Seasonal and geographical distribution of cave-dwelling bats in Romania: implications for conservation

Z. L. Nagy¹ & T. Postawa²

¹ Foundation for School, Cluj-Napoca, Romania

² Institute of Systematics and Evolution of Animals, Polish Academy of Sciences, Kraków, Poland

Keywords

bats; caves; conservation; Carpathians; Dobrogea; species–environment relationship.

Correspondence

Z. L. Nagy, Foundation for School, Soimului Str. 24/A, 400486 Cluj-Napoca, Romania.
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Abstract

Caves offer bats refuges for hibernation, breeding and other social events. Their quality is important for species distribution. The role of cave microclimate as well as other environmental factors influencing the distribution of cave-dwelling species, is poorly known. We tested the significance of cave variables (length, temperature, elevation, occurrence of water) and geographical location for the presence of bats during hibernation and the breeding season in five regions in Romania. To detect species' environmental relationships, we used canonical correspondence analyses for winter bat aggregations and principal components analysis for maternity colonies. We analysed the factors influencing the distribution of bats by using two sets of explanatory variables reflecting cave characteristics and geographical locations. Winter aggregation was divided into three groups: (1) bat species that prefer high temperatures (*Rhinolophus euryale*, *Myotis cappacini*) and hibernate at a low altitude; (2) species ranging from mid- to high elevation and low temperature (*Myotis myotis/oxynathus* group); (3) species that hibernate in large, cold cave systems with a constant flow of the water (*Pipistrellus pipistrellus*, *Nyctalus noctula*, *Barbastella barbastellus*). Maternity colonies were divided into those that select either high (rhinolophids) or low temperatures (*My. myotis/oxynathus* and *Miniopterus schreibersii*). The most important factors influencing the distribution of bats are the temperature in caves and their geographical location. This information was combined with IUCN's Red List data as well as with the number of individuals occurring in caves with the aim of identifying the key sites for conservation. The majority of these sites, which also constitute the refuges for vulnerable species, are located in west and south-western Romania. Seven caves provide shelter throughout the year for 122 000 individuals of 14 species.

Introduction

Bats use caves for hibernation, reproduction, rearing of young and other social events (Kunz, 1982). In Europe, caves are used regularly or occasionally by 46 bat species (Fauna Europaea, 2004). One of the most important factors determining the presence of bats in caves is microclimate, both during hibernation (Gaisler, 1970; Harmata, 1973; Kunz, 1982; Speakman & Thomas, 2003) and during reproduction (Racey, Speakman & Swift 1987; Plachter & Plachter, 1988). Bat species differ in their thermopreferenda and therefore choose different shelters (Nagel & Nagel, 1991). The microclimate is dependent on the length of the cave, the number of entrances and depth (denivelation – distance between the highest and the deepest place in the cave) as well as the average temperature (Kowalski, 1954), which in turn is related to latitude, longitude and altitude. The number of bat species using a cave is correlated with its length (Arita, 1996), density of underground sites in each area (Brunet & Medellin, 2001) and environmental factors,

such as geographical location and temperature range (Řehák, 2006; Ulrich, Sachanowicz & Michalak 2007).

Romania has a varied landscape with many uplands and mountains, including half the Carpathian range. These contain over 12 000 karst caves (Bleahu *et al.*, 1976). The distribution of caves, their size (length and height), altitude, presence/absence of water and microclimate differ widely between the surveyed regions of Romania, and as a consequence, the bat fauna is varied (Dumitrescu, Tanasachi & Orghidan 1963). Most described caves are in the Apuseni Mountains, the Southern Carpathians and the Banat Mountains. In the Dobrogea Plateau, natural caves are small and have dynamic microclimates. In the Eastern Carpathians, although karstic caves are rare, sandstone caves, as well as mine tunnels, are found (Bleahu *et al.*, 1976). Many of the caves are used by bats during both winter and summer, and some constitute the largest hibernacula in Central Europe for such species as *Pipistrellus pipistrellus* (Nagy & Szanto, 2003) and *Miniopterus schreibersii* (Benda *et al.*, 2003). The years 1960–1970 in Central Europe were marked by a rapid

decline of numerous bat species, especially *Rhinolophus hipposideros*, *Myotis emarginatus* and *Myotis myotis* (Stebbing, 1988). During the 40 years since Dumitrescu's *et al.* (1963) study, our knowledge of the distribution and status of cave-dwelling bats has progressed little.

In this study, we repeated and extended the original surveys, with the aim of collecting and analysing data on the recent distribution and abundance of bats. To understand the distribution patterns of the species, we tested the hypothesis that bat species are randomly distributed in space and time, and their presence and density is independent of environmental factors. To test the significance of geographic and microclimate factors, we analysed cave parameters, together with bat distribution data in five distinct geographical units (Apuseni Mountains, Banat Mountains, Dobrogea Plateau, Eastern Carpathians and Southern Carpathians). The aim was to establish what environmental factors predict the presence or absence of species, and where in Romania these factors offer the most suitable conditions for a large number of species and individuals. Based on these analyses, we identified candidate special protected areas in different regions.

In addition, following the Eurobats Agreement and Action Plan for the conservation of bat populations throughout Europe, we proposed to update the basic knowledge relevant to one aspect of bat conservation in Romania – the importance of caves for the conservation of bat biodiversity.

