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THE GREATER HORSESHOE BAT, *RHINOLOPHUS FERRUMEQUINUM* IN CROATIA: PRESENT STATUS AND RESEARCH RECOMMENDATIONS

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In this paper we present the current known distribution and status of *Rhinolophus ferrumequinum* in Croatia. Distribution, size and status of maternity and winter colonies is presented and discussed in relation to different aspects of biology (altitude, temperature requirements etc.). Overall and regional population estimates are calculated for this species considering the most recent population data. We also present causes of threat and make a proposal for further research, monitoring and conservation measures for greater horseshoe bat in Croatia.

Key words: *Rhinolophus ferrumequinum*, Croatian fauna, distribution, population estimate, conservation, monitoring

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U radu se prikazuje danas poznato rasprostranjenje i status vrste *Rhinolophus ferrumequinum* u Hrvatskoj. Prikazano je rasprostranjenje, veličina i status porodiljnih i zimskih kolonija u odnosu na različite aspekte biologije (nadmorska visina, temperaturni zahtjevi itd.). Procjene brojnosti izračunate su po regijama te ukupno za čitavu Hrvatsku koristeći najnovije podatke o brojnosti. Također se prikazuju i raspravljaju uzroci ugroženosti te se daju prijedlozi daljnjih istraživanja, praćenja stanja i zaštite velikog potkovnjaka u Hrvatskoj.

Ključne riječi: *Rhinolophus ferrumequinum*, fauna Hrvatske, rasprostranjenje, procjena brojnosti, zaštita, praćenje stanja

INTRODUCTION

The greater horseshoe bat, *Rhinolophus ferrumequinum* (Schreber, 1774) is rare in many European countries (HUTSON *et al*., 2001). Species is distributed in southern Europe and Northern Africa through the Mediterranean Sea including all central European large islands. In Britain the distribution includes south west England and south and west Wales. In former times, the distribution had reached the southern

part of the Netherlands, Germany, Poland and the Ukraine. Toward the east it is distributed in the Middle East to the Caucasus up to China, Korea and Japan (DIETZ *et al*., 2009, Fig. 1). Being of particular conservation concern, it is the subject of considerable research and monitoring. A severe decline has been reported in northwest Europe leaving the populations close to extinction (e.g. United Kingdom, Germany, Austria) or probably completely extinct (Belgium, Netherlands) (AULAGNIER *et al*., 2008). The main reasons for such declines are directly related to high industrialization and intensive agriculture causing fragmentation and isolation of habitats, conversion of deciduous forests into intensive agricultural land and intensive use of pesticides. The use of pesticides directly reduces the availability of the preferred insect prey (e.g. melolonthid beetles, noctuid moths, crane-flies) or can indirectly cause reproduction problems or even death (like pesticides used for remedial timber treatment (MITCHELL-JONES *et al*., 1989). In Germany (DIETZ *et al*., 2009), *R. ferrumequinum* is near extinction mainly caused by heavy usage of highly toxic pesticides such as Lindane and DDT in the past. Negative trends have reversed in some countries (UK, BATTERSBY, 2005), probably due to recent change of management regimes of forests and agricultural land, but in others the negative trend continues (Austria, SPITZENBERGER, 2001). Further threats are adverse weather conditions, loss of roosts and human disturbance in wintering and maternity roosts (RANSOME, 1999).

Population estimates across western Europe range from 50–70 animals in Germany, 200 in Austria, less than 500 in Switzerland, 5000 in Slovenia, 6600 in the UK, less than 25 000 in Spain, 15 000–30 000 in Bulgaria and 26 000 in France (DIETZ *et al*., 2009). In Hungary, this species has a negative trend and is facing extinction in the NW part of the country (BIHARI *et al*., 2007). The total estimate of the *R. ferrumequinum* population in European countries is below 100 000 animals (DIETZ *et al*., 2009). No population estimates and trends are available from Bosnia and Herzegovina. In Serbia, *R. ferrumequinum* is considered common with stable population (EUROBATS national report 2009). In the Fourth Report to the National Implementation of the Agreement on the Conservation of Bats in Europe (2004–2006) we estimated the population of Croatia to be around 35 000 animals and in this paper we present the results of intensive field surveys and monitoring conducted since then.

R. ferrumequinum prefers warm, usually southern slopes and valleys with water and a mosaic of deciduous forests and pastures (SCHOBER & GRIMMBERGER, 1998). Another very important habitat requirement is the presence of underground sites for hibernation that should be not far from the feeding habitat and should provide a variety of temperatures (GAISLER, 2001). Karstic areas therefore provide optimal habitat conditions for *R. ferrumequinum*. The species' altitudinal distribution ranges from sea level up to 1390 m a. s. l., though with most records between 100 and 700 m a. s. l. (Austria, SPITZENBERGER, 2001).

The earliest and also most complete data about *R. ferrumequinum* in Croatia were published by Beatrica Đulić. She started her research work in the Veternica cave near Zagreb (ĐULIĆ, 1953; ĐULIĆ, 1955) and later covered all parts of Croatia, first the Continental region with the Hrvatsko zagorje region and then the littoral region (ĐULIĆ, 1959a, ĐULIĆ, 1963). She also did research in Dalmatia (DULIC & FELTEN, 1964; DULIČ & KOVAČIĆ, 1992; KOVAČIĆ & ĐULIĆ, 1989), especially on the Croatian

