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Habitat factors influencing bat assemblages hibernating in abandoned mines in the Štiavnické vrchy Mts. (Slovakia) – preliminary results

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With 3 figures

1 Introduction

Bats of temperate climatic zones survive lack of food during cold periods in hibernation (MCNAB 1982). Saving of body energy requires physiological expences (reviewed by HUMPHRIES et al. 2003), which animals minimize by selection of a suitable environment (cf. NAGEL & NAGEL 1991). Generally, the ambient temperature (especially in bats hibernating in underground roosts) is the most important factor influencing this behaviour (e. g. KOVATS 1989, NAGEL & NAGEL 1991, SANDEL et al. 2001, BORDA et al. 2004, LOPEZ-GONZALEZ & TORRES-MORALES 2004). Comparisons between temperature requirements of a number of bat species resulted in the finding that the minimum average temperature for the family *Rhinolophidae* was significantly higher than for the species from family *Vespertilionidae* (WEBB et al. 1996). Temperature demands are species-, sexual- and age-specific (cf. *Myotis daubentonii* in KOKUREWICZ 2004). This variability has also very probably a geographical background (WEBB et al. 1996). Also more stable ambient temperature (during winter season) can be an important factor influencing the underground roost-site selection (e. g. *Hipposideros armiger terasensis* in HO & LEE 2003). Relative humidity, air circulation and type of habitat, are other important roost-site selection factors for hibernation as well as for reproduction (e. g. BETTS 1997, BORDA et al. 2004). Bats mostly hibernate in sites with high relative air humidity (DAAN 1973, KOKUREWICZ 2004). Human disturbances plays a special role. Direct human impact on hibernating bats can be evident in tactile (SPEAKMAN et al. 1991) and nontactile (THOMAS 1995, MANN et al. 2002) disturbance. Higher body weight loss in hibernating bats is connected to this factor (JOHNSON et al. 1998). Other potential factor influencing the occurrence of bats in underground sites can be the presence of aerial microorganisms (BORDA et al. 2004).

Some old mines in Slovakia are very important habitats for bats (e. g. DANKO 1997). In the area of the Štiavnické vrchy Mts. (central Slovakia) the occurrence of bats has mainly been reported in abandoned mines (UHRIN et al. 1995, 2002). The aim of this study was to identify the influence of selected environmental factors at the examined undergrounds sites, on the species composition of hibernating bat assemblages in this model area.

2 Material and methods

2.1 Study area

Štiavnické vrchy Mts. (263-1009 m a.s.l.) are situated in the south part of the Western Carpathians (central Slovakia; Fig. 1). The origin of this mountain complex is volcanic which is reflected by a rich geological composition; primarily andesite and ryolite, breccias and tuffs, also sandstone, slates, quartzite and limestone are found locally. The largest part of the area belongs to the temperate climatic region, apart from the highest location which are colder. The area has rather low precipitation (annual average about 800 mm). Indigenous forests (southern part: beech-oak woods; central part: mainly maple- and lime-beech woods, northern part: mixed oak, beech, fir and spruce forests) were