Methods

Study area

The study was conducted in the Romanian part of the Carpathian Mountains and Dobrogea on the Black Sea coast. The Carpathians is a major mountain system in Central and Eastern Europe, curving for 1500 km along the north and east sides of the Danube Plain. The geologically young mountains are divided in Romania into the Eastern Carpathians, the Southern Carpathians and the Banat and Apuseni Mountains. The mountains are characterized by a varied landscape, limestone areas rich in caves and a temperate continental climate. Karst areas are most evident in the Apuseni Mountains with 1047 km², followed by Dobrogea (953 km²) and the Banat Mountains (807 km²), while the Southern and Eastern Carpathians have <800 km². The average number of caves per km² is the highest in the Apuseni Mountains (0.788), <0.5 in other regions and the lowest in Dobrogea (0.062) (Bleahu *et al.*, 1976). The study areas reach the highest altitude in the Southern Carpathians (up to 2500 m a.s.l.), Eastern Carpathians (up to 2300 m a.s.l.), followed by Apuseni Mountains (1800 m a.s.l.) as well as Banat Mountains (1400 m a.s.l.), and the altitude of the Dobrogea Plateau varies between 200 and 400 m a.s.l. The mean annual temperature in most of the study area is between 2 and 6 °C, although it is 6–8 °C in the Banat Mountains and 10–11 °C in the Dobrogea Plateau (Bulla & Mendol, 1999).

Caves survey

Caves were selected and visited on the basis of earlier research (Dumitrescu *et al.*, 1963) and roosting potential, that is those with large entrances, corridors and chambers. The geographical position of the cave (latitude, longitude, altitude) was measured using an eTrex Garmin GPS. Cave parameters (length and denivelation) were taken from the Romanian caves register (Goran, 1981). The presence of water in the caves was noted. We visited 79 caves in five regions of Romania (Fig. 1) a total of 236 times for mapping and survey. In the Apuseni Mountains, 36 caves were surveyed from 230 to 850 m a.s.l. (mean: 430 m a.s.l.) and varying in length from 19 to 4750 m (median: 350 m). In the Eastern Carpathians, 11 caves and one mine were visited, from 590 to 1503 m a.s.l. (mean: 778 m a.s.l.), and from 11 to 1527 m long ($M = 125$ m). In the Southern Carpathians, 15 caves were visited, from 287 to 1150 m a.s.l. (mean: 632 m a.s.l.), and from 50 to 10 000 m long ($M = 725$ m). In the Banat Mountains, 10 caves were visited, from 60 to 606 m a.s.l. (mean: 250 m a.s.l.), and from 94 to 1666 m ($M = 254$ m) long. In the Dobrogea Plateau, five caves and 1 mine were visited, from 12 to 107 m a.s.l. (mean: 44 m a.s.l.) and from 42 to 3200 m long ($M = 132$ m). Using a digital thermometer [Checktemp 1, Hanna Instruments (Cluj-Napoca, Romania) with an accuracy ± 0.5 °C], we measured cave temperatures near the largest aggregation of bats in both summer and winter. For each cave, one to four temperature measurements were made in one season, the average of which was used in subsequent analyses. The only temperature values used were those from caves hosting more than 20 bats.

Bat survey

Between 1995 and 2005, maternity colonies (pregnant females or females with young) were investigated between May and August, and winter aggregations were surveyed between December and March. Single individuals and clusters of less than 50 individuals were directly counted. Larger clusters were photographed using a digital camera and the bats were counted from photos. Bat species were identified without handling, using only the external morphological features described in Schober and Grimmberger (1997) and Dietz and von Helversen (2004). Species that were difficult to distinguish in the field, such as *My. myotis* and *Myotis oxygnathus*, *P. pipistrellus* and *Pipistrellus pygmaeus*, *Myotis mystacinus*, *Myotis alcaethoe* and *Myotis brandtii*, were recorded as *My. myotis/oxygnathus*, *P. pipistrellus sensu lato* (s.l.) and *My. mystacinus* group, respectively. The maximum numbers of bats from several years/or several visits in one season, from each cave, are presented in Table 1.

Analysis

Caves with over 20 bats (winter) or with nursery colonies of more than 20 individuals (summer) were selected. Species with less than 100 individuals (<0.17%) in all caves (during hibernation) or specimens not belonging to maternity colonies were excluded from ordination analysis. Before analysis, log-transformation of data [$\ln(x + 1)$] was performed to

Figure 1 Map of Romania with the location of caves; site numbers – corresponded to the caves list in Table 1. Open circle, Eastern Carpathians; closed circle, Apuseni Mountains; rhombus, Southern Carpathians; triangle, Banat Mountains; black circle, Dobrogea Plateau.

reduce the influence of extreme values of bat numbers, during both the hibernation and maternity periods. To investigate how the hibernating bat communities changed between regions, we used canonical correspondence analyses (CCA) (ter Braak, 1995; ter Braak & Šmilauer, 2002). Factors influencing hibernating bats were analysed using two sets of exploratory variables reflecting cave characteristics and geographical locations. Caves were described by four variables: length, temperature, elevation (at the entrance) and presence/absence of water (regular underground stream or lake); geographical location was described by five regions (Apuseni Mountains, Eastern Carpathians, Southern Carpathians, Banat Mountains and Dobrogea Plateau). For maternity colonies, the main gradients of variation were described from principal components analysis (PCA) because environmental data (parameters of caves and regions) were uncorrelated in the CCA analysis (ter Braak, 1995; ter Braak & Šmilauer, 2002). Statistical analyses were performed using CANOCO 4.52 (ter Braak & Šmilauer, 2002) and KyPlot 2 beta 13. Evaluation of the relative importance of the sites was based on the method of Mitchell-Jones *et al.* (2000). Each site was assigned a combined total by adding scores for the species observed in the caves. Vulnerable species were given four points and species considered at a lower risk or near threatened were given two points. Four priority levels were used to grade the site. Priority level 1 refers to the most important underground roosts, which

support the largest populations of most bat species and have the scores of 10 000 or more; level 2 refers to important underground sites, in which there are large populations and many bat species ($1000 < \text{score} < 10\,000$); level 3 includes sites of lower priority used by few species in small number ($100 < \text{score} < 1000$); while level 4 are sites used by few bats ($\text{score} < 100$).

