numbering up to several thousands of individuals (Betke et al., 2008). Dissimilar aggregation tendencies are observed within the species also in the same winter accommodation. During winter, bats may move and change their roosting place, which sometimes leads to change in the size and composition of grouping in the hibernaculum (Орлова et al., 1983; Томиленко, 2002).

The study of bat hibernation is often limited to descriptive field observations (e.g. when and where mammals have wintered) or physiological research in the laboratory (e.g.

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study of metabolism and endocrine system functions of animals), without the environmental context. Initial studies assess the changes in the number of individuals depending on the microclimate of the caves. Most of them concern the bat's thermopreferendum (Gaisler, 1970; Bauerova and Zima, 1988; Boyles et al., 2019). Currently, the description of the hibernation process is based on the measurements of temperature (T) as the only parameter of the roost site microclimates (Harmata, 1969; Boyles et al., 2019), and occasionally temperature and humidity (Kunz, 1982. Nagel, Nagel., 1991; Visnovska et al., 2006; Boyles et al., 2008; Boratyński et al., 2012). Few authors take into account the temperature, humidity, air velocity and thermal conductivity coefficient of the substrate (λ) in the search for optimal values defining the so-called thermal comfort of selected species (Kłys, 2004; Kłys and Wołoszyn, 2005; Kłys, 2008; Kłys, 2013) Physiologists often define the conditions that minimize energy expenditure as "optimal" (Day and Tomasi, 2014), the research and analysis of the hibernation process should not be based on the determination of these conditions, but on predicting of bat behaviour (Humphries et al., 2003; Boyles et al., 2019).

The authors chose for the study the western barbastelle *Barbastella barbastellus* (Schreber, 1774) species which uses all available hibernation strategies (Kłys, 2013), both individually and in clusters, sometimes up to several hundred individuals. The changes in the roost site climate (Kłys and Wołoszyn, 2005) were analyzed through the changes in the size of the roosting place parameters (temperature T and relative humidity Rh) and air flow velocity v in the context of their influence on the formation of aggregation of this species.

The aim of the study was the evaluation of the air temperature, its relative humidity and air flow speed influence on bat aggregation during their winter hibernation.

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For this purpose appropriate model describing an influence of the air physical parameters on bats' grouping was constructed, analysis of the model would provide an outline of the relationship between grouping and the determined air parameters, and allow to find explanation of bats' behaviour.

2. Methods

The research was carried out in the underground systems of Poland: Forty Nyskie (Generalna ... 2014), Fortified part of Międzyrzecze (Nietoperek ... 2021) and Mopkowy Tunel (Mopkowy ... 2017). The data of the roost site climate was collected between the years 2002 and 2007 on the basis of the permits of the Provincial Nature Conservators and the Ministry of the Environment (DOPog-4201-04A-2/03 / al .; DOPog-4201-04A-6/04 / al .; DLOPiK-op / Ozgi- 4200 / IV.D-16/6568/06 / aj.) The most important criteria for selecting research sites were the large number of wintering specimens of the selected species.

Data was collected during the peak of hibernation (December - February). Due to the fact that the hibernating animals were not awakened, neither gender nor age was determined, in the places where bats hibernate, data was collected with use of measuring devices from SENSOTRON (Kłys 2013). Hibernation strategies were simplified in this work in relation, in order to illustrate the essence of the problem, what is more wintering was distinguished: individual and in groups (social) (Fig. 1, Fig. 2).

The influence of the air temperature (*T*), relative humidity (Rh) and flow speed (*v*) on bats' group formation was studied. Using explanatory variables *T, Rh* and *v* the bats' count *n* in the group was modelled. In calculation total number of 180 observations was used.

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3. Statistical methods

The aim of the statistical methods application was the construction of a model describing an influence of the air physical parameters on bats' grouping.

At the starting point of the analysis, the were studied the relationships between explanatory variables *T, Rh* and *v*. For this purpose the Principal Component Analysis (PCA) was used (Jolliffe 2002; Jackson 1991). Because the explanatory variables come from different units, before PCA they were centred with the mean column and scaled with the standard deviation.