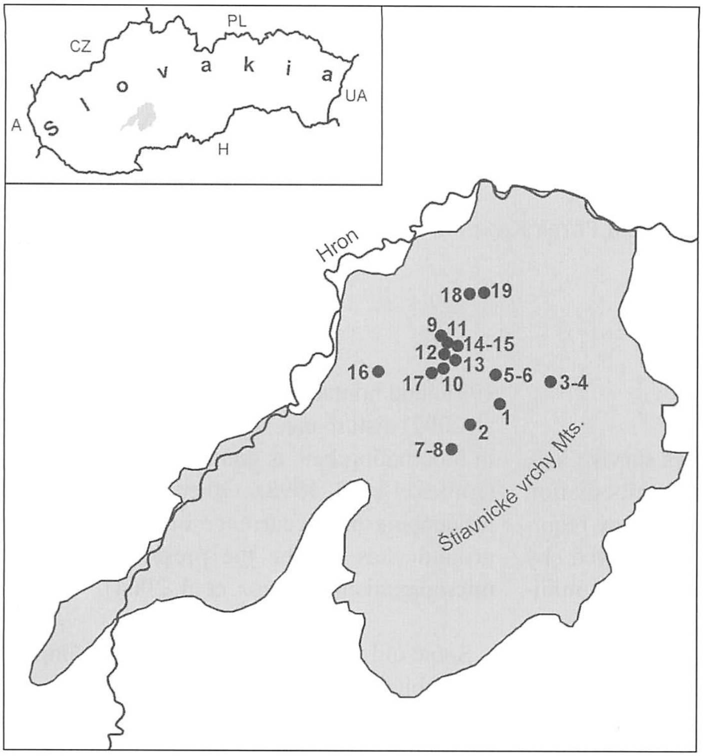

Fig. 1. Studied localities in abandoned mines occupied by hibernating bat assemblages in the Štiavnické vrchy Mts.: 1 – IG; 2 – KU; 3 – LK1; 4 – LK2; 5 – SMS; 6 – SMP; 7 – VS1; 8 – VS 2; 9 – FL; 10 – LA; 11 – NR; 12 – PR; 13 – PJ; 14 – RA1; 15 – RA2; 16 – SCH; 17 – ZS; 18 – KJ; 19 – RE1 (Abbreviations see in Table 1)

Abb. 1. Untersuchte Lokalitäten in den ehemaligen Bergwerkstollen in den Štiavnické vrchy Bergen, die von Winterschlafgemeinschaften von Fledermäusen aufgesucht werden.

changed due to mining in the past; and in many sites are substituted by spruce monocultures. Today this area is covered with forests, meadows, fields and settlements (see MIKLÓS & HRNČIAROVÁ 2002).

2.2 Bat assemblage and habitat description

Altogether 35 underground localities were checked in the study area. Periodically once in January, hibernating bats were visually counted in all positive localities (n = 19) in 1998-2004 (2-6 checks/locality, lower number of checks in some cases was caused by subjective reasons). The abundance (n) and dominancy (d %) of individual species were recorded in the examined bat assemblages. These assemblages were characterized by Index of diversity – *H'* (SHANNON & WEAVER 1963) and Index of equitability – *e* (SHELDON 1969).

In all studied localities the following environmental factors were determined: (I) altitude of mine entrance (m a.s.l.); (II) mine entrance orientation; (III) mine entrance size (cm); (IV) geological substrate; (V) gallery length (m; = length of controlled route); (VI) mine segmentation (number of tunnels); (VII) presence of stagnant water (estimated % of floor cover); (VIII) ambient temperature (°C) – measured at least 35 m from the mine entrance (or at the end of a shorter mine), 190 cm over the floor; (IX) relative humidity (%) – measured similar to temperature; (X) character of locality (= air circulation: static, static-dynamic, dynamic). The description of the environment in the individual localities is shown in Table 1.

2.3 Statistical analyses

Because the longest gradient in Detrended Canonical Correspondence Analysis (DCCA) was 2.092, the influence of selected environmental factors on bat assemblages occupying the studied underground roost was investigated using Redundance Analysis (RDA) (LEPŠ & ŠMILAUER 2003). In total, 17 localities were analyzed (due to rebuilding of entrance, the

Table 1. Feature description of abandoned mines occupied by bat assemblages in the Štiavnické vrchy Mts.

Tabelle 1. Beschreibung der Habitatparameter der untersuchten ehemaligen Bergwerkstollen in den Štiavnické vrchy Bergen

Locality	Altidude of entrance (m a.s.l.)	Entrance orientation	Entrance size*	Substrate **	Gallery length	Segmentations ***	Stagnant water (%)	Temperature (C°)	Humidity (RH %)	Character ****
IG	590	NE	L&B	A	250	B	5	8.5	91.2	S
KU	600	SW	M	A	350	B	50	8.7	87.0	D
LK1	600	S	L	R	80	D	25	0.0	78.0	S
LK2	600	S	L	R	80	D	25	5.7	89.0	S
SMS	770	SE	S&B	A	25	A	0	12.4	87.4	S
SMP	770	S	L	A	15	A	0	12.0	92.1	SD
VS1	660	N&S	M	A	50	A	100	–	–	D
VS2	660	S	XS	A	30	A	100	–	–	S
FL	770	SE	M	A	> 2000	C	10	8.5	87.7	S
LA	500	S	M	A	190	A	5	7.3	96.8	S
NR	835	SW	L	A	650	B&D	0	3.9	77.7	D
PR	710	N&S	XS	A	50	A	0	5.8	76.5	D
PJ	690	S	L	A	250	B	5	9.8	82.9	S
RA1	810	S	S	A	650	B&D	10	3.2	75.0	D
RA2	810	S	S	A	650	B&D	10	3.5	79.8	D
SCH	330	S	XS	A	> 2000	C&D	0	4.7	71.2	SD
ZS	490	S	M&B	A	> 600	B	0	6.5	87.3	SD
KJ	410	NE	M	A	110	A	90	6.8	87.0	S
RE1	510	S	XS	L	60	A	0	7.6	93.0	S