Results

Throughout the study, we recorded 22 species (Table 1). In total, we encountered *c.* 150 000 individuals in both seasons: 45 000 in summer and 105 000 during winter. During the hibernation period, bats were found in 96% of visited caves, but aggregations of over 20 individuals were fewer (54%). Cave hibernacula were situated at an average altitude of 490 m a.s.l. (Median = 380 m a.s.l.), their internal temperature was $7.0 \pm 3.90^\circ\text{C}$ (average $\pm$ sd), and water (stream or lake) was found in 48.6%. During summer, bats were found in 92% of caves visited, but maternity colonies in only 49%. Caves used for maternity roosts were found at an average altitude of 335 m a.s.l. ($M = 305$ m a.s.l.) and temperature of $13.9 \pm 3.88^\circ\text{C}$, and water was present in 53.8%. The Apuseni Mountains provide shelters for the largest colonies and aggregations during the year, followed by caves in the Southern Carpathians, where predominantly winter aggregations are usual. Situated between these regions, the warmer Banat

Table 1 Cave characteristics and occurrence of bat species observed during the study

Nr	Cave	Level	Altitude	Length	Season	Rfer	Rhip	Reur	Mcap	Mmbl	Nnoc	Ppip	Msch	Other	Max
Dobrogei															
1	Cheia	-	40	42	w	-	-	-	-	-	-	-	-	-	0
2	Casian	-	50	58	s	-	-	-	-	1	-	-	-	Mmbr (1), Paur (1) Paur (1)	3
3	Gura Dobrogei	3	107	500	s	-	-	-	-	2	-	-	-	Eser (1), Paur (1)	1
					w	14	-	-	-	60	-	-	3	Rmeh (1), Mdau (5)	4
					s	1	-	-	-	100	-	-	6	Mdau (1), Mmbr (1), Eser (11), Paur (1)	65
4	La Adam	-	28		s	-	-	-	-	-	-	-	-	Rmeh (2)	110
5	Limanu	3	25	3200	w	-	-	-	-	-	-	-	-	-	2
6	Tunnel in Hagieni Forest	3	12	132	s	1	-	-	-	-	-	-	-	-	0
Eastern Carpatian															
1	Mina lui Mantz	4	917	80	w	-	-	-	-	18	-	-	-	Mdau (4)	0
2	Lilieclor din Rarau	2	1503	170	s	-	-	-	-	2262	-	-	-	Mdau (1), Mmbr (3) Mdau (1), Mdau (2), Mmbr (2)	2266
3	Sugau	3	1058	1021	w	-	-	-	-	24	-	-	-	Mnat (1) Mema (1)	29
4	Locsur	-	590	220	s	-	6	-	-	61	-	-	-	-	62
5	Varghis Valley 9	-	590	500	w	-	3	-	-	8	-	-	-	-	9
6	Varghis Valley 12	-	590	25	w	-	1	-	-	-	-	-	-	-	13
7	Varghis Valley 23	-	590	11	w	-	-	-	-	-	-	-	-	Mnat (1), Paur (1), Bbar (5)	3
8	Varghis Valley 27	-	590	15	w	-	10	-	-	-	-	-	-	-	1
9	Mare Meresti	2	590	1527	w	2	169	-	-	2	-	-	-	Mdau (1), Mmbr (1), Bbar (5)	7
					s	-	-	-	-	2000	25	-	-	Mmbr (1), Mema (1), Eser (5), Paur (1), Paus (2)	12
10	Gabor	4	591	171	w	-	8	-	-	969	-	-	-	Eser (3), Paur (2), Bbar (3)	1096
11	Gyilkos, Budoshegy	-	1050	25	w	-	-	-	-	1	-	-	-	-	34
12	Valea Crisului Ploti	-	675	15	w	-	-	-	-	1	-	-	-	Eser (1), Paur (4)	1
															6

Table 1 Continued.

Nr	Cave	Level	Altitude	Length	Season	Rfer	Rhip	Reur	Mcap	Mmbl	Nnoc	Ppip	Msch	Other	Max
Southern Carpatian															
1	Lazului	3	370	4200	w	6	13	-	-	-	8	1	-	Paur (6), Bbar (2)	31
					s	4	1	4	8	4	-	-	3	Mmbr (1), Eser (1), Paus (2), Paur (1), Bbar (2)	24
2	Fusteica	2	200		w	94	3	10	43	16	-	-	-	Paur (1), Bbar (2)	106
				1270	s	3	-	-	35	2150	-	-	500	Paus (1)	2226
3	Valea Cheile	-	287	50	w	-	3	-	-	0	-	-	-	Paus (1), Bbar (1)	5
	Sohodolului				s	-	-	-	-	1	-	-	-	-	1
4	Paros	-	700	200	w	-	1	-	-	-	-	-	-	-	1
					s	1	-	-	-	-	-	-	-	-	1
5	Ponorici - Cioclovina cu Apa	-	431		s	15	-	-	-	-	-	-	-	-	15
6	Cioclovina Uscata	-	431		s	10	-	-	-	2	-	-	-	-	12
7	Ilileilor de la Manastirea Bistrita	-	850	250	w	11	-	-	-	5	-	-	-	Paus (1)	17
8	Valea Clengii	-	1150		s	-	-	-	-	2	-	-	-	-	2
9	Muieni	2	560	3566	w	1634	59	-	-	11	-	-	-	Mdau (3)	1701
					s	-	-	-	-	50	-	-	-	-	50
10	Polovragi	3	650	9171	w	61	30	-	-	52	-	-	-	Mdau (1), Mema (8)	152
					s	3	-	-	-	-	-	-	-	Paur (1)	4
11	Sura Mare	1	460	10300	w	-	-	-	-	0	-	34000	-	Bbar (30)	34030
12	Coltul Surpat	3	835	367	w	235	13	-	-	115	-	-	-	Mdau (2)	330
13	Dambovicioara	-	1117	555	w	2	7	-	-	5	-	-	-	-	14
					s	-	1	-	-	-	-	-	-	-	1
14	cu Ilieci din Satul Pestera	3	950	162	w	29	2	-	-	5	-	-	-	Mmbr (1), Eser (2), Paur (1), Bbar (7)	32
					s	2	-	-	-	38	-	-	-	-	40
15	Valea Fundata	4	788	870	w	26	4	-	-	6	1	-	-	Eser (1), Paur (1)	35
Banat Mountains															
1	Gaura Haiduceasca	2	540	714	s	1	-	-	-	1	-	-	1000	-	1002
2	Gaura cu Musca	2	70	254	w	52	-	14	195	-	-	-	25	-	221
					s	4	2	400	500	1350	-	-	700	-	2454
3	Padina Matei	3	606	94	s	60	-	-	-	-	-	-	-	-	60
4	Ilileilor din Carasova	3	226	640	w	20	4	2	-	1	-	-	-	-	27
					s	3	-	25	-	1	-	-	-	-	29
5	de dupa Carsa	-	225	736	w	1	-	-	-	-	-	-	-	Paus (1)	2
6	Gura Poncovei	1	60	1666	w	263	7	20	-	-	32	1000	50	Mdau (4), Paur (1), Bbar (1)	1294
					s	220	-	-	-	3000	-	-	5000	Paur (6)	8226