Due to relatively low number of bats' clusters, the quantile regression (QR) model was used (Koenker et al., 2018; Davino et al., 2014) for the cluster size modelling. In quantile regression the conditional quantile τ of the response variable, for example median, was estimated.

QR model is an extension of the ordinary linear regression that is used when the conditions of linear regression are not met.

In the quantile regression model all determined explanatory variables and interactions between them were included. According to Chambers (Chambers and Hastie, 1993) the model is described by the mathematical formula below:

$$n \sim T*Rh*v \qquad (1)$$

where "~ " separates response variable on the left from the explanatory variables on the right. The "*" operandadds interactions between variables to the model. For numerical variables it includes a point-wise product of the variables.

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In Eq. 2 the expanded, but equivalent to Eq. 1 form, is presented:

$$n \sim T+Rh+v+T{:}\mathrm{Rh}+T{:}v+Rh{:}v+T{:}\mathrm{Rh}{:}v \quad (2)$$

where "+" separates predictor terms in an additive model, and ":" separates interacting terms.

The statistical computations were performed with use of R language (Team, 2020). For QR computation the R package quantile regression was used (Koenker, 2020).

4. Results

Tab. 1 Shows the summary of statistical parameters that describe the observations. During observations the range of the temperature variations was 6.4 °C. But at most, the 50% of temperatures changed in the interquartile range *IQR* ($IQR=q_{75} - q_{25}$) of the width 1.62 °C. This value indicates stable temperature conditions during at least a half of bats' observation period. Changes in relative humidity exceeded 34 %. But, similarly as for *T,* the predominating changes measured by *IQR* did not exceed 7%.The wind speed change fluctuated from nearly 0 up to almost 1.2 m/s. The corresponding *IQR* was 0.10. Group formation was not frequent. Starting from 91% quantile of *n,* bigger than 1 values were observed.

The structure and relationships between explanatory variables was assessed with use of the PCA method. The share of the first principal component (PC) in variability is 58 % of the total variance, and share of PC2 is 25 %. The first 2 PCs contain 83 % of the total variance.

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In Fig. 1 a biplot of the PC1 and PC2 is presented. There were no significant relationships between the parameters during the study. The points describing physical parameters form a relatively homogeneous structure, however, several outliers can be observed. Lack of tendency to grouping of observations and no common relationships among them promotes these variables for predictors in a regression model.

Eq. 3 shows the expression describing relationship between 3 explanatory variables and response:

$$n=\beta_0+\beta_1 T+\beta_2 Rh+\beta_3 v+\beta_4 TRh+\beta_5 Tv+\beta_6 Rhv+\beta_7 TRhv \qquad (3)$$

In the expression $\beta_i(i=\{1...7\})$are structural parameters of the model.

For τ = {0.925, 0.950, 0.975}the values of the structural parameters and corresponding standard errors *SE,* and *p*-values for null hypothesis H_0: β_i=0 were calculated. The standard errors were computed with use of the bootstrap method.

Tab. 2 Shows results of the computations.

The critical *p*-value = 0.05 was considered for rejection of the null hypothesis. The H_0 hypothesis cannot be rejected for all structural parameters when τ = 0.95. No statistically significant relationships between air parameters and bats' grouping were observed. Both for τ = 0.95 and 0.975 the interaction terms occurred significantly different from 0, though for $\beta_7$the critical value was slightly exceeded. The null hypothesis can be rejected also for the intercept $\beta_{0.}$

5. Discussion

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The visible influence of *T*, *Rh* and *v* on grouping of the bats was not observed. The computation results indicate the influence of interactions between these parameters on the response. Interaction between the two numerical variables in regression model produces a new variable -the product of selected variables. Because interactions are products, their influence is important when both factors increase or decrease together. If the value of one factor increases and the value of the other decreases, their product changes only slightly and no influence on predictor is observed.

The main results from the quantile regression model application for bats' cluster size description can be summarised as follows:

- the negative value of β_4 indicates decrease in bats' group size with increasing *T* and *Rh*.
- the positive value of β_5 indicates increase in bats' group size with increasing *T* and *v*,
- the negative value of β_6 indicates decrease in bats' group size with increasing *v* and *Rh*,
- the negative value of $\beta_7$indicates decrease in bats' group size with increasing T, *v* and *Rh*.