Abbreviations of locality names: FL – Floriánka, IG – Ignác, KU – Kunia, LA – Laura, LK1 – Lom v Kysihýbli 1, LK2 – Lom v Kysihýbli 2, NR – Nad Rabensteinom, KJ – Pod Kamenným jarkom, PR – Pod Rabensteinom, PJ – Pri jedli, RA1 – Rabenstein 1, RA2 – Rabenstein 2, RE1 – Repište, SCH – Schöpfer, SMP – Staré mesto puklina, SMS – Staré mesto štôlňa, VS1 – Vodná štôlňa 1, VS2 – Vodná štôlňa 2, ZS – Zlatý stôl

* L – > 220 cm, M – 170 ≤ 220 cm, S – > 60 ≤ 170 cm, XS – ≤ 60 cm, B – enclosed with bars

** A – andesite, R – ryolite, L – limestone

*** A – 4–5 tunnels, B – 2–3 tunnels, C – one-way tunnel, D – large space

**** S – static, SD – static-dynamic, D – dynamic

internal microclimate was strongly changed in two localities and hence these were excluded from the analyses). Input data consist of the sum of recorded bat species and selected environmental factors (see chapter "Bat assemblage and habitat description"). Data were not transformed, scaling was focused on inter-species correlations and score of the species was divided by the standard deviation. The importance the influence of environmental factor on the species composition variability was tested by Monte-Carlo permutation test with 9999 permutations. Factor values were scaled to the categories and analyzed by CANOCO for Windows 4.5. Similarity of hibernating bat assemblages (n = 19 localities) were examined unsing Ward's method (percent disagreement) in a tree diagram of similarity (Hierarchical Classification Analysis) (analyzed by STATISTICA '99).

3 Results

3.1 Hibernating bat assemblages

The occurrence of 15 bat species was recorded in the study area. Because of the difficulties in visual species determination (e. g. sibling species), the total number of taxons found was higher (Table 2). The most dominant species was *Rhinolophus hipposideros*; with the mean dominance ≥ 50 % in 12 localities (n = 19) over the investigated period. In some localities, this most frequent species reached also the highest abundance (even 124 ind. in FL; Abbreviations see in Table 1). The dominance of the second

Table 2. Bat assemblages description (mean Index of diversity – *H'* and equitability – *e*, minimal and maximal abundance – $n_{min-max}$) and mean dominancy (d %) of individual taxons hibernating in abandoned mines in the Štiavnické vrchy Mts. during six winter seasons (1998-2004)

Tabelle 2. Beschreibung der Fledermausgesellschaften (mittlerer Diversitätsindex – *H'* und Ähnlichkeit – *e*, minimale und maximale Häufigkeit – $n_{min-max}$) und mittlere Dominanz (d %) der einzelnen Arten, die in den ehemaligen Bergwerkstollen der Štiavnické vrchy Bergen überwintern, über einen Zeitraum von 6 Wintern (1998-2004)