Table 1 Continued.

Nr	Cave	Level	Altitude	Length	Season	Rfer	Rhip	Reur	Mcap	Mmbl	Nnoc	Ppip	Msch	Other	Max
7	Despicatura	3	164	105	w	-	-	-	-	-	-	-	-	-	0
8	Grota Haiducilor	3	160	143	s	-	80	3	-	10	-	-	-	-	90
9	Lui Adam	2	295	212	s	4	2	-	1	2	-	30	1	Mdau (1)	36
10	Grota Ungurului de la Pecinica	2	295	212	w	1	-	2	-	-	-	-	50	-	51
	Apuseni Mountains	2	295	212	w	-	-	200	-	-	-	-	5	-	205
	Avenul Betfia	2	275	264	s	-	-	200*	250*	1500	-	-	150	Mema (35)	2101
1	Barta Sat	-	699	19	s	-	-	-	4	10	-	-	1	-	15
2	Tasad	2	230	150	w	-	1	-	-	-	-	-	-	-	1
3	Stracos	-	268	965	s	-	20	450	-	3	-	-	-	-	451
4	Copilului	-	396	3177	w	13	4	-	-	2	-	-	-	Mdau (1), Paur (1)	18
5	Osoi	1	396	270	s	6	-	-	-	14	-	-	-	-	14
6	Ticlutui	3	328	717	s	-	-	-	-	-	-	-	1	-	1
7	Igrita	1	242	145	w	1	1	-	-	-	-	-	-	-	2
8	Astileu	-	517	1000	w	1	-	-	-	-	-	-	-	-	0
9	Galaseni	3	354	1110	s	1	-	-	-	1	-	-	-	-	2
10	Vadul Crisului	2	772	1177	w	56	8	-	-	3000	-	-	2000	-	3500
11	Batranului	2	360	554	s	1	-	-	-	36	-	-	-	Mnat (1)	100
12	cu Apa de la Bulz	3	316	230	w	6	1	-	-	4	-	-	1	-	1
13	Ungurului De la Izvor	4	500	1232	w	1	-	-	-	5000	-	-	3000	-	8
14	Moanei	-	316	195	s	-	-	3	-	-	-	-	-	Mema (1), Mbec (1)	6001
15	Napistileu	3	354	1000	w	98	14	-	-	4	-	-	-	-	5
16	Lestana	2	772	1177	s	582	7	1	-	-	-	-	-	Mmbr (2), Mema (1)	102
17		2	360	554	w	1	-	-	-	183	-	-	-	-	5
18		2	316	230	s	403	-	-	-	2	-	-	-	-	772
		3	500	1232	w	5	-	-	-	9	-	-	2	-	3
		4	316	230	w	75	2	-	-	1800	-	-	200	-	407
		4	500	1232	w	11	6	-	-	2	-	-	-	-	2005
		4	500	1232	w	30	-	-	-	6	-	-	-	Paur (1)	221
		4	500	1232	w	30	-	-	-	1	-	-	-	Bbar (1)	24
		4	500	1232	w	30	-	-	-	-	-	-	-	Mbec (1)	1
		4	500	1232	w	30	-	-	-	-	-	-	-	Paus (1)	4
		4	500	1232	w	30	-	-	-	-	-	-	-	Mdau (1)	30
		4	500	1232	w	30	-	-	-	-	-	-	-	-	6
		4	500	1232	w	30	-	-	-	-	-	-	-	Eser (1)	1

Table 1 Continued.