The purpose of hibernation is to minimize energy consumption during the unfavourable period of food shortage. This process is characterized by controlled reduction of metabolism and, consequently, body temperature (Wermundsen and Siivonen, 2010). Each species has its own optimal metabolic rate that guarantees it will survive the unfavourable period.

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Loss of energy can occur in various processes, including heat exchange with the environment or evaporation. Heat exchange with the environment can be regulated by hibernation strategies, which determine the participation of individual heat transport mechanisms between the bat's body and the air (convection) or between the body and the ground (conduction) (Kłys, 2013).

The formation of clusters causes the reduction of ratio in the surface area to body weight and, consequently, a smaller evaporation and heat exchange (giving up). This ratio is of great importance especially in small animals. It is commonly believed that clusters can facilitate energy saving, e.g. by reducing water losses in the body (Studier, 1970; Procter and Studier, 1970; Stapp et al., 1991; Canals, 1998; Brown, 1999; Jefimow et al. 2011; Wojciechowski et al., 2011; Boratyński et al., 2012) or compensate for energy losses (Boyles et al., 2008). Often the effect of hydration is more important than nutritional status. Even in conditions of high air humidity (90-98%), the loss of moisture can be significant, depending on the intensity of metabolic processes, which in turn depend on the rate of heat loss to the environment, individuals may also have negative effects, such as extending the hibernation time or mutual awakening.

The amount of energy consumed depends on the microclimate, and more specifically on the roost site climate in which the bat hibernates. In favourable conditions of the climate, bats should hibernate individually, while in unfavourable conditions (causing too high consumption of energy) they should form clusters or leave the hibernacula.

Our own observations show that, unlike other species, *Barbastella barbastellus* bats hibernate at a relative air humidity that rarely exceeds 90%. Approaching the upper limit of the humidity range causes the aggregation of individuals into clusters, which is confirmed by the studies of other authors (Ransome, 1990; Thomas and Cloutier, 1992;

Thomas, 1995), while there is no reference to the correlation of the values of other air parameters.

The work of Wermundsen and Siivonen 2010 verified the belief that some bat species prefer thermally stable habitats, while others choose conditions that vary in terms of temperature. The authors of this article observed that bats (*Eptesicus nilssonii, Myotis brandtii/mystacinus, Myotis daubentonii* and *Plecotus auritus*) in the initial period of hibernation chose places with the highest air temperature and humidity, and in the last stage, places with the lowest values of these parameters, although the range and extremes of temperatures were similar throughout all hibernation period.

Encarnacao et al., (2012), in studies on the influence of the habitat on the strategy of the *Myotis daubentonii* bats hibernation, observed the occupation of more favourable habitats by reproductive females, and less favourable by males. Males from different habitats showed different hibernation strategies that depended, among others, on air parameters. In less favourable conditions of the habitat, they observed the grouping of males into clusters, which they explained as an energy-saving strategy. They used temperature and air humidity measurements to determine the conditions of the roost site climate.

The basic parameters characterizing the microclimate are temperature (Ta), humidity (Rh) and air velocity (v) (Pawiński et al., 1995; Paszyński et al., 1999).

During the analysis of the influence of two parameters (variables) on the Western Barbastellus hibernation strategy, it was noticed that the increase of the Ta product causes clustering of *Barbastella barbastellus*. Increasing Ta causes an increase in Tb, which in turn causes an increase in the metabolic rate of the bat, so that it uses up energy stores faster in the form of accumulated fat. The temperature of bats usually oscillates around

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the ambient temperature (Geiser, 2004; Dunbar and Tomasi, 2006; Boyles et al., 2008; Kłys, 2013), regardless of whether the animals hibernate individually or in aggregation.