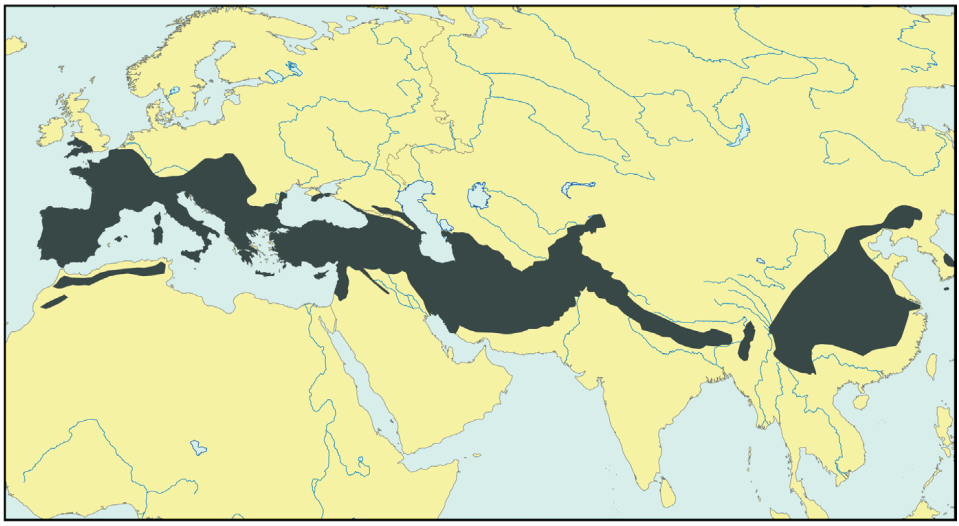

Fig.1. The distribution of the Greater horseshoe bat (DIETZ *et al.*, 2009)

islands (ĐULIĆ, 1968; DULIĆ & TVRTKOVIĆ, 1970; DULIĆ & TVRTKOVIĆ, 1979; ĐULIĆ, 1989). Using the method of ringing for the first time in Croatia, she reported *R. ferrumequinum* to be a sedentary species with movements of up to 32 km in NW Croatia (ĐULIĆ, 1957). During her survey in Slovenia she found only colonies consisting of up to 15 animals in contrast to the much bigger colonies around Zagreb (ĐULIĆ, 1959b). *R. ferrumequinum* is the subject of a European Action Plan prepared under the Bern Convention (HUTSON *et al.*, 2001). According to the Croatian Red Data Book (TVRTKOVIĆ & HOLCER, 2006) the current threat status of this species is NT (near threatened). It is protected by the Nature Protection Act of the Republic of Croatia, listed on Appendix II of the Bonn Convention and Appendixes II and IV of the Habitats Directive.

This paper reviews the present and former distribution of the greater horseshoe bat in Croatia; it examines its present status, present potential causes of threat and recommends a proposal for further research and conservation in Croatia. The definitive status of the population in Croatia is still unknown, but there are no significant declines recorded from known colonies (TVRTKOVIĆ & HOLCER, 2006).

MATERIALS AND METHODS

Data were obtained from the literature, personal observations and unpublished data provided by experts from the Croatian Natural History Museum. For the analysis of maternity and winter roosts we used data from only the past 50 years. A total of 64.7% of our data was collected within last 10 years, 25.6% is older than 10 years, 1.8% older than 20 and 7.8% older than 40 years. Localities were categorized as caves, lofts and others (underground artificial roosts, mostly tunnels and mines). We counted the individuals using binoculars and distinguished between adult indi-

viduals and young of the year. Colonies counted between May and August were regarded as maternity colonies if we caught females with developed nipples and for the old data we referred to the reproduction period given by SCHOBER & GRIMMBERGER (1998) and GAISLER (2001). Colonies counted between September – November and March – April were regarded as migration and those counted between December and March as hibernating colonies (DIETZ *et al.*, 2009). Temperature and relative humidity data were collected using HOBO model H8pro data-loggers that were placed inside the caves as near to the colony as possible. Data were recorded every 6 hours and presented as monthly average, minimum and maximum.

Using the collected data, we prepared distribution maps of *R. ferrumequinum* in Croatia. The location coordinates were taken with GPS, and the coordinates for old data were taken from the map using Arc GIS program. The distribution of *R. ferrumequinum* in Croatia is presented within 10 km UTM squares, while the data about nursery and winter colonies are presented as exact locations. Using published data (AULAGNIER *et al.*, 2008; HUTSON *et al.*, 2001) about the causes of threat and decline of *R. ferrumequinum* and other species that use the same or similar habitats for roosting and foraging, we made an analysis of potential causes of threat to prevent their decline and to protect the greater horseshoe bat in Croatia.

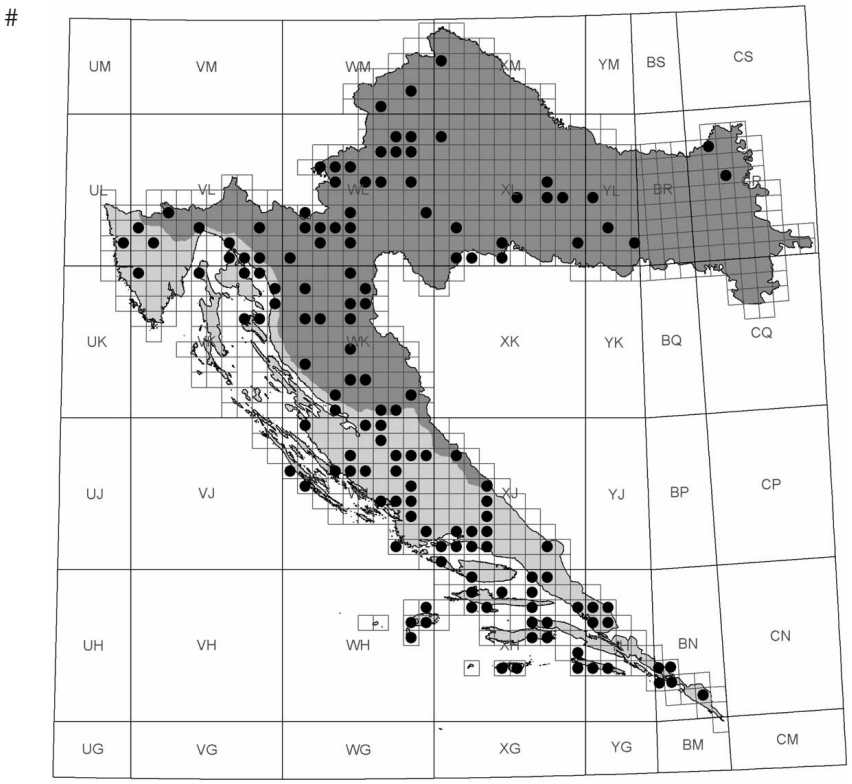

Fig. 2. Distribution of *R. ferrumequinum* in Croatia (all records). The division into two regions of Croatia is shown: Continental (dark grey) and Mediterranean (grey).

