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ECOLOGICAL ASPECTS OF BAT HIBERNACULA IN TEMPERATE CLIMATE ZONE OF CENTRAL EUROPE

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Abstract. In temperate climate zone, undergrounds (caves) are the main place for bat hibernation. It is possible to distinguish three kinds of usage of caves by bats: caves used as a hibernaculum, where bats spend the winter period, caves used as shelters for reproductive colonies during the summer period, and caves used as temporary shelters during transitional period (spring and fall) and also as places for food. Caves used as hibernaculum must offer a suitable microclimate for bats. Several important physical factors decide on the selection by bats of a refugee for a period of hibernation. The hibernaculum should have a zone of total darkness. During hibernation bats pay special attention to air circulation, humidity and temperature. These factors are also of significance in forming the microclimate condition inside cave system. Throughout the influence above mentioned factors, a connection between microclimatic condition and topoclimate appears in the cave system and, as a consequence, a refugioclimate forms.

Résumé. Dans la zone de climat tempéré, les refuges souterrains sont le principal lieu d'hibernation des chauves-souris. On distingue trois modes d'utilisation des grottes par les chauves-souris: les grottes utilisées en tant que lieu d'hibernation, dans lequel les chauves-souris restent pendant l'hiver; les grottes utilisées comme gîtes pour les colonies de reproduction au cours de l'été et les grottes utilisées comme gîtes temporaires au cours des périodes de transition (au printemps et en automne) comme endroits propices pour y trouver leur nourriture. Les grottes qui constituent des refuges pour l'hibernation doivent offrir un microclimat optimum. Quelques facteurs physiques importants contribuent à la sélection d'un refuge pour la période d'hibernation. L'endroit d'hibernation est totalement obscur. Les chauves-souris sont particulièrement attentives pendant l'hibernation à la circulation de l'air, à l'humidité et à la température. Ces facteurs sont très importants pour la formation des conditions microclimatiques et topoclimatiques qui apparaissent dans le réseau de galeries.

Key words: Chiroptera, ecology, hibernation, cave microclimate, refugioclimate.

INTRODUCTION

Bats are small, endothermic mammals. They have high metabolic rates and food intakes. But food supply for bats is usually seasonal. For this reason animals such as bats (and another small vertebrate insectivorous animal) need to choose adequate strategies in order to survive during the period when food is scarce.

Among some survival strategies there are: switch to an alternative and more plentiful food supply, store food in times of plenty, migrate to a place where there is food or hibernate (Altringham, 1996).

The majority of bats from temperate zones across the globe choose the last-named option. We can name such survival strategy "escape in time", this in contrast to the survival strategy used by a lot of migratory bird species, namely "escape in space" (Wołoszyn, 2007).

For hibernating bats it is very important to find a safe and ecologically adequate hibernaculum (Wołoszyn, 2008). Before they began to use man-made shelters, bats used two main types of roosts: caves and trees.

Bats will prepare themselves for hibernation by depositing large reserves of fat. To do this, many bats appear to depend more on regular post-feeding torpor than an increase feeding activity.

Some bats are known to forage close to the sites used at least in the early stage of hibernation. A bat will typically enter hibernation with fat reserves of 20 – 30 % body weight (Altringham, 1996). At least 165 days has been estimated to be maximum, uninterrupted hibernation period possible for medium size vespertilionid bat (Altringham, op. cit.; Kunz & Fenton, 2003; Mitchell-Jones et al., 2007). In the wild, hibernation is usually interrupted by frequent arousal.

Torpor used on a daily basis for energy budgeting, or for long period of hibernation, is an important and integral component of the life history strategy of bats above all in the temperate regions, like Europe.

MATERIAL AND METHODS

Among all types of refugees, the caves are more important because they provide permanent roosts which can be used by many generations of bats.

Bats can use underground shelters dependent of environmental conditions and geographical position. During hibernation, bats are exposed to disturbance, and extensive disturbance may be dangerous to them and may limit their chances of surviving the winter time. For this reason, protection of hibernacula is substantial for bat protection.

During hibernation bats pay special attention to temperature, air circulation, and humidity. These factors are also of significance in forming the microclimate condition inside cave system.

Throughout the influence above mentioned factors, a connection between microclimatic condition and topoclimate appears in the cave system and, as a consequence, a refugioclimate forms.

In temperate climate zone including Central Europe, caves are the main place for bat hibernation, but it is possible to distinguish three kinds of usage of caves by bats:

- Caves used as a hibernaculum, where bats spend the winter period
- Caves used as shelters for reproductive colonies during the summer period
- Caves used as temporary shelters during transitional period (spring and fall) and also as places for food.