Locality	*H'*	*e*	$n_{min-max}$	*Rfer*	*Rhip*	*Mmyo*	*Mbly*	*Mmyo/bly*	*Mbech*	*Mnat*	*Mema*	*Mmys/bra*	*Mdau*	*Eser*	*Enil*	*Paur*	*Paus*	*Paur/aus*	*Bbar*	*Mschr*
IG	1.69	0.70	15–40	5.6	59.4	8.0		1.1	0.9		4.4		14.7			2.3	2.2		1.2	
KU	0.48	0.36	22–37		73.9	8.4			0.5				0.5							
LK1	0.14	0.94	2–7			4.0													96.0	
LK2	1.85	0.93	4–15		18.9	38.3	5.0		2.5		9.7		15.7			2.9		2.9	4.2	
SMS	0.20	0.60	0–2		20.0									10.0	20.0	10.0				
SMP	0.23	0.73	0–3	16.7	25.0	8.3									25.0					
VS1	0.00	1.00	1–2																100.0	
VS2	0.00	1.00	1–7		50.0														50.0	
FL	0.98	0.45	140–161	6.2	81.4	8.5				0.3	3.6									
LA	0.78	0.60	6–17	1.5	80.1	12.8					2.8		2.8							
NR	0.56	0.32	32–139	3.5	5.0	1.1								0.4					90.0	
PR	1.13	0.83	4–19		50.1	8.5									1.3		2.3		37.8	
PJ	1.60	0.80	11–24	8.7	54.0	26.1					11.2									
RA1	1.23	0.57	23–53		3.3	67.2		0.5		1.6	0.9	1.1	0.8		0.5	0.5	0.9		22.7	
RA2	1.48	0.86	12–21	1.5	53.6	30.6					6.5		3.3						4.5	
SCH	1.34	0.62	270–406	36.4	55.3	7.0					1.1		0.1				0.1			0.1
ZS	0.89	0.88	4–10		72.9						4.2	6.3	5.0						11.7	
KJ	1.02	0.70	4–12	5.6	74.1	15.8					3.0		1.5							
RE1	0.95	0.96	0–6		50.0	8.3					4.2					4.2			8.3	

Abbreviations of species names: *Rfer – Rhinolophus ferrumequinum* (Schreber, 1774), *Rhip – Rhinolophus hipposideros* (Bechstein, 1800), *Mmyo – Myotis myotis* (Borkhausen, 1797), *Mbly – Myotis blythii* (Tomes, 1857), *Mmyo/bly – Myotis myotis/blythii*, *Mbech – Myotis bechsteinii* (Kuhl, 1817), *Mnat – Myotis nattereri* (Kuhl, 1817), *Mema – Myotis emarginatus* (Geoffroy, 1806), *Mmys/bra – Myotis mystacinus/brandtii*, *Mdau – Myotis daubentonii* (Kuhl, 1817), *Eser – Eptesicus serotinus* (Schreber, 1774), *Enil – Eptesicus nilssonii* (Keyserling et Blasius, 1839), *Paur – Plecotus auritus* (Linnaeus, 1758), *Paus – Plecotus austriacus* (Fischer, 1829), *Paur/aus – Plecotus auritus/austriacus*, *Bbar – Barbastella barbastellus* (Schreber, 1774), *Mschr – Miniopterus schreibersii* (Kuhl, 1817) (Abbreviations of locality names see in Table 1)

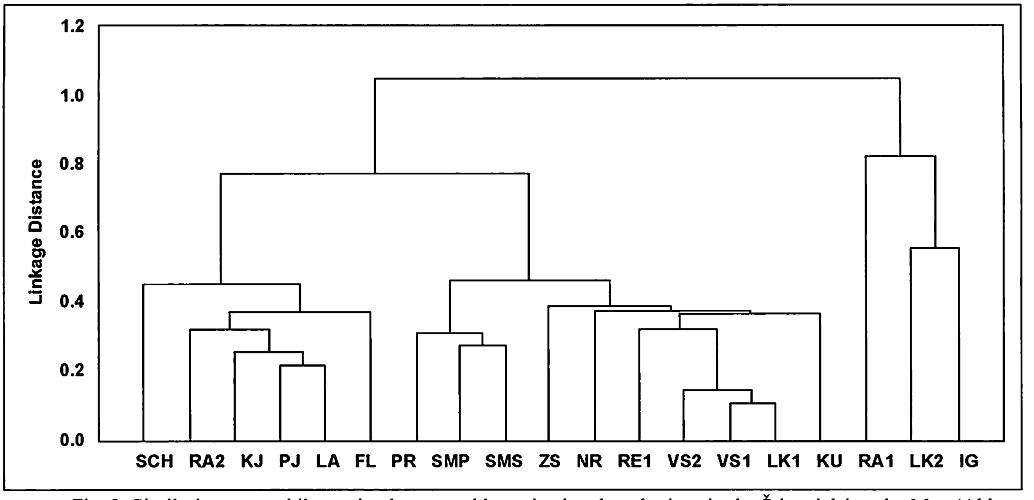

Fig. 2. Similarity among hibernating bat assemblages in abandoned mines in the Štiavnické vrchy Mts. (Abbreviations see in Table 1)