Three bio-geographical regions are recognized in Croatia, according to the European Environment Agency (EEA, 2008). For the analysis of the distribution of both wintering and nursery colonies of *R. ferrumequinum* we have combined together Continental and Alpine regions making the basic division on only the Continental and Mediterranean regions (Fig. 2). Our population estimate is calculated based on overall maximum nursery size estimates for the two regions according to the surface area. The resulting population density (no. of bats per km^2) was corrected and an overall estimate calculated. Also, we have used the winter data from Vis island for additional calibration with the assumption that the population is quite isolated from the mainland and nearby islands.

Maximum numbers of counted individuals recorded for both wintering and nursery colonies have been used for the analysis.

RESULTS

A total of 234 records of *R. ferrumeqiunum* in Croatia are presented in 144 UTM 10 km squares (17.4% of total 828 UTM squares) (Fig. 2). Detailed information

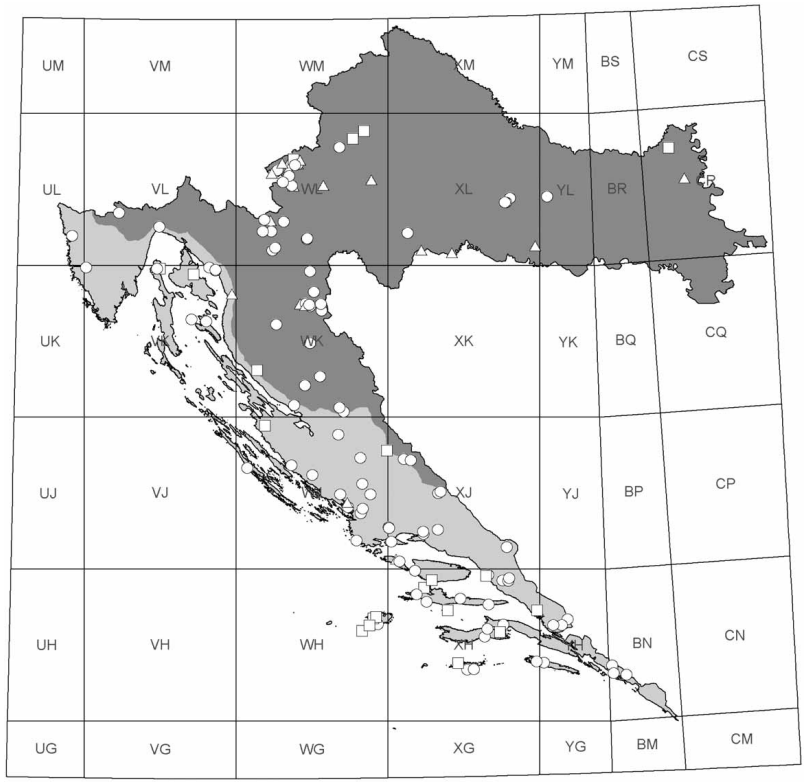

Fig. 3. Distribution of roosts of *R. ferrumequinum* in Croatia. Types of shelter: circle – cave, triangle – loft, attic, square – mine, tunnel (other type).

about records (dates, source, and remarks) is given in PAVLINIĆ *et al*. (2010). *R. ferrumequinum* was recorded in a total of 189 roosts, of which 136 are caves, 23 lofts and attics and 30 other types of roost (tunnels and mines). A total of 137 roosts are precisely located on the map (Fig. 3).

More roosts have been recorded in the Mediterranean region – 80, of which 61 are caves, 4 lofts and attics and 15 tunnels and mines. Within the Continental region 57 roosts were recorded of which 36 are caves, 16 lofts and attics and 5 tunnels and mines.

Out of 42 nursery roosts, 26 are caves, 10 lofts and 6 other type of artificial roost. Out of a total of 57 hibernation roosts, 55 are caves and only 2 are found in different types of underground place. Out of 70 migratory roosts 48 are caves, 11 lofts and 11 others. Only 9 roosts (all of them caves) were found to be used both for hibernation and nursery colonies – 5 were in the Mediterranean region (Miljacka II, Tradanj, Vilina, Vištičina and Zagorska) and 4 were in Continental region (Dragina cave, Matešića cave, Vrlovka cave and Barićeva cave).

Nursery colonies

The distribution of 42 known nursery colonies recorded in Croatia in the past 50 years is shown in Fig. 4. Out of the total, 13 roosts (3 lofts, 2 tunnels, 2 mines, 5 caves) contained 50 or less individuals. 27 roosts (9 attics and lofts, 2 tunnels, 16 caves) contained between 50 and 500 individuals and only 2 caves contained more than 500 individuals. The two largest colonies live in caves (Golubinka and Tradanj) on the coast. The present condition of Golubinka cave is unknown since no surveys have been made since the discovery in 1999. Tradanj cave, however, has been visited monthly during 2006 and detailed temperature and humidity recordings were undertaken. The average temperature during March and April was almost constantly around 13.5 °C (not shown) and the first *R. ferrumequinum* arrived in May when the temperature rose. At that time of the year, the animals were deep inside the cave and were inactive during the day. The large colony found in July was so near the entrance that part of it was exposed to daylight and animals reacted immediately as we approached the cave. The average temperature outside the cave showed a significant increase from 18 °C in May through 22 °C in June and 25 °C in July. From these observations it is obvious that nursery colonies of *R. ferrumequinum* prefer very warm roosts during this period.