RESULTS

1. Underground systems as a principal place of hibernating bats

In Central European climate zone caves are the main places for bat hibernation during winter. However, bats also use man-made constructions very often such as various kinds of buildings, cellars, left drifts (for example, Tarnogóry-Bytom old mine system, Silesia, Poland), dungeons, wells, etc., provided that they constitute suitable microclimates (Altringham, 1996; Kłys, 2003; Kłys et.al., 2007; Kłys & Wołoszyn, 2005; Michell-Jones et al., 2007; Postawa, 2000; Wołoszyn, 1976, 1998, 2004).

Natural as well as artificial rock hollows comprise a special environment, which is characterised by a suitable ecoclimate, peculiar conditions for organic material circulation and very often by a specific animal world (Vandel, 1965).

A characteristic feature of cave climate is the predominance of three elements: temperature and humidity of air and absence of light. The aforementioned climate factors show a distinct gradient. As far as making one's way inside the cave the amount of light decreases gradually until complete darkness prevails.

Temperature and air humidity are very changeable in parts near the entrance, whereas deep inside the cave they are very stable.

2. Characteristics of underground shelters

In the Underground system, which is becoming 'popular' for bat hibernation, microclimatic conditions are different in comparison to the outside environment. They change already in small distances (Chromow, 1977). Microclimate here is more stable and milder, which certainly depends on the size of the underground system and the scale of climatic changes, on long-term, seasonal and day-to-day basis. Of crucial importance to a number of morphological and geographical factors there are: cave within an area, exposure and size of the entrance, size and horizontal expansion and horizontal tunnels, and also water flow and type of bedrock (Mitchell-Jones et. al., 2007; Kłys, 2003; Kozakiewicz, 1997; Postawa, 2000; Wołoszyn, 1976).

Animals living in caves show different degrees of adaptation to such an environment. Taking into consideration that aspect, three ecological groups were singled out: troglobiont, troglophile, trogloxene, the most species-rich group of cave inhabitants. These are species living mostly on the surface, which occasionally penetrate the caves and manage to survive in such extreme environment. To the trogloxene group belong bats, which regularly hibernate in caves.

For choosing an appropriate system of underground hibernaculum bats must have three main elements of the choice the refugee for a period of hibernation by bats: hibernaculum should have a zone of total darkness, where a stable temperature, humidity, usually close to fully saturate the air with water vapor, a small flow of air. The wintering depends on the species.

As far as meteorological conditions in places of hibernation (refugioclimate) are concerned, the strategy of bat hibernation needs to be considered. Thus we were able to single out two main types of hibernacula, the first being air as the cooling factor for bats (as e.g., *Rhinolophus* sp.), the other being rock features (e.g., for some species of the genera *Myotis* and *Plecotus* which simply prefer to squeeze into cracks very often). Of course, we know a number of intermediate forms, in which bats use both strategies for cooling or create a group. Certainly, a complex array of factors has an impact on the organism of hibernating bats, and not all of them are known at times. That is why data collected in a hibernaculum should concern, first of all, all factors of cooling, such as air and type of rock as well as a strategy of hibernation and others which would seem interesting to the observer.

One of the items in research of bat hibernation is to specify the individual value of physical factors (mutually complementary). Also extremely important is the methodology for measuring these factors (Kłys et al., 2005). Many papers on meteorological conditions at bat occurrences lack a description of methodology and measuring equipment, which precludes proper interpretation of such data (Kłys et al., 2005). It often happens that do not take into account the presence of someone who is measuring the measurement (Caputa & Kłys, 2005).

3. The most important physical factors that govern bat hibernation.

Caves used as hibernaculum must offer a suitable microclimate for bats. During hibernation bats pay special attention to air circulation, humidity and temperature. These factors are also of significance in forming the microclimate condition inside cave system.

Several important physical factors decide on the selection by bats of a refugee for a period of hibernation:

- Darkness
- Temperature
- Humidity
- Air circulation
- Thermal conduction of rocs
- Impact of outside/external climate condition
- Phases changes of air
- Penetration of geothermal warmth

Throughout the influence above mentioned factors, a connection between microclimatic condition and topoclimate appears in the cave system and, as a consecquence, a refugioclimate forms.

3.1. Darkness

The hibernaculum should have a zone of total darkness. As far as making one's way inside the cave the amount of light decreases gradually until complete darkness prevails. That is where we find most overwintering bats.

3.2. Temperature

In a study of hibernating bats, the most important factor is often considered to be the air temperature, because this is an universal indicator of rapid response even to small changes in circulation and in terms of humidity in the subterranean setting. However, it is very difficult to deal with thermal conditions of this system without knowledge of humidity and intensity of air circulation.