The speed of the air flow has a decisive influence on the intensity of the heat exchange process in the convection mechanism. It determines the type of flow (laminar, transitional, turbulent), which determines the thickness of the laminar (Prandtl) layer that forms around the bat's body. The (Prandtl) film has the main resistance to heat penetration because it conducts heat which is much less efficient compared to heat transfer in a turbulent area. The greater the velocity values, the smaller the Prandtl film thickness and the more intense the heat transfer.

The Ta increase also increases the evaporation of water from the bat's organism, which simultaneously increases energy loss (Wermundsen and Siivonen, 2010). The increase in air Rh, on the other hand, reduces water loss. It is then possible to hibernate individual individuals.

An increase in the air flow velocity (v) increases the reception of moisture from the bat's organism to the environment or increases evaporation due to the transport of warmer or drier air, displacing the moist, cool air surrounding the bat (Wermundsen and Siivonen, 2010). At the same time, the higher the degree of air saturation with water vapor, the more difficult it becomes to collect heat by evaporation (Thomas and Cloutier, 1992; Thomas, 1995; Paksuz et al., 2007).

However, analysing the changes in two parameters does not present a full picture of the thermal comfort of a hibernating bat.

When taking into account three variables, hibernation of individual animals was observed in the conditions of simultaneous increase in T_a, Rh and v values or a simultaneous decrease in the values of these parameters.

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With an increase in T_a and Rh, the metabolic rate increases, and heat transfer occurs mainly by convection. Increasing the air velocity v allows to receive heat and moisture from the body, and this in turn allows you to maintain optimal energy expenditure.

When the values of all parameters are decreasing simultaneously, the metabolic rate decreases and the evaporation intensity decreases, so low air velocities are sufficient for the heat dissipation.

In this study, the authors did not take into account the heat transfer between the bat's body and the ground, taking place through heat conduction. The intensity of heat transfer in this mechanism depends on the value of the thermal conductivity coefficient of the substrate (λ), which determines the heat conductivity and is characteristic for a given material. In the conducted research, bats on the same basis adopted different strategies (they hibernated separately or formed aggregations).

6. Conclusion

It was found that the clustering of bats is closely associated with the analysed parameters. The statistical analysis using the quantile linear regression method showed that the interactions between the parameters T, v and Rh are significant.

In the case of the *Barbastella barbastellus* species, the formation of clusters and an increase in the size of the group of bats with an increase in the products T and v were observed. These conditions can be described as less favourable for hibernation, which may result in too high rate of heat transfer to the environment. The decrease in the number of clusters indicates more favourable conditions for hibernation and it is followed

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by an increase in the products of T and Rh, v and Rh, and a simultaneous increase or decrease in the values of the three parameters: T, v and Rh.

Data availability

Data and/or code are provided as private-for-peer review via the following link: https://repo.uni.opole.pl/info/researchdata/UO30dbd9c5ed004e7eae780273fdb8c917/Szczeg%25C3%25B3%25C5%2582y%2Brekordu%2B%25E2%2580%2593%2BDane%2Bbadawcze%2B%25E2%2580%2593%2BUniwersytet%2BOpolski?r=researchdata&ps=20&tab=&lang=pl&pn=1&cid=1706867

Upon acceptance, Data will be provided via Knowledge Base of the University of Opole via the link provided above.

Author contributions

GK, JMF and ZZ developed the research questions, experimental design, and methods. GK conducted the fieldwork and lab work and led data analysis with input from GK, JMF and ZZ wrote and edited the manuscript. ZZ carried out a statistical analysis.

Competing interests

The contact author has declared that neither of the authors has any competing interests.

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References

https://doi.org/10.5194/bg-2022-159
Preprint. Discussion started: 27 July 2022

Bauerova, Z., Zima J.: Seasonal chan ges in visits to a cave by bats. Folia Zoologica. 37, 97-111, 1988.

Betke, M., Hirsch, D.E., Makris, N.C., McCracken, G.F., Procopio, M., Hristov, N.I., Teng, S., Bacchi, A., Reichard, J., Horns, J.W., Crampton, S., Cleveland, C.J., Kunz, T.H.: Termal imaging reveals significantly smaller Brazilian free-tailed bat colonie than previously estimated. Journal of Mammalogy. 89 (1), 18-24, 2008.