In total 27 nursery colonies have been found in the Mediterranean region. 18 of them (that is 60% of all nursery colonies with > 50 animals in Croatia) contained > 50 animals (average of 300 bats), making this region clearly the most suitable for nursery colonies. Most nursery colonies were found in caves (19, average of 421 bats), 6 were found in tunnels and other type of roost (average of 108 bats) and 2 were found in lofts (average of 325 bats).

In the Continental region, 15 nursery colonies were found (7 with 50 or more animals, average 90 animals). In this region 8 nursery colonies were found in lofts (average 126 bats), 5 in caves (average 59 bats) and only 2 in abandoned mines (average 26 bats).

Data on the reproductive status of females showed great variability in the time of birth. In the southern part of the Mediterranean region we have found pregnant

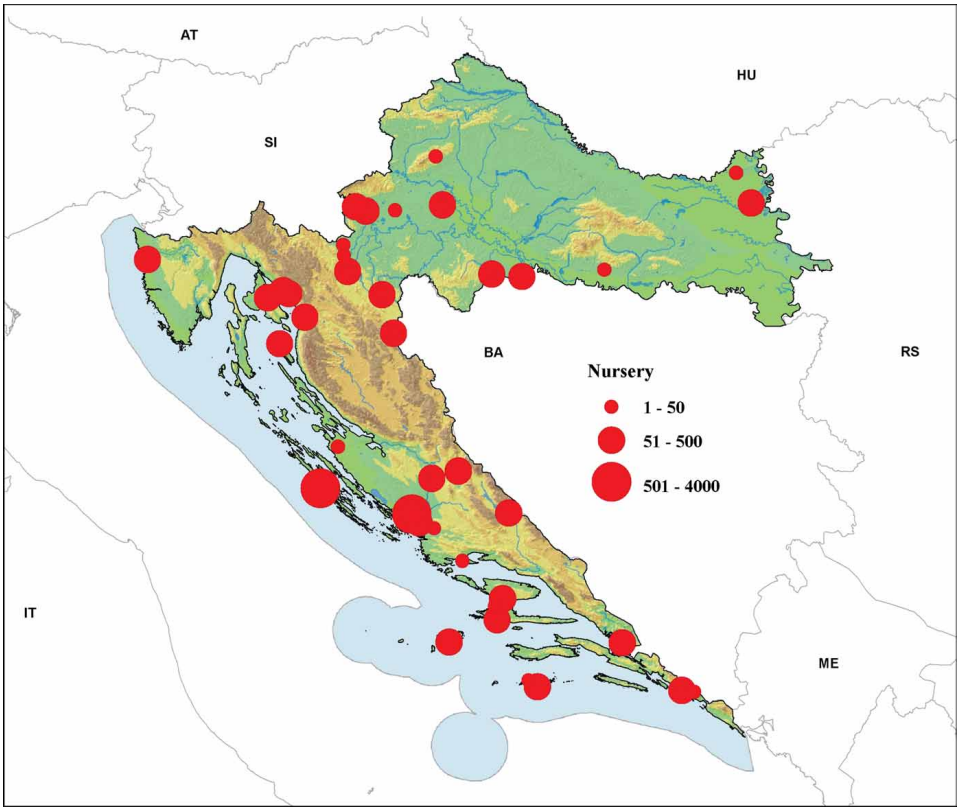

Fig. 4. Distribution and size of 42 nursery colonies of *R. ferrumequinum* in Croatia.

females at the beginning of July (Vilina cave) and at the same time in the Vištičina cave young bats were at least 2 weeks old. Hairless young found on 31st July in Tradanj were no older than a few days. Nursery colonies in the Continental region showed even higher variability – the first pregnant females in Matešića cave were caught on April 20th, while in the colony in Vratovo we found young animals that were still unable to fly at the beginning of September.

Hibernation colonies

The distribution of 57 known hibernation sites recorded in Croatia in the past 50 years is shown in Fig. 5. Out of the total, 30 wintering sites contained 10 or less animals (53.8%) and 7 housed 250 or more animals (average 450 animals). The relationship between number of colonies and their size during winter is presented in Fig. 6. Only two wintering sites were not in caves but in artificial shelters (Markuševac bunkers, Medvednica Mt. near Zagreb and Vora mine on the island of Vis).

The numbers of hibernating *R. ferrumequinum* in two caves (Vrlovka and Ozaljska) have declined from 350 (09.01.1956 ĐULIĆ, 1959; ĐULIĆ, 1963) to only 5 animals today. Since Vrlovka cave was also used as a nursery, it must be considered as the