Air temperature inside the deeper portions of cave is independent to a remarkable degree of seasonal changes which take place at the surface and keep the level close to average many years' air temperature around the cave.

Choose a place with a stable temperature, where temperatures are low in amplitude (Kłys, 2008 a). It should be noted that temperature so far was the primary parameter to characterize hibernating bats, and numerous authors wrote about the temperature of such animals. Before going into hibernation, bats choose locations with a relatively low temperature, from 17°C to near 15°C (Harmata, 1969, 1973). However, each species prefers different amplitudes of temperature (Harmata, 1969, 1973). Information published in same papers on bats hibernating in air temperature below 0^{o}C probably were the result of the fact that the measurements concerned only the temperature of the cave corridor and not the temperature of refugioclimate.

3.3. Humidity

Air humidity (relative and absolute) in cave systems is a factor which is variable in time and space. It depends on climate, season and intensity of rainfall and air direction (outside the subterranean system). Differences between air humidity near the entrance and in deeper parts can be significant. Air humidity inside corridors situated close to the entrance changes seasonally.

The humidity regime is as complex as the temperature regime. It was formed as a result of incoming humidity from the surface, progressively cooled air inside and its humidification during the contact with underground and infiltrated waters.

In contrast to subterranean air temperature, spatial distribution of humidity and its course are characterised by a relatively low variability. This is the result of different processes that form humidity conditions. In the undergrounds, water vapour essentially comes from two sources: from incoming air (process of circulation: outside – inside), from dropping infiltrated water in the molecular processes of diffusion and evaporation. An additional source of water vapour is stagnant water or water flows on the bottom. A decrease of air temperature causes an increase of relative humidity and, in some cases, flowing air loses some water vapour as a result of condensation.

Of course, when bats choose a place for hibernation, humidity plays an important role (Thomas & Cloutier, 1992). Air saturated by water vapour cannot take off heat from the bats' bodies through evaporation without simultaneously increasing air temperature. The lower the relative humidity of the air, the greater the role played by cooling of the body through evaporation. Lesiński (1986) and Bogdanowicz & Urbańczyk (1983), indicating relative humidity for hibernating bats in the field of 75–95%, suggested that species exposed to lower temperatures during hibernation (including the Brown long-eared bat) are more plastic than those favouring higher temperatures, where humidity specifications are concerned. Bernard et al. (1991) gave values of relative humidity in the field of 69-97 %. At the Tarnowskie Góry-Bytom underground system, relative humidity near hibernating bats was 95-100% (Kłys, 2008 b).

3.4. Air circulation

Air circulation of different rates appears in almost all underground systems. The flow of air is also different in the various parts of such systems. In large chambers, air movement is almost imperceptible, and it increases very rapidly in the narrow corridors.

In the past it was generally recognised that air movement negatively affects the choice of place for bat hibernation; animals usually choose places where there is a lack of air (Kallen, 1964; Tinkle & Patterson, 1965).

Such applications can probably explained the small movements of air below 0.1 ms^{-1}. As a result of the study, carried out recently by the senior author (Kłys, 2003) it appears that these suggestions are erroneous, and that some species of bats do not spend the winter period in places where movement was below 0.1 ms^{-1}. The results show that both studied species of bats (i.e. *Myotis myotis* and *Plecotus auritus*) spend the winter period in nearby locations with much larger movement of air, and if only the structure (morphology) of wall is so complex they are able to find microniches where parameters of air flow are optimal. In our studies it appeared that they were limited to 0.02 – 0.09 ms^{-1}. Thus, slow movement of air in the underground systems is of great importance in shelter habitat during the winter. Air speed is such that it causes a rapid entry of bats into the hibernation, and so slowly that it does not lead to rapid cooling of hibernated bats. Our studies show that bats can link very precisely the movement of air to the value of other examined factors.

3.5. Impact of outside/external climate condition

Constant circulation of atmospheric air with air inside is the most important factor shaping the climate in an underground system. Air circulation has an impact on the variability of temperature, humidity and air pressure, as well as on processes of evaporation and condensation. The main cause of appearance of air circulation underground is the difference in density of two air masses: surface and underground, two surface masses (exogenic factors) or two underground ones (endogenic factors). At the same time, as shown by research into the exchange of air flow and change the existing atmosphere, although these changes are minor. This is responsible for the transmission of information with the outside world in places where bats hibernate.

Thus, the choice of places for hibernation depends on parameters of air flow, causing an increase in opportunities for heat exchange between bats bodies and surrounding air molecules. As a consequence, it results in a more rapid way to put heat convection when entering hibernation (other methods are limited). The shortening of the time simultaneously saves energy.