Boratyński, J., Rusiński, M., Kokurewicz, T., Bereszyński, A., Wojciechowski, M.: Clustering behavior in wintering great er Mouse-eared bats *Myotis myotis* – the effect of micro-environmental conditions. Acta Chiropterologica. 14 (2), 417-424, 2012.

Boyles, J. G., Johnson, J.S., Thomas, A.B., Lilley, M.: Optimal hibernation thery. Mammal Review. 50 (1), 91-100, 2019.

Boyles, J.G., Storm, J.J., Brack, V.Jr.: Thermal benefits of clustering during hibernation: a field test of competing hypotheses on *Myotis sodalis*. Functional Ecology. 22, 632– 636, 2008.

Brown, P.E.: California leaf-nosed bat *Macrotus californicus*. In (D. E. Wilson and S. Ruff, eds.) The Smithsonian Book of North American Mammals. Smithsonian Institution Press, Washington D. C., 74-75, 1999.

Canals, M.: Thermal energetic of small animals. Biological Research. 31, 367-374, 1998.

Смирнов Д. Г., Курмаева Н. М., Вехник В. П.: Динамика численности и пространственное распределение зимующих рукокрылых (Chiroptera, Vespertilionidae) в одной из штолен Самарской Луки, // Plecotus et al. - № 2. - С. 67-78, 1999.

https://doi.org/10.5194/bg-2022-159
Preprint. Discussion started: 27 July 2022

Chambers, J.M, Hastie, T.J.: Statistical Models in S. Chapman & Hall Computer Science Series. New York. 1993.

Davino, Q.C., Furno, M., Vistocco, D.: Quantile Regression. Wiley Series in Probability and Statistics. Chichester. West Sussex. Wiley, Hoboken. 2014.

Davydow, A.F.: Energetics and Thermoregulation in Chiroptera. Journal of Evolutionary Biochemistry and Physiology. 40 (3), 241-249, 2004.

Day, K.M., Tomasi, T.E.: Winter energetics of female Indiana bats *Myotis sodalis*. Physiological and Biochemical Zoology. 87, 56– 64, 2014.

Dunbar, M.B., Tomasi T.E.: Arousal patterns, metabolic rate, and an energy budget for ekstern red bats (*Lasiurus borealis*) in Winter. J. Mammal. 87, 1096-1102, 2006.

Encarnação, J.A., Reiners, T.E.: Erratum to: Mating at summer sites: indications from parentage analysis and roosting behaviour of Daubenton's bats (*Myotis daubentonii*). Conserv Genet. **13,** 1433. 2012.

French, A.R.: The patterns of mammalian hibernation. Am. Scient. 76. 569-575, 1988.

Gaisler, J.: Remarks on the thermopreferendum of Palearctic bats in their Natural Habitats. Bijdragen tot de Dierkunde. 40, 33-36, 1970.

Geiser, F.: Metabolic rate and body temperature reduction during hibernation and daily torpor. Annual Reviews of Physiology. 66, 239–274, 2004.

Geiser, F., Ruf, T.: Hibernation versus daily torpor in mammals and birds: physiological variables and classification of torpor patterns. Physiological Zoology. 68 (6), 935-966, 1995.

Generalna Dyrekcja Ochrony Środowiska 2014.: Obszary Natura 2000. http://natura2000.gdos.gov.pl/wyszukiwarka-n2k (accessed 2 December 2021). 2014.

https://doi.org/10.5194/bg-2022-159
Preprint. Discussion started: 27 July 2022

Biogeosciences Discussions
Open Access

Harmata, W.: The thermopreferendum of some species of bats (Chiroptera). Acta Theriologica. 14, 49–62, 1969.

Hoffman, R.A.: Speculations on the regulation of hibernation. Ann Acad Sci Fenn. Set A 4. 71, 199-216, 1964.

Humphries, M.M., Thomas, D.W., Kramer, D.L.: The role of energy availability in mammalian hibernation: a cost-benefit approach. Physiological and Biochemical Zoology. 76, 165–179, 2003.