Nr	Cave	Level	Altitude	Length	Season	Rfer	Rhip	Reur	Mcap	Mmbl	Nnoc	Ppip	Msch	Other	Max
19	Fata Apei	–	515	350	w	9	2	–	–	–	–	–	–	Bbar (2)	17
20	cu Apa de pe Valea Lesului	2	823	2300	w	865	5	–	–	3596	–	–	4	Mdau (10), Mdas (15), Mmbr (4), Mema (3), Eser (2), Paus (1), Paur (3), Bbar (8)	4197
21	Valea Daica	–	590	70	w	1	2	–	–	–	–	–	–	Rmeh (1)	4
22	Alba	–	275	40	w	–	–	–	–	–	–	1	–	–	1
23	Rosie	–	271	55	w	–	–	–	–	–	–	–	–	Paus (1)	1
24	Meziad	1	305	4750	w	423	50	2	–	100	300	600	1100	Mdau (2), Bbar (1)	1821
25	Calului	3	305	115	s	5	4	2	–	2500	6	1	6000	Mdau (1), Paur (1)	7006
26	Fagului	3	850	1510	w	46	–	10	–	–	–	–	–	–	80
27	Sighistel Valley 27	–	500	170	s	–	2	–	–	–	–	–	–	–	50
28	Coliboaia	1	555	1060	w	750	11	–	–	3	–	–	–	–	2
29	Magura	2	550	1885	w	186	42	–	–	18	–	250	80	Mdau (3)	6
30	Fanate	2	560	450	s	42	–	–	–	2	–	–	–	Mdas (1), Mbec (1)	765
31	Cu Apa din Moneasa	3	250	2012	w	103	29	–	–	10	–	–	435	Mdau (2), Mnat (2)	4000
32	Cu ilieci din Moneasa	3	380	103	w	20	6	–	–	10	–	3	400	Mdau (3), Mbec (2), Bbar (2)	379
33	Uscata din Moneasa	–	260	59	w	45	8	–	–	–	–	–	–	Mdau (3), Mnat (27), Mbec (3)	86
34	Cetatuia Mare	3	420	90	w	16	12	–	–	6	–	3	–	Mdau (1), Mema (1), Mnat (8), Paus (2), Bbar (1)	50
35	Huda lui Papara	1	567	2022	w	715	60	3	–	5100	1060	20000	33000	Mnat (3), Mbec (2)	12
36	Cheile Ampoitei	–	390	311	w	3	–	–	–	1000	–	–	0	–	1
														Bbar (3)	143
															53341
															1501
															16

Site numbers refer to the locations given in Fig. 1. Rhinolophidae: Reur – *Rhinolophus euryale*; Rfer – *Rhinolophus ferrumequinum*; Rhip – *Rhinolophus hipposideros*; Rmeh – *Rhinolophus mehelyi*. Vespertilionidae: Mcap – *Myotis capaccinii*; Mmbl – *Myotis myotis/oxynathus*; Mdau – *Myotis daubentonii*; Mdas – *Myotis dasycneme*; Mmbr – *Myotis mystacinus/brandtii/alcahoae*; Mema – *Myotis emarginatus*; Mnat – *Myotis nattereri*; Mbec – *Myotis bechsteinii*; Eser – *Eptesicus serotinus*; Paur – *Plecotus auritus*; Paus – *Plecotus austriacus*; Vmur – *Vespertilio murinus*; Ppip – *Pipistrellus pipistrellus*; Nnoc – *Nyctalus noctula*; Bbar – *Barbastella barbastellus*; Msch – *Miniopterus schreibersii*

Mountains are home especially to nursery colonies. The Eastern Carpathians, with cold caves at a high elevation, host small numbers of bats in both seasons, and the Dobrogea region with small caves characterized by dynamic temperatures host exclusively maternity colonies (Fig. 2).

Various bat species were found under different microclimatic conditions (Table 2). For this reason, we analysed winter and summer periods separately.

Bats assemblages during the hibernation period

During the hibernation period, we found 22 species: *Rhinolophus ferrumequinum*, *R. hipposideros*, *Rhinolophus euryale*, *Rhinolophus mehelyi*, *Myotis daubentonii*, *Myotis dasycneme*, *My. myotis*, *My. oxygnathus*, *My. emarginatus*, *Myotis nattereri*, *My. mystacinus*, *My. brandtii*, *Myotis bechsteinii*, *Myotis capaccinii*, *Plecotus auritus*, *Plecotus austriacus*, *Barbastella barbastellus*, *Mi. schreibersii*, *Eptesicus serotinus*, *Vespertilio murinus*, *P. pipistrellus* and *Nyctalus noctula*. The maximum number of bat species was found in the caves in the Apuseni Mountains (20 species), the Southern Carpathians (16 species) and the Banat Mountains (13 species), and in the

caves in the Eastern Carpathians (11 species) and the Dobrogei Plateau (nine species). Almost half (48%) of the underground sites where bats hibernated are situated at the middle altitudes between 300 and 600 m a.s.l. Nearly 29% are located from the sea level to 300 m a.s.l., between 600 and 1200 m a.s.l. 22%, and about 1% over 1200 m a.s.l. Aggregations of < 500 bats occurred in 83.3% of caves, from 500 to 5000 individuals in 13.6%, more than 10 000 individuals (10 000–60 000) in 3.0%. The largest aggregations comprised five bat species, that is *Mi. schreibersii* – up to 33 000 individuals, *P. pipistrellus* s.l. – up to 34 000 individuals, *My. myotis/oxygnathus* – up to 5100 individuals, *R. ferrumequinum* – up to 1600 individuals and *N. noctula* – up to 1000 individuals. Aggregations of other species consisted of about 200 individuals. The largest aggregations of bats were situated in caves in the Apuseni Mountains and the Southern Carpathians. CCA had eigenvalues for the first four axes of 0.275, 0.223, 0.107 and 0.066, respectively. Together, these explained 42.1% of the species variance and 89.8% of the species-environmental variance. Monte-Carlo tests showed that the overall CCA was significant ($P = 0.002$). The tri-plot of the first two axes (Fig. 3) showed a relatively good separation of the different roost parameters, geographical regions and bat species. Axis 1 (17.2%) displays the gradient of temperature: from the lower elevations and warmer caves of the Banat Mountains ($r = -0.662$) to higher altitudes ($r = 0.640$) and colder caves of the Eastern Carpathians ($r = 0.440$). *My. capaccinii* and *R. euryale* formed numerous aggregations in the caves of the Banat Mountains. *My. myotis/oxygnathus* comprised the largest aggregation in the Apuseni Mountains and the Eastern Carpathians, and they were less numerous but frequent in the Southern Carpathians. Axis 2 (14.0%) displays the gradient from caves with high temperature ($r = 0.466$) to long caves ($r = -0.533$) and those with water ($r = -0.352$). *P. pipistrellus* s.l., *N. noctula* and *B. barbastellus* prefer cold caves. *P. pipistrellus* and *N. noctula* comprise aggregations in huge caves, frequently with water. *P. pipistrellus* s.l. comprise one of the largest winter aggregations in Romanian caves (> 55 000 individuals). *Mi. schreibersii* is frequent and numerous in the caves of the Apuseni Mountains, where they comprise the second largest winter aggregation (> 33 000 individuals). They also

Figure 2 The number of wintering bats (white bars) and reproductive colonies (grey bars) in the caves' surveyed regions: Apuseni Mts. (AM), Eastern Carpathians (EC), Banat Mts. (BM), Southern Carpathians (SC) and Dobrogea Plateau (DP). Calculations based on the maximum number of aggregations in the years 1995–2005.