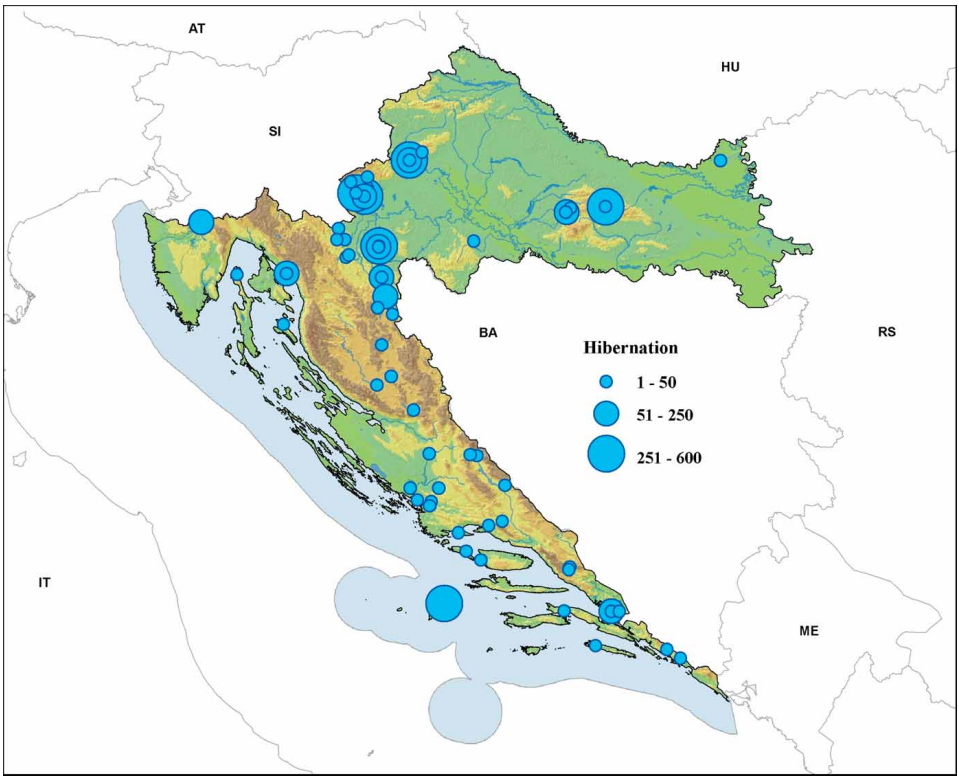

Fig. 5. Distribution and size of 57 hibernation colonies of *R. ferrumequinum* in Croatia.

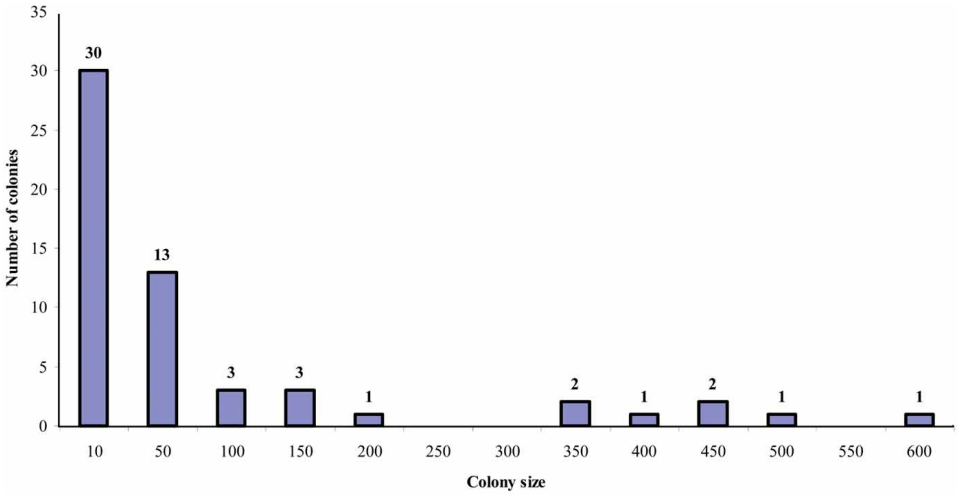

Fig. 6. Distribution and size of winter colonies of *R. ferrumequinum* in Croatia.

most seriously affected known underground site used by *R. ferrumequinum* due to inappropriate exploitation. Veternica cave near Zagreb was the subject of systematic bat monitoring and research over many years (ĐULIĆ, 1960; 1963; unpublished data) and the results are used to analyse the population trend of *R. ferrumequinum* during hibernation. Veternica cave represents the fifth largest underground complex in Croatia (more than 7 km of tunnels) but only the first 400 meters are easily accessible and this part has been fitted with lighting and further adapted for visiting tourists and other commercial activities. All the data about *R. ferrumequinum* are from this part of the cave. To prevent further unauthorised visits and disturbance, special gates were installed in 2005. The design was based on the recommendation of bat expert from the Croatian Natural History Museum and the population of greater horseshoe bats during winter has stayed stable and ranges from 100 to more than 250 individuals. Temperature monitoring showed that inside Veternica cave the temperature ranged between 5.6 °C and 8.6 °C during winter. Artificial tunnels in the vicinity of Veternica (Markuševac) hosted single *R. ferrumequinum* during the winter. Here the temperature ranged from 9 °C in December to 8.5 – 8.6 in January and February 1993 and 6.8 °C in February 1999 (D. Holcer, unpublished data). Today these tunnels are in commercial use and most of the entrances are closed with gates inappropriate for bats. Apart from the record from Jopićeva cave, the wintering colony in Uviraljka discovered in 2006 is one of the largest in Croatia. Although the cave has been the subject of regular yearly visits and monitoring since 2002, the number of wintering *R. ferrumequinum* was constantly < 10 animals. Only after a completely new part of the cave was discovered in 2006 was a large colony found. Results of the temperature monitoring in both the »old« (logger 1) and »new« (logger 2) parts of the cave clearly showed that the »old« part was more influenced by external temperature changes – colder during winter – and that *R. ferrumequinum* preferred the warmer second part of the cave (Fig. 7). Minimum temperature was recorded in January 2008 and was 4.13 °C (logger 1) and 5.45 °C (logger 2).