Jackson, J. E.: A User's Guide To Principal Components. John Wiley & Sons. New York, 43, 1991.

Janicki, B., Cygan–Szczegielniak, D.: Hibernacja zwierząt. Medycyna weterynaryjna. 366–369, 2006.

Jefimow, M., Głąbska, M., Wojciechowski, M.S.: Social thermoregulation and torpor in Siberian hamster. Jour nal of Experimental Biology. 214, 1100–1108, 2011.

Jolliffe, I.T.: Principal Component Analysis. 2nd ed. New York. Berlin. Heidelberg: Springer. 2002.

Kłys, G.: Przyroda Podziemi Tarnogórskich. Pyrzowice-Sosnowiec PTG. 2004.

Kłys, G.: Wybrane aspekty hibernacji nietoperzy, in. Kłys, G., Wołoszyn, B.W., Yagt-Yazykova, E., Kuśnierz, A. (Eds.), Wpływ środowiskowych warunków na wybór hibernaculum przez nietoperze. ZPW Plik Bytom. 2008.

Kłys, G., Wołoszyn, B.: The influence of weather and interior microclimate on the hibernation of common long-eard bats (*Plecotus auritus*). Nature Journal. 38, 57-68, 2005.

https://doi.org/10.5194/bg-2022-159
Preprint. Discussion started: 27 July 2022

Kłys, G.: Multifactor Analysis of Refugioclimate in Places of Hibernation of Chosen Bat Species. T. 8 Studia Chiropterologica. Chiropterological Information Center, Institute of Animal Systematics and Evolution, Polish Academy of Sciences. 2013.

Koenker, R.: Quantreg: Quantile Regression. R Package Version 5.67 (version 5.67). R. https://CRAN.R-project.org/package=quantreg. 2020.

Koenker, R., Chernozhukov, V., He, X., Peng, L.: Handbook of Quantile Regression. Chapman & Hall/CRC Handbooks of Modern Statistical Methods. Boca Raton: CRC Press. Taylor & Francis Group. 2018.

Kunz, T.H.: Age estimation and post-natal growth in the bat *Myotis lucifugus.* Journal of Mammalogy. 63 (1), 23-32, 1982.

Lyman, C.P., Willis, J.S., Malan, A., Wang, L.H.C.: Hibernation and torpor in mammals and birds. Academic Press, New York. 1982.

McNab, B.K.: Evolutionary alternatives in the physiological ecology of bats, in Kunz, T.H. (Eds.), Ecology of bats. Plenum Press, New York, London, pp.151–200, 1982.

Mopkowy tunel koło Krzystkowic 2017.: Centralny rejestr form ochrony przyrody., Regionalna Dyrekcja Ochrony Środowiska w Gorzowie Wielkopolskim. http://crfop.gdos.gov.pl/CRFOP/widok/viewnatura2000.jsf?fop=PL.ZIPOP.1393.N2K.PLH080024.H (accessed 2 December 2021). 2017.

Nagel, A., Nagel, R.: How do bats choose optimal temperatures for hibernation?. Comp. Biochem. Physiol. 99A (3), 323-326, 1991.

Nelson, R.A.: Protein and FAT metabolizm, in hibernating bears. Federation Procedings. 39, 2955-2958. 1980.

https://doi.org/10.5194/bg-2022-159
Preprint. Discussion started: 27 July 2022

Barbastella barbastellus hibernation

Nietoperek PLH 080003 NATURA 2000.: - standard data form 2021. https://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=PLH080003 (accessed 2 December 2021). 2021.

Орлова, Н.Г., Дмитриев, В.Е., Рыбаков С.А.: Условия и места зимовок рукокрылых на восточном склоне Кузнецкого Алатау. Экология наземных позвоночных Сибири. Томск. ТГУ, 53-59, 1983.

Paksuz, S., Ozkan, B., Postawa, T.: Seasonal changes of cave-dwelling bat fauna, and their relantionship with microclimate in Dupnisa Cave System (Turcish Thrace). Acta zoologia cracoviensia. 50 A (1-2), 57-66, 2007.