Table 2 Characteristics of the caves used by hibernating bat aggregations and maternity colonies (average $\pm$ SD; median in parentheses): altitude (m a.s.l.), temperature ($^{\circ}$ C), presence of water (%)

Species	Elevation (m a.s.l.)		Temperature ($^{\circ}$ C)		Water (%)	
	w	s	w	s	w	s
<i>Rhinolophus ferrumequinum</i>	435 (375)	404 (500)	7.0 $\pm$ 2.92	13.3 $\pm$ 3.71	48.4	60.0
<i>Rhinolophus hipposideros</i>	469 (425)	233 (230)	6.6 $\pm$ 3.56	21.5 $\pm$ 6.18	48.1	0
<i>Rhinolophus euryale</i>	246 (236)	225 (230)	8.2 $\pm$ 6.19	16.0 $\pm$ 2.13	85.7	60.0
<i>Rhinolophus mehelyi</i>	–	25 (25)	–	18.4 $\pm$ 0.00	–	0
<i>Myotis capaccinii</i>	143 (152)	144 (135)	4.6 $\pm$ 1.98	14.1 $\pm$ 2.28	66.7	75
<i>Myotis myotis/oxygnathus</i>	553 (554)	333 (305)	6.9 $\pm$ 3.35	13.1 $\pm$ 2.43	41.9	66.7
<i>Miniopterus schreibersii</i>	319 (300)	327 (333)	7.4 $\pm$ 4.54	13.0 $\pm$ 2.32	61.5	78.6
<i>Nyctalus noctula</i>	407 (362)	–	5.2 $\pm$ 2.55	–	80.0	–
<i>Pipistrellus pipistrellus</i> s.l.	357 (370)	–	4.5 $\pm$ 2.56	–	62.5	–
<i>Barbastella barbastellus</i>	498 (479)	–	4.3 $\pm$ 4.08	–	63.7	–

Figure 3 Canonical correspondence analysis of winter aggregations of bats. Species–environment correlations were $r=0.839$ (axis 1) and $r=0.781$ (axis 2). Ordination tri-plot based on 31 caves (open circles), nine bats species (triangles) and 10 environmental factors (arrows): regions and cave parameters. Species: Reur, *Rhinolophus euryale*; Rfer, *Rhinolophus ferrumequinum*; Rhip, *Rhinolophus hipposideros*; Mcap, *Myotis capaccinii*; Mmbl, *Myotis myotis/oxynathus*; Msch, *Miniopterus schreibersii*; Ppip, *Pipistrellus pipistrellus* s.l.; Nnoc, *N. noctula*; Bbar, *B. barbastellus*. Nine bat species account for 99.9% of all individuals. Other bat species: Rmeh, *Rhinolophus mehelyi*; Mdau, *Myotis daubentonii*; Mdas, *Myotis dasycneme*; Mmbr, *Myotis mystacinus/brandtii*; Mema, *Myotis emarginatus*; Mnat, *Myotis nattereri*; Mbec, *Myotis bechsteinii*; Eser, *Eptesicus serotinus*; Paur, *Plecotus auritus*; Paus, *Plecotus austriacus*; Vmur, *Vespertilio murinus*; account for about 0.1%. Caves: number corresponds with the number of the caves in Table 1; a, Apuseni Mountains; b, Banat Mountains; d, Dobrogea Plateau; e, Eastern Carpathians; s, Southern Carpathians.

occurred frequently, but were less numerous in the Banat Mountains caves. Other species like *R. ferrumequinum* and *R. hipposideros* showed similar distribution patterns.

The remaining species occur in small numbers during hibernation in underground roosts, rarely forming aggregations of more than 10 individuals. *My. daubentonii* and *P. auritus* occur throughout the study area. *B. barbastellus* congregate in two sites with fewer than 10 individuals, although they occur sporadically in the Carpathians. Such forest- and crevice-dwelling species as *E. serotinus*, *P. austriacus*, *V. murinus*, *My. emarginatus*, *My. mystacinus/brandtii/alcaethoe*, *My. nattereri*, *My. bechsteinii* or *My. dasycneme* are recorded sporadically and individuals of *R. mehelyi* are recorded as vagrants during winter in the Dobrogea Plateau.