Abb. 2. Ähnlichkeiten zwischen Winterschlafgemeinschaften von Fledermäusen in den ehemaligen Bergwerkstollen in den Štiavnické vrchy Bergen

species *Myotis myotis* was > 25 % in four localities (RA1, LK2, RA2 and PJ). Localities with the highest diversity were LK2 (mean *H'* = 1.85), IG (1.69) and PJ (1.60). These localities have an entrance higher than at 220 cm and static character of air circulation with January temperature 5.7-9.8°C and relative humidity 83.0-91.0 %. The lowest species richness was found in localities with shorter galleries (< 80 m), probably with less stable microclimate. Such hibernating sites were occupied mostly by *Barbastella barbastellus*. Apart from localities with low abundance, the highest equitability had assemblages in static or static-dynamic mines in localities LK2 (mean e = 0.93), ZS (0.88) and RA2 (0.86). Localities with the highest number of hibernating bats were SCH (n_{max} = 406 ind.), FL (161) and NR (139; Table 2).

Bat assemblages hibernating in the studied localities were clustered into three groups. The first locality group (SCH, RA2, KJ, PJ, LA and FL) consisted of assemblages with a dominance of species of the genus *Rhinolophus*, accompanied by regular, but low abundance of *M. myotis*. Owing to high data heterogeneity, it was not possible to find common assemblage features in the second locality group (PR, SMP, SMS, ZS, NR, RE1, VS1, VS2, LK1 and KU). The third group represented localities (RA1, LK2 and IG) with the highest number of hibernating bat species in the Štiavnické vrchy Mts. (Fig. 2).

3.2 Factors influencing habitat selection

The major part of investigated habitat factors in underground roosts (altitude, orientation and size of entrance, presence of stagnant water, substrate) had no significant influence on the occupancy or abundance of bat species or their possible influence for bat's hibernation was excluded later. The entrance size could have some influence because the species diversity was higher in the localities with large entrance. However, due to difficulties in measurement (e. g. more and unknown entrances) it was not considered as an important factor. Gallery length (in accordance also with the mine segmentation) had significant importance on bat occupancy and abundance (Monte-Carlo test, F = 2.63, p = 0.004). Naturally, more individuals hibernated in longer mines. The second significant factor was found to be the ambient temperature of mine (Monte-Carlo test, F = 5.26, p = 0.041).

Regarding the determined factors, it was possible to divide the bat species into three groups. The first group consisted of species (*Rhinolophus ferrumequinum*, *R. hipposideros*, *Myotis myotis*, *M. emarginatus* and *Miniopterus schreibersii*) preferring longer or warmer mines in the Štiavnické vrchy Mts. This group represented typical underground-hibernating bat species. In the second group (*Eptesicus serotinus*, *E. nilssonii*, *Barbastella barbastellus* and partly also *Plecotus* sp.) occurred species which were found in colder (shorter) undergroud roosts (Fig. 3). These higly resistant species are probably not dependent on such roost types and a major part of the population uses other roosts for hibernation in the study area. Because of the low abundance or rare findings it was not possible to put in relation, the occurrence of other species with environmental factors (Records of less abundant species resulted more probably from a higher probability of recording them in longer mines than from their habitat preference).

4 Discussion

With the presented results we attempted to identify environmental factors influencing the