Paszyński, J., Miara K., Skoczek, J.: Wymiana energii między atmosferą a podłożem jako podstawa kartowania topoklimatycznego. Dokumentacja Geograficzna 14. IG i PZ PAN. Warszawa. 1999.

Pawiński, J., Roszkowski, J., Strzemiński, J.: Przewietrzanie Kopalń. Śląskie Wydawnictwo Techniczne, Katowice. 1995.

Procter, J. W., Studier, E.H.: Effects of ambient temperature and water vapor pressure on evaporative water loss in *Myotis lucifugus*. Journal of Mammalogy. 51, 799–804, 1970.

Ransome, R.D.: The natural history of hibernating bats. Christopher Helm, London. 1990.

Stapp, P., Pekins, P.J., Mautz, W.W.: Winter energy expenditure and the distribution of southern flying squirrels. Canadian Journal of Zoology. 69 (10), 2548–2555, 1991.

Storey, K.B., Storey, J.M.: Facultative metabolic rate depression: molecular regulation and biochemical adaptation in anaerobiosis, hibernation and aestivation. Quarterly Review of Biology. 65, 145-174, 1990.

Barbastella barbastellus hibernation

Studier, E.H.: Evaporative water loss in bats. Comparative Biochemistry and Physiology. 35, 935–943, 1970.

Team, R.C.: R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna. Austria. http://www.R-project.org. 2020.

Thomas, D.W.: Hibernating Bats Are Sensitive to Nontactile Human Disturbance. Journal of Mammalogy. 76, (3), 940-946, 1995.

Thomas, D.W., Cloutier, D.: Evaporative water by hibernating little brown bats, *Myotis lucifugus.* Physiological Zoology. 65, 443–456, 1992.

Томиленко, А.А.: Зимовка рукокрылых (Vespertilionidae) в Новосибирскойобласти. Plecotus. et al., pars spec, 99–106, 2002.

Visnovska, Z.: Spatial distribution of hibernating bats (Chiroptera) in relation to climatic conditions in the Demanovska ice cave (Slovakia). Proceedings of the 2"^^ international workshop on ice caves, Demanovska Dolina, - Slovak Republic. Liptovsky Mikulas, 87-97, 2006.

Wang, L.C.H.: Mammalian hibernation. In: Grout B. W. W., Morris G. J. eds. The Effects of Low Temperature on Biological Systems. London, Edward Arnold.: 349-386, 1987.

Wermundsen, T., Siivonen, Y.: Seasonal variation in use of winter roosts by five bat species in south-east Finland. Central European Journal of Biology. 5 (2), 262-273, 2010.

Wojciechowski, M., Jefimow, M., Pinshow, B.: Heterothermy, and the Energetic Consequences of Huddling in Small Migrating Passerine Birds. Integr. Comp. Biol. 51 (3), 409-418, **2011.**

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Table 1. The statistical parameters of the data collected during observation. The *min* and *max* are the minimum and maximum values in the data, q_{25} and q_{75} are respectively the lower and upper quartile, *median* is the median (q_{50}) value, *mean* is the arithmetic average, and *SD* stands for the standard deviation.

parameter	*T*[°C]	*Rh*[%]	*v*[m/s]	*n*[-]
min	6.00	56.4	0.01	1
q_{25}	8.28	74.5	0.05	1
median	9.05	78.4	0.12	1
q_{75}	9.90	81.3	0.15	1
max	12.40	91.8	1.17	220
mean	8.87	77.7	0.19	4.5
SD	1.29	6.8	0.25	18.9

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Table 2. The structural parameters β_i values, their standard errors *SE*, and p-values for null hypothesis H_0: $\beta_i=0$

Structural parameter	value	*SE*	*p*-value
		$\tau = 0.925$	
β_0	10	14	0.474
β_1	-3.3	7.9	0.681
β_2	1.4	8.9	0.872
β_3	2	17	0.917
β_4	-3.5	6.2	0.573
β_5	4	12	0.763
β_6	-3	12	0.818
β_7	-1.8	7.0	0.802
		$\tau = 0.950$	
β_0	46	16	0.005
β_1	9	10	0.360
β_2	-13.6	10.0	0.176
β_3	35	19	0.065
β_4	-16.7	7.3	0.024
β_5	31	15	0.036
β_6	-29	13	0.033
β_7	-16.9	8.6	0.051