It was assumed previously that the flow of air is a negative factor for bats. Recent research indicates, however, the important and positive role of this factor in the selection of spaces for hibernation. Its action can be demonstrated in at least two examples:

- A moderate flow of air accelerates biological cooling of bats and facilitates them to entry into hibernation (Kłys, 2003);
- In vertical caves located highly in the mountains, with many entrances, warmer air is sucked into the bottom hole and is directed up through corridors to the top hole while heating corridors located above. This allows bats to find a convenient place to hibernate in higher positions than would be possible in caves developed horizontally (Piksa & Nowak, 2000).

4. Caves used as shelters for reproductive colonies during the summer period

In Central European climate zone, bats undergo strong synantropisation and do not form reproductive colonies in caves. We know two exceptions in Poland:

- Cave *Studnisko* in the Sokolie Mountains (Góy Sokolie), in which there is a reproductive colony of the Mouse-eared bat (*Myotis myotis*) (Gas & Postawa, 2001);
- MRU – Reserve *Nietoperek*, where the same species forms a reproductive colony (Sachanowicz et. al., 2006).

5. Caves used as temporary shelters during transition period and also as places for feeding activity

During the transition period, i.e., when bats change their shelters - in spring from winter shelters to summer ones and in autumn vice versa, using caves for temporary refugee. The area near the entrance of the cave is used by bats during the summer as foraging place. The increased air humidity and absence of a stronger flow of air enable bats to feed on insects here (Altringham, 1996; Ciechanowski et. al., 2004; Kozakiewicz, 1996; Labocha et. al., 2005; Postawa et. al., 2005).

DISCUSSIONS

Understanding the main habitat factors governing bat hibernation and knowledge of the link between habitat conditions (ecoclimate) could have essential theoretical and practical significance. Knowledge of these factors enables forecast, creation of artificial habitats for threatened and endangered species of bats. There is a possibility to modulate conditions for hibernation – artificial habitats and protection of those already in existence. For large systems, changes caused by excessive ventilation are not as dangerous for hibernating bats as small systems where an increase or decrease of air flow would have a negative impact on bats.

The sum of factors such as temperature, humidity and air traffic are elements of refugioclimate conducting potential areas for bat hibernation. It should be noted that air traffic is the most important factor in the choice of place for bat hibernation. At the same time, the sum of many variables can determine comfort of hibernation.

Bat bodies, when entering hibernation, may cast off heat to the environment by radiation, evaporation, convection and conduction. The amount of heat given off absorbed by the body through convection depends on heat conductivity of the body, and the difference between air temperature surrounding the body (rock) and skin. By convection, i.e. direct heat rise from the surface of the skin, increases the intensity of heat at the surface of the bat's body. This is the only way to reduce, in a short time, body temperature (at high humidity). A slow entry into hibernation (long-term reduction of body temperature) would increase loss of energy. The size of cooling air operations, i.e. cooling intensity, expresses the heat loss of 1 cm^2 area within one second. Bats need the shortest time to go into hibernation. Wind factor (air flow) has a twofold task; first, to shorten the time for going into hibernation, and second, remove heat to maintain life processes within the hibernating bat. In our studies it appeared that they are limited to 0.02 – 0.09 ms^{-1}. Thus, slow movement of air in the underground systems is of great importance in shelter habitat during the winter.

Donation of heat from the body through convection depends on the rate of air and is directly proportional to the difference of temperature of the body surface and air.

With a certain combination of factors such as temperature, humidity and air traffic the settling of hibernating bats reaches its optimum.

ASPECTE ECOLOGICE ALE ADĂPOSTURILOR DE HIBERNARE ALE LILIECILOR ÎN ZONA DE CLIMĂ TEMPERATĂ DIN EUROPA CENTRALĂ

REZUMAT

În zona de climă temperată, adăposturile subterane sunt principalul loc de hibernare al liliecilor. Se pot distinge trei moduri de folosire a peşterilor de către lilieci: peşteri folosite ca loc de hibernare, în care liliecii stau în perioada de iarnă, peşteri folosite ca adăposturi pentru coloniile de reproducere în timpul verii şi peşteri folosite ca adăposturi temporare în timpul perioadelor de tranziţie (primăvara şi toamna) sau locuri de procurare a hranei. Peşterile folosite ca locuri de hibernare trebuie să ofere liliecilor un microclimat optim. Câţiva factori fizici importanţi contribuie la selectarea unui refugiu de către lilieci pentru perioada de hibernare. Locul de hibernare trebuie să fie total întunecat. Pentru perioada hibernării liliecii sunt foarte atenţi la circulaţia aerului, umiditate şi temperatură. Aceşti factori sunt foarte importanţi în formarea condiţiilor microclimatice şi topoclimatice care apar în reţeaua de galerii.

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