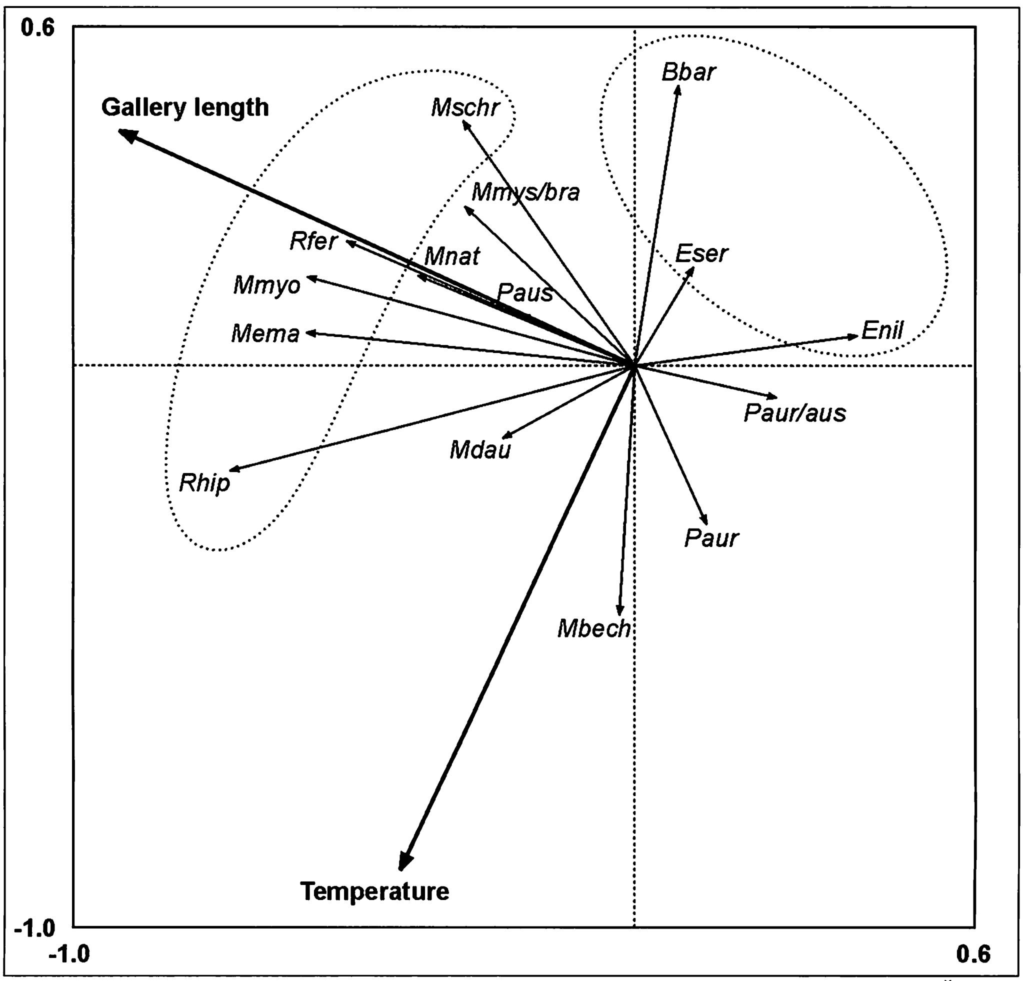

Fig. 3. Habitat factors determining preferences of bat species hibernating in abandoned mines in the Štiavnické vrchy Mts. (Abbreviations see in Table 2)

Abb. 3. Einfluß von Habitatfaktoren auf Fledermäuse, die in den ehemaligen Bergwerkstollen in den Štiavnické vrchy Bergen überwintern.

preference of underground roosts by bats during hibernation in the study area of the Štiavnické vrchy Mts. Primarily, ambient temperature, relative humidity and air circulation were considered as principal factors influencing the bat occupancy of underground roosts. Using statistical methods we found that hibernating-site occupancy was significantly influenced by two factors – gallery length and ambient temperature. To some extent, these factors reflect or correlate with air relative humidity and circulation. Temperature has direct influence on energy demands during hibernation (HUMPHRIES et al. 2002) and is the most important roost-site selection factor in hibernating bats (e. g. KOVÁTS 1989, NAGEL & NAGEL 1991, WEBB et al. 1996, SANDEL et al. 2001, HO & LEE 2003, BORDA et al. 2004, KOKUREWICZ 2004, LOPEZ-GONZALEZ & TORRES-MORALES 2004). However, temperature is only a reflection of the underground habitat itself (localization, shape, size etc.). Longer gallery length means more stable temperature conditions and therefore our recognized significant influences of these two factors in our study area should in general occur simultaneously. Similar to our results, correlation between gallery length and bat occupancy was found in species of the genus *Corynorhinus* (LOPEZ-GONZALEZ & TORRES-MORALES 2004). Similarity of ecological demands in individual groups of bats (Fig. 3) is in accordance with Webb et al. (1996). In contrast to some cases (e. g. *Hipposideros armiger terasensis* in HO & LEE 2003), where entrance orientation, size, and size of area covered with stagnant water were found to influence bat occupancy, we did not find any influence of other habitat factors. Similar investigations have not shown any important relationship between habitat features (except temperature) and occupancy by hibernating bats (e. g. KOVÁTS 1989, CLARK et al. 1996, SHERWIN et al. 2000). Our results allow us to conclude about probable complex influences of several more or less important habitat factors.