Bats colonies during summer

In summer, eight species formed nursery colonies: *R. ferrumequinum*, *R. hipposideros*, *R. euryale*, *R. mehelyi*, *My. myotis/oxynathus*, *Myotis capaccinii* and *Mi. schreibersii*, and 11 bat species using caves as temporary shelters. Aggregation to 500 bats accounted for 74.0%, from 500 to 5000 individuals: 12.0%, from 5000 to 10000 individuals: 6.0%. The largest and most numerous maternity colonies

Figure 4 Principal components analysis and species (maternity colonies) grouped in relation to caves. Rfer, *Rhinolophus ferrumequinum*; Rhip, *Rhinolophus hipposideros*; Rmeh, *Rhinolophus mehelyi*; Reur, *Rhinolophus euryale*; Msch, *Miniopterus schreibersii*; Mmbl, *Myotis myotis/oxynathus*; Mcap, *Myotis capaccinii*.

was comprised of *My. myotis/oxynathus* (50–5000 individuals $M = 1500$), and *Mi. schreibersii* (40–6000 individuals $M = 600$ ex.). *R. ferrumequinum*, *R. euryale* and *My. capaccinii* were rare, and formed smaller colonies ranging from 30 to 220 individuals ($M = 60$), from 10 to 450 ($M = 200$) and 15 to 500 ($M = 143$) respectively. *R. hipposideros* and *R. euryale* were found in two colonies and *R. mehelyi* formed one colony. Another 11 bat species were found sporadically and do not form nursery colonies in the caves: *My. daubentonii*, *My. dasycneme*, *My. emarginatus*, *My. mystacinus*, *My. bechsteinii*, *P. auritus*, *P. austriacus*, *B. barbastellus*, *E. serotinus*, *P. pipistrellus* and *N. noctula*. The first two axes of the PCA described 72.8% of the variability, and showed separation of several bat groups (Fig. 4). Axis 1 revealed the dominant gradient (56.3%), showing the difference between rhinolophids, which prefer higher temperatures and occur more frequently in the southern part of Romania, and *My. myotis/oxynathus* along with *Mi. schreibersii*, which comprised huge aggregations at lower temperatures, which were found throughout the study area. Axis 2 (16.5%) was distinguished between *R. euryale* and *My. capaccinii*, which preferred the warmer temperature and occurred frequently in Banat, Dobrogea and the Southern Carpathians, and *R. ferrumequinum*, which occurred in a wider and lower temperature range in south-western Romania.

Evaluation of conservation value of underground roosts

Ten bat species form large aggregations in the winter and the maternity colonies in the summer occur frequently in caves.

Table 3 Number of caves and their conservation status in the investigated regions of Romania

Region	Level 1	Level 2	Level 3	Level 4	Without level	Total
Banat Mountains	1	3	4	–	2	10
Dobrogea Plateau	–	–	3	–	3	6
Eastern Carpathians	–	2	1	2	7	12
Southern Carpathians	1	2	4	1	7	15
Apuseni Mountains	5	7	8	3	12	36
Total	7	14	20	6	31	79

Apart from *N. noctula* and *P. pipistrellus* s.l., the remaining species, *Mi. schreibersii*, *My. capaccinii*, *My. myotis/oxynathus* and the rhinolophid species, are heavily dependent on underground habitats. For all caves investigated, the highest proportions with a conservation value between 1 and 4 were found in the Banat (80.0%) and Apuseni Mountains (62.2%), middle values in the Southern Carpathians (53.3%) and in the Dobrogea Plateau (50.0%) and the lowest in the Eastern Carpathians (41.7%) (Table 3). The caves with scores between 1000 and more than 10 000 are located in the Southern Carpathians, the Banat and Apuseni Mountains. Seven caves with the highest score are identified as containing the roosts for 122 000 individuals of 14 species throughout the year. Two of these caves house colonies in the summer (Astileu and Ticlului), one is used by bats only for hibernation (Sura Mare cave), while Gura Ponicevei, Meziad and Huda lui Papara caves house bats all year. Huda lui Papara cave is one of the largest European hibernacula, with one aggregation of up to 56 000 individuals.

Discussion

The bats were unequally distributed between regions, both in abundance and in species composition. Such environmental characteristics as latitude, area and temperature are the main predictors of bat species richness in Europe (Ulrich *et al.*, 2007). Because insectivorous bats are heterothermic, the microclimate of their roosts plays an important role in their energy expenditure, both in winter (Kowalski, 1954; Kunz, 1982; Arita, 1996; Speakman & Thomas, 2003) and in summer (Racey *et al.*, 1987; Plachter & Plachter, 1988). Location, size, air-volume of the cave, and consequently, microclimate differentiate the regions studied.

The results of the present study revealed that a combination of cave microclimate and geographical factors favours the presence of some species while eliminating others. We were able to distinguish four groups of species.

Extensive cave systems without the distinction of geographical position, with a constant water flow, are places for hibernation of species that tolerate a low fluctuating temperature: *P. pipistrellus* s.l. (Racey, 1974; Nagel & Nagel, 1991), *N. noctula* (Gaisler, Hanák & Dungal 1979) and *B. barbastellus* (Rydell & Bogdanowicz, 1997). The largest group consisted of *P. pipistrellus*, with two large aggregations totalling 50 000 individuals and smaller clusters ranging from 100 to 1000 bats. Very often, such aggregations

are found together with a smaller number (up to 1000 individuals) of hibernating *N. noctula*. These two species, which also occur in tree holes, bat boxes, buildings and particularly in the Carpathian Basin, use caves for hibernation (Nagy & Szanto, 2003). Except during winter, these species were found in caves very rarely.