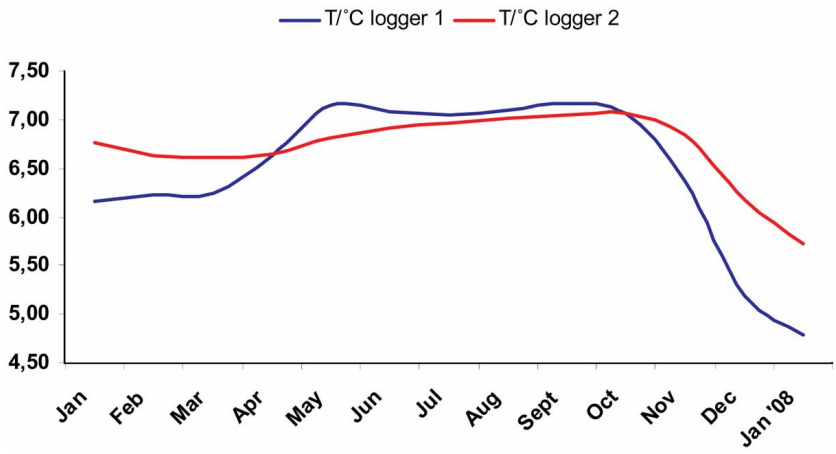

Fig. 7. Average monthly temperature from the »old« (logger 1) and »new« (logger 2) part of Uviraljka cave in the period from January 2007 – January 2008. Values are presented in additional table.

	logger 2			logger 1		
	T/ °C			T/ °C		
	min	avg	max	min	avg	max
Jan	6.60	6.76	6.85	5.86	6.16	6.67
Feb	6.57	6.63	6.67	6.06	6.23	6.37
Mar	6.52	6.61	7.28	6.04	6.25	6.75
Apr	6.55	6.65	6.75	6.14	6.63	7.08
May	6.75	6.82	6.87	6.90	7.14	7.33
Jun	6.87	6.91	6.95	6.95	7.08	7.28
Jul	6.93	6.96	6.98	6.98	7.04	7.08
Aug	6.98	7.01	7.03	7.05	7.10	7.15
Sept	7.03	7.05	7.08	7.13	7.17	7.20
Oct	7.03	7.06	7.1	6.75	7.06	7.23
Nov	6.52	6.85	7.05	5.55	6.37	6.95
Dec	5.58	6.17	6.57	4.26	5.18	5.91
Jan '08	5.45	5.72	5.93	4.13	4.78	5.27

In total, 25 hibernacula have been found in the Mediterranean region (3 localities with 50 or more animals, maximum count of 400 on the island of Vis), all being caves except for one mine. In the Continental region, 30 winter roosts were found (10 of them with 50 or more animals, average 281 animals) with the maximum of 600 hibernating *R. ferrumequinum*. All except two hibernation roosts are in caves.

At the time of migration, 37 localities of *R. ferrumequinum* were found in addition to those that were also used as summer and winter roosts. The largest number

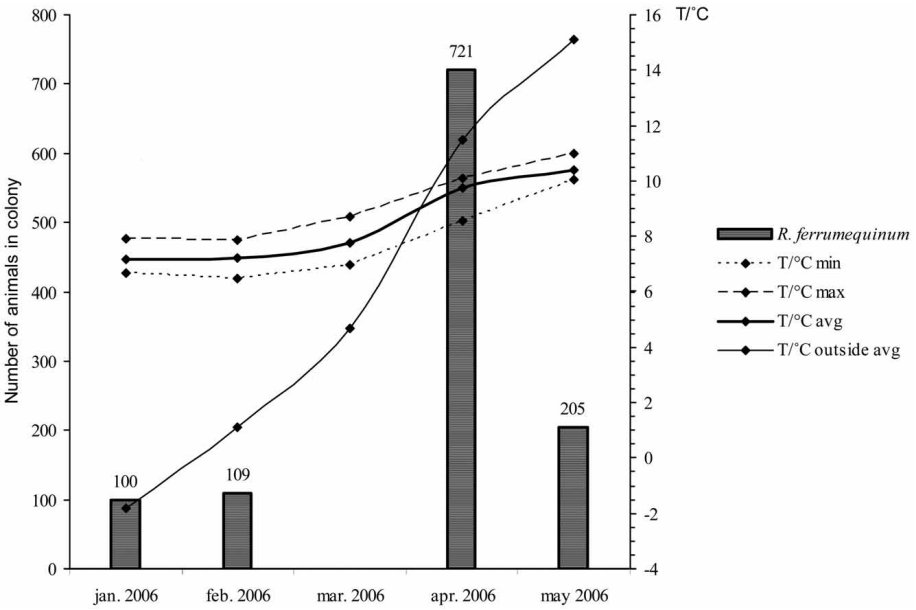

Fig. 8. Temperature and number of *R. ferrumequinum* in Matešića cave from January to May 2006. Outside temperature represent the average from the nearest town Slunj.

of *R. ferrumequinum* during the migration period is found in Matešića cave that is used all year around. A sudden increase in numbers is directly connected with the increase in temperature both outside and inside the cave (Fig. 8).

Altitudinal distribution and population estimate

The altitudinal distribution of *R. ferrumequinum* is presented in Fig. 9 and Fig. 10. Out of the 66 localities shown, 50 % are below 200 m a. s. l. and 75% are below 400 m a. s. l.

The highest altitude nursery colony was found in Suhi Rumin pit (510 m a. s. l.) and Matešića cave (320 m a. s. l.) in the Dinaric part of the Continental region. All other large nursery colonies were situated below 200 m a. s. l. (Fig. 9).

Močiljska cave (near Dubrovnik) is the highest recorded roost during winter (913 m a. s. l.). Next highest is the hibernation colony found in Uviraljka cave (855 m a. s. l.) in the isolated karst part of Continental region, followed by the cave in Brest (> 700 m a. s. l.) in the Dinaric part of the same region (Fig. 5).

Out of 9 caves that were recorded as both hibernation and nursery roost, 7 are situated at altitudes of less than 250 m a. s. l.

A total of 1550 adult females has been counted within the Continental region and when divided by the given area (40 336 km^2) the result is a density of 0.04 *R. ferrumequinum* per km^2. Within the Mediterranean region, a total of 9250 adult females has been recorded, but since the area is considerably smaller (16 260 km^2) the density is 0.6 bats per km^2. The estimated density of *R. ferrumequinum* on Vis island, based on the maximum number of bats recorded during winter, is a little over 0.2 bats per km^2. From these data we have estimated the density within the Continental region to be between 0.2 km^{-2} (8000) and 0.3 km^{-2} (12000) and within the Mediterranean part 0.6 km^{-2} (9000) to 0.7 km^{-2} (11000). This would suggest an overall population estimate of *R. ferrumequinum* in Croatia to be between 17 000 and 23 000.