Besides the mentioned measured factors, the bats were also influenced by direct human impact. Disturbance of bats had possible impact on bats in several studied localities (SMP, SMS, LK1 and LA). Protection of these localities by closing the entrance with bars is questionable because it can result in an unpredictable final response: from an increase of abundance after installing the bars (e. g. KOVÁTS 1989, MARTIN et al. 2003) to an increase of abundance after removal of bars (e. g. LUDLOW & GORE 2000). It also again indicates the species-specificity in roost-site requirements. After a change in microclimate in locality SCH (cutting of next one, previously buried, entrance) a decrease in hibernating bats to 66 % was recorded compared to the former winter abundance. The extinction of a numerous colony of *M. schreibersii* (ca. 1200 ind.) in the Štiavnické vrchy Mts. (unknown reasons) also supports a Pan-European decreasing trend (cf. UHRIN et al. 1997). Because of the arousal and increase in flight activity of hibernating bats (also during visits of researchers), it is appropriate to minimize this disturbance (see THOMAS 1995). In spite of this fact, a general increase in bat populations hibernating in underground sites (especially *M. myotis* and *R. hipposideros*) was observed in the Central European region over the last decades (Zima et al. 1994). Because of the high abundance of *R. ferrumequinum*, *R. hipposideros* and *M. myotis*, the abandoned mines in the Štiavnické vrchy Mts. require our attention and protection.

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Summary

Altogether 35 underground localities – abandoned mines, were controlled in the study area in 1998-2004. Occurrence of 15 hibernating bat species was recorded in 19 of them. The most dominant species was *Rhinolophus hipposideros* followed by *Myotis myotis*. Bat assemblages hibernating in the studied localities were clustered. One locali-

ty group consisted of assemblages with dominance of the genus *Rinolophus*, accompanied by regular but low abundance of *M. myotis*. Another group represented localities with the highest number of hibernating bat species in the area. Gallery length and ambient temperature of the mine had significant importance on bat occupancy and abundance. Regarding the determined factors, bat species were divided into the groups of similarity. One group consisted of species preferring longer or warmer mines in the area (*Rhinolophus ferrumequinum*, *R. hipposideros*, *Myotis myotis*, *M. emarginatus* and *Miniopterus schreibersii*). In the other group occurred species which were found in colder (shorter) underground roosts (*Eptesicus serotinus*, *E. nilssonii*, *Barbastella barbastellus* and partly also *Plecotus* sp.).

Zusammenfassung

Der Einfluß von Habitatfaktoren auf Winterschlafgemeinschaften von Fledermäusen in ehemaligen Bergwerkstollen in den Štiavnické vrchy Bergen (Slowakei) – vorläufige Ergebnisse

Insgesamt 35 unterirdische Anlagen (ehemalige, jetzt aufgegebene Bergwerkstollen) wurden von 1998-2004 im Untersuchungsgebiet kontrolliert. Das Vorkommen von 15 überwinternden Fledermausarten wurde für 19 Stollen bestätigt. Die am stärksten dominierenden Arten waren *Rhinolophus hipposideros* und *Myotis myotis*. Überwinternde Fledermausgemeinschaften wurden nach der Ähnlichkeit der Arten in Gruppen klassifiziert. In einer Gruppe dominierte die Gattung *Rhinolophus*, begleitet mit regelmäßigen, aber niedrigen Abundanzen von *M. myotis*. Die andere Gruppe wurde von den Lokalitäten gebildet, in denen die höchste Anzahl der Arten überwintert hat. Die Stollenlänge und die Temperaturen hatten signifikanten Einfluß auf Vorkommen und Abundanz der Fledermäuse. Nach den festgestellten Faktoren wurden die Fledermausarten nach ihrer Ähnlichkeit in Gruppen getrennt. Eine Gruppe wurde von den Arten gebildet, die längere und wärmere Stollen bevorzugen (*Rhinolophus ferrumeqinum*, *R. hipposideros*, *Myotis myotis*, *M. emarginatus* und *Miniopterus schreibersii*). Die andere Artengruppe bevorzugte kühlere (kürzere) Winterquartiere (*Eptesicus serotinus*, *E. nilssonii*, *Barbastella barbastellus* und teilweise auch *Plecotus* spec.).

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