The second group of species occurs predominantly in the south of Romania, at a low elevation and at warm temperatures, like *My. capaccinii* (Serra-Cobo, 1992; Cruicitti, 1993), *R. euryale* (Gaisler, 2001; Paksuz, Özkan & Postawa 2007) and *R. mehelyi* (Benda *et al.*, 2003). The former species were found close to large water reservoirs, and in Romania, they reach the northern border of their distribution (Spitzenberger & von Helversen, 2001). We identified two important sites in the Danube Valley (Southern Carpathians and Banat Mountains.), both hosting nursery colonies, and another population in Dobrogea. Similar discontinuity is reported in neighbouring southern countries, such as Bulgaria, Turkey and Greece (Hanák *et al.*, 2001; Benda *et al.*, 2003; Furman & Özgül, 2004). In winter, only small aggregations of fewer than 10 individuals were found, close to water sources and at a lower altitude in the Danube Valley. Bats probably migrate south and form huge aggregations in Bulgarian caves during wintering (T. Ivanova, pers. comm.). A single large hibernation aggregation of *R. euryale* in Romania was noticed in Lui Adam Cave with a particularly high temperature during the winter of over 18.0 °C. Thermal conditions of this cave are created by hot springs at 45–55 °C (Decou, Negrea & Negrea 1974). It seems that the presence of karst is more important for the occurrence of a species. In the entire Balkans, *R. euryale* is one of the most frequently recorded bats in karstic areas (Krystufek *et al.*, 1992; Benda & Horaček, 1998; Hanák *et al.*, 2001). *R. mehelyi* also uses warm caves with little temperature fluctuation (Paksuz *et al.*, 2007). However, the presence of these species is restricted to the Black Sea coast area, with only one known nursery colony, and no known hibernacula. The eastern part of the Danubian Lowland in Bulgaria and the karstic region of Romanian Dobrogea represent the northern margin of the known distribution of these species in the Balkans (Benda *et al.*, 2003).

In contrast to warm caves located on a low altitude (Dobrogea Plateau, Banat Mountains, Apuseni Mountains), mid- to high elevation, cooler caves (Apuseni Mountains, Southern and Eastern Carpathians) are preferred by *My. myotis/oxynathus* and *Mi. schreibersii*, the third group of species in our analyses. *My. myotis/oxynathus* are the most common species in such roosts in both seasons. These

species overlap in most of our target areas, show similar characteristics of distribution, except Eastern Carpathians, from where *Mi. schreibersii* is missed. The altitudinal distribution shows similar patterns in winter and in summer for *My. myotis/oxygnathus* (Pandurska, 1993; Benda *et al.*, 2003), and for *Mi. schreibersii* (Benda *et al.*, 2003). Likewise, also, the temperature within hibernacula for *My. myotis* (Harmata, 1973) and for *Mi. schreibersii* (Alcalde & Escala, 2000) is similar. Hibernacula of *Mi. schreibersii* rarely contain more than a few hundred bats, with one exception: Huda lui Papara cave, which contains large aggregations of up to 33 000 individuals. During the breeding season, both species choose caves with similar microclimates (Rodrigues *et al.*, 2003; Paksuz *et al.*, 2007), often forming mixed colonies.

The fourth group of species are *R. hipposideros* and *R. ferrumequinum*, occurring in caves during hibernation, but predominantly using attics during the breeding period. They have similar distribution patterns, but *R. hipposideros* is less abundant. Hibernaculum temperature is higher for *R. hipposideros* (Harmata, 1973; Gaisler, 2001) than for *R. ferrumequinum* (Pandurska, 1993). Both species are widespread, found frequently in caves during the winter months. *R. ferrumequinum*, one of the most common bat species from Romania, forms the largest known hibernation aggregation of up to 1600 specimens in the Southern Carpathians. Hibernating individuals in the Western part of Romania came from attic-dwelling colonies located in the Tisa River lowlands, Hungary (Dobrosi & Gulyás, 1997).

Underground shelters selected by the bats are patchily distributed in different geographical regions. The south-western karstic regions in Romania have the highest number of bat species (including vulnerable ones) and individuals. Throughout this range, a number of protected areas, national parks and Natura 2000 sites were established. Caves with touristic or scientific value in Romania are often administrated by non-governmental organizations under contract with the Ministry of the Environment. In a few cases, some of these caves are important refuges for bat species. Collaboration between custodians, bat protection societies and environmental protection institutions is crucial at the local and regional level. Often, even when the custodians had approved management plans for caves, they had no financial resources for adequate site protection. Management plans for these areas should include the requirements of bats roosting in caves. These needs should reflect the individual species conservation ecology and the status of the surrounding feeding habitats. Special attention should be paid to those caves that house a very large number of specimens (like *Mi. schreibersii*) or are the last known refuge for vulnerable species occurring in small numbers (such as *R. mehelyi*), which are highly sensitive to human disturbance. Similar treatments should be applied to those caves that house Mediterranean species in a small number on the edge of their distribution (*R. euryale*, *My. capaccinii*). As a result of direct human pressure, there is a possibility of the disappearance of these species in the mid-term, as was shown by the drastic decline in recent decades of *R. mehelyi* in Romania. This vulnerable bat formed colonies with 500

individuals in Dobrogea in the middle of the 1970s (Červený, 1982), and has shown a rapid decline in recent decades (Grimmberger, 1993; this paper). Comparing the distributional data for *Mi. schreibersii*, it is apparent that from 14 colonies or aggregations described in the 1960s (Dumitrescu *et al.*, 1963), 11 have now disappeared from all regions. Large *Myotis* species and rhinolophids show similar trends. The largest winter aggregation described in Romania for *My. myotis/oxygnathus* was recorded in Rarau cave (Eastern Carpathians), with 8000 individuals (Valenciuc, 1982), reduced nowadays to 2000 bats.

Our recommendations are to protect key sites in the Apuseni and Banat Mountains, which contain underground formations. These regions have the largest number of caves mid- to low attitude, some of which are also warm, and in which the highest numbers of species were recorded. Specific requirements of the identified groups are a focus in these places. Our results confirm the conclusions of Brunet and Medellín (2001) that a high density of caves in one area offers suitable living conditions for large populations of different species, forming hotspots at a regional level. These areas function as core areas for a few species. In contrast, the Dobrogea region will remain only at the margins of the distribution range of a few species because cave density is low and the number of bats found there has declined over recent decades.

Protection of caves, especially from human disturbance, should be undertaken by rangers of the protected areas, with direct control over the access of visitors and scientists in sensitive periods. Another possibility is to grill the caves. However, most of the caves in which bats roost in Romania have very large entrances, which make it impossible to construct such barriers. Bat conservation action should also be coordinated at the European level in view of the fact that middle- and long-distance migrations occur in many species.

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