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	τ= 0.975		
β_0	56	17	0.001
β_1	3	10	0.791
β_2	-9	11	0.441
β_3	28	19	0.133
β_4	-20.7	8.6	0.016
β_5	37	16	0.020
β_6	-29	13	0.031
β_7	-18.0	9.2	0.052

Fig. 1. Wintering of a single individual *Barbastella barbastellus*

Fig. 2. Group wintering of *Barbastella barbastellus*

Fig. 3.The biplot containing projected scores in PC1 and PC2 coordinates.

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Fig. 1.

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Fig. 2.

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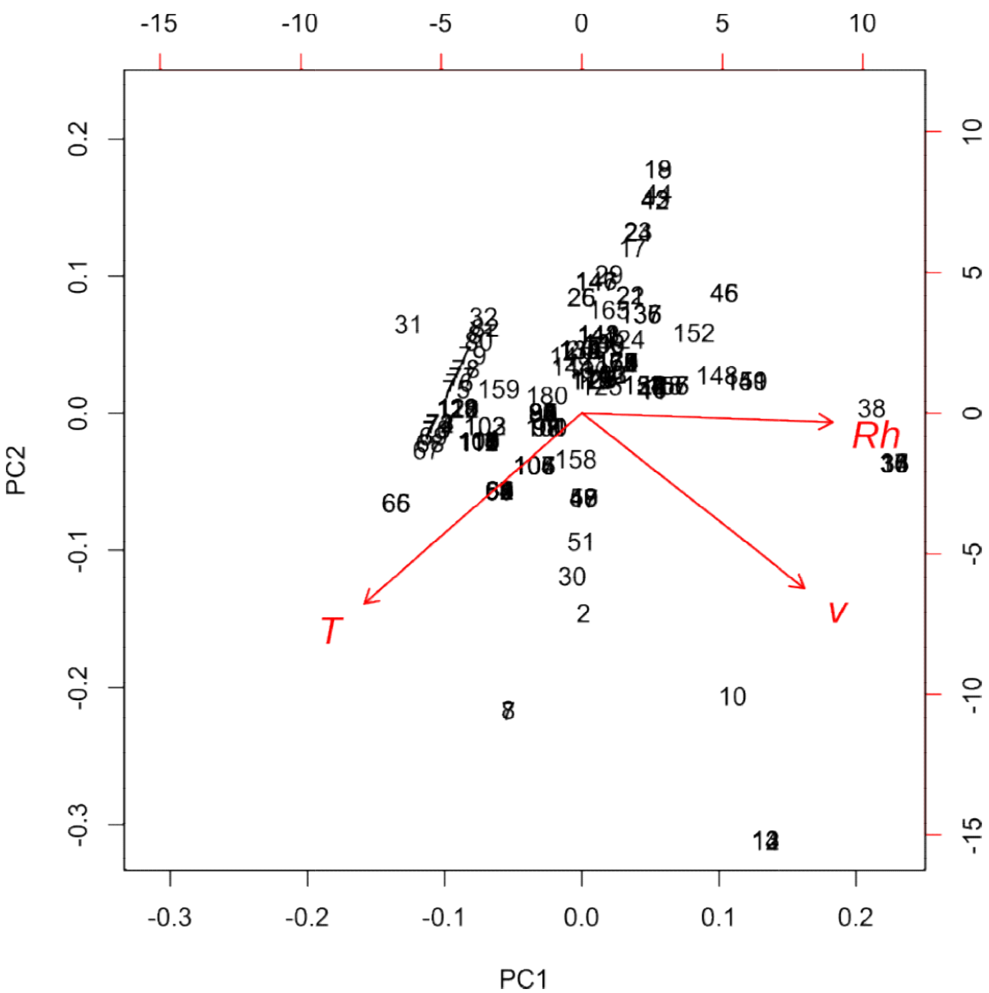

Fig. 3.