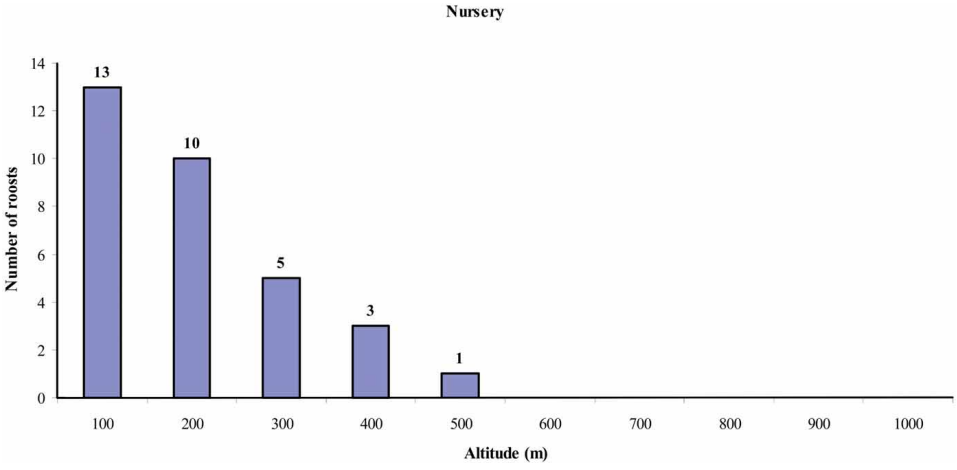

Fig. 9. Altitudinal distribution of nursery roosts of *R. ferrumequinum* in Croatia.

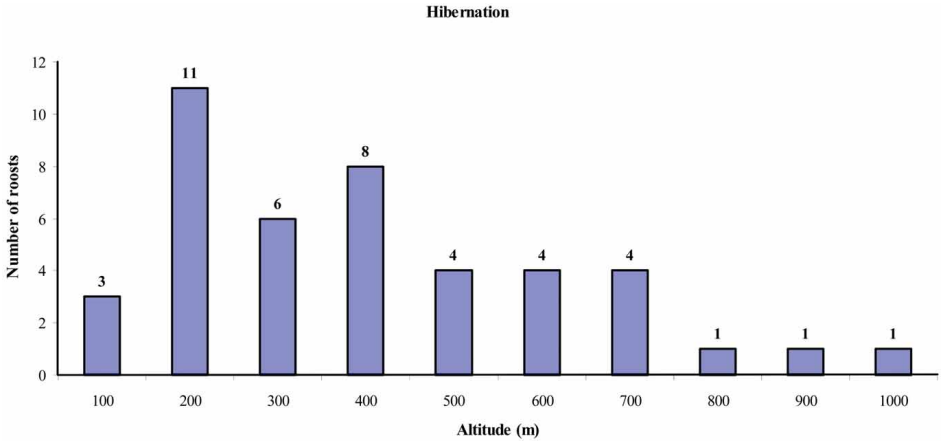

Fig. 10. Altitudinal distribution of hibernation roosts of *R. ferrumequinum* in Croatia.

DISCUSSION

Population estimate

The estimated number of 35 000 breeding animals in Croatia (Fourth National Report on the implementation of the EUROBATS Agreement) seems to be an overestimate in the light of the data presented here. While the Mediterranean region is quite well investigated, in the light of some recent discoveries we assume that the population of the Continental region is somewhat difficult to estimate. It seems that at lower altitudes, where most of the nurseries are in house attics, many maternity colonies lost their roosts as a direct consequence of the last war (1991–1995). In this region of Croatia there is still a huge number of abandoned houses and even whole villages. Interestingly enough, during our survey of one of such villages we were granted entrance to many intact but abandoned attics (>10) that looked ideal for bats but we found a colony in an attic that had a partially destroyed roof with a huge hole in it. The only difference was that this house was deep in the forest and was almost completely overgrown by the surrounding trees.

Temperature requirements

It seems that females of *R. ferrumequinum* seek the highest possible temperature during the day and do not even hesitate to expose themselves and their young to direct sunlight for short periods. Eastern part of the Continental region of Croatia offers, apart from many potential roosts, an important advantage to *R. ferrumequinum* in having relatively high daily temperatures and high numbers of very or extremely hot days especially during May and July (more hot days than in the Mediterranean region). On the other hand, this part of Croatia is lacking adequate winter roosts which could be a limiting factor for the population.

The most important nursery colonies of *R. ferrumequinum* in Croatia are situated in the Mediterranean region inside warm caves. Apart from a high temperature inside the cave, it seems important to have a possibility to exploit high temperatures

outside. Tradanj cave is the best example of that phenomenon. The cave entrance is on the eastern slopes facing south and it is effectively protected from the cold northern winds by both vegetation and position. An almost similar situation is in the case of the Miljacka II colony where *R. ferrumequinum* are hanging high in the entrance part sheltered only from direct sunlight. Sea caves (Golubinka, Medvi-đina), apart from being protected from wind, can also benefit from the water that prevents high temperature oscillations especially during the night.

Data on the average temperature inside the nursery roosts ranged from 9 to 21 °C in caves and as high as 36.8 °C in attics and lofts (GAISLER, 2001). Our results showed that nursery colonies *of R. ferrumequinum* in Croatia are highly dependent on high temperatures and will mostly choose sites that offer additional warming, regardless of the region where they are found. Caves of the Mediterranean region represent the most suitable choice only when they are on southern slopes and protected from direct wind. Lofts and attics in this region are not suitable probably because of excessive temperatures generated during the day.

Different temperature regimes and the ability of females to regulate the time of birth resulted in quite different parturition data, but without an obvious pattern that young are born earlier in the Mediterranean region than in others. On the contrary, our data could be interpreted in a way that the females in colder parts and caves tend to have their young as early as possible in order to take advantage of the spring peak of insects and improve their chances of becoming independent before the start of the cold period. RANSOME & MCOWAT (1994) showed a connection between time of birth and temperature (spring, summer) that was also connected to the population dynamics in the way that very late birth (28th July) was followed by the population loss. Therefore, data from our observations could be used as indication of potential population level fall at given roosts.

According to SCHOBER & GRIMMBERGER (1998), *Rhinolophus ferrumequinum* hibernates from the end of September or October to April and winter roosts are located in caves and tunnels with temperatures between 7 and 10 °C, rarely lower. Data from Croatia showed that the species is tolerant of even lower temperatures (Uviraljka, Fig. 7) down to 6 °C, but on the other hand, the average temperature probably should not exceed 12 °C. Average temperatures are considerably higher than those recorded in hibernacula of *R. euryale* (ĐULIĆ, 1960). Temperatures from Tradanj cave (not shown) of more than 13 °C average during February and March could be the main reason for the absence of *R. ferrumequinum* during the winter. The period of hibernation in the Mediterranean region lasts from October to March.

Migrations

Movements between summer and winter roosts are common within a distance 10 to 60 kilometres, with the longest migration of 320 and possibly 500 km (HUTTERER *et al*., 2005). In Croatia a distance of 32.5 km has been recorded (ĐULIĆ, 1957): the bat was ringed during winter in Veternica cave and found in Zagorje area during the nursery period. Record of bat ringed in Aflenz (Austria) (SPITZENBERGER, 2001 after KEPKA, 1960) and later found in Šašinovec (Croatia) is the longest documented migration distance of this species in Croatia. Also, recently new evidence of transboundary migrations of *R. ferrumequinum* in the Pannonian basin have been revealed (MIKUSKA

& MIKUSKA, 2003). The ringing site was on a small hill in Hungary, only 20 km from the wintering site in Croatia where a live animal was found in February 2002, 7 years after it had been ringed. This and some other findings of bats ringed in Hungary clearly demonstrate that Croatia shares bat populations with other countries and that for their protection it is necessary to further improve our knowledge about routes and periods of migration.

New research on migration should concentrate on finding connections between nursery and hibernation roosts in the Mediterranean region. There are some indications that animals from Tradanj cave are using both Miljacka II cave (distance 28 km) and Škarin Samograd cave (distance 20 km) for winter but these should be confirmed by methodical ringing.

Potential causes of threat

There are different correlated biotic and abiotic factors which have negative effects on bat populations. Human impact is the main negative factor.

Loss of roosts and human disturbance at roost sites

This is the most important threat to *R. ferrumequinum* in Croatia. The greater horseshoe bat is sensitive to disturbance. Both winter and summer roosts are affected by human activities ranging from occasional visits by cavers to organized tourism with complete adaptation of the cave for commercial exploitation. Adaptation for tourism is becoming more and more intensive and quite common on the mainland where caves are considered to have a high potential for tourism. The caves are adapted for touristic use without any consultation with bat experts considering lights, gates and dynamics of visiting, although this could provide satisfactory solutions for both tourism and bat protection in some cases. Some caves are deliberately destroyed like Dragina cave. The measures proposed for compensation are unsatisfactory because of lack of experience and lack of control of their implementation.

In 2 attics (Vratovo, Kopačevo) the colonies consisting of together more than 600 females disappeared. The same happened in 2 caves (Punta Noža, Vrlovka) that were used by 350 females. The colony in Vratovo was mixed with more than 500 *Myotis emarginatus*. All animals left the attic after a severe drop in temperature at the beginning of July 1998. Numerous dead bats (females and juveniles) were found. The attic in Kopačevo, situated in an old house, was destroyed, but there is a possibility that the bats escaped. Vrlovka cave has been adapted for tourism with lights and gates and is today used as a hibernaculum only by few individuals. A recent visit of Punta Noža, Vis, revealed a complex of caves – one was completely without any bat remains, and one situated above the sea had quite large pile of very old guano along with only few fresh droppings, suggesting that it has been recently used as an occasional roost.

The small number of nursery colonies found in the attics of houses definitely does not decrease the importance of this kind of roost, especially in the Continental part. Colonies living in abandoned houses face at least two major problems – inappropriate restoration (wrong period, closing of all entrances) or complete destruction of the roof.

No nursery colonies were found in churches. The recent intensive survey of more than 100 churches in the Continental region revealed the main reason; all entrances

are closed either with windows or wire to prevent pigeons from entering. Some churches are inappropriately illuminated from the outside (towers) and some had their roofs renewed during summer and without appropriate measures for bat protection. All this resulted in very disappointing results not only for *R. ferrumequinum* but for all bat species that use church lofts.

The use of timber treatment chemicals in the attics of buildings is also thought to have had a severe impact on some populations. Such chemicals are used to control various types of wood-boring insects and fungi, and those containing chlorinated hydrocarbons, such as lindane and pentachlorophenol, resulted in the death of bats (RACEY & SWIFT, 1986). Although there is very little information or even evidence about usage of these chemicals in Croatia this could be a potential cause of threat especially in the northern part.

Use of agricultural pesticides

The main problem for bats is that the use of pesticides causes food shortage. It reduces the number of insects and their diversity, and this may have implications for bat populations (HUTSON *et al.*, 2001, ex. *R. hipposiderros*, BONTADINA *et al.*, 2008). The scaraboid and geotrupid dung beetles are a dominant part of the diet during the summer, autumn, and winter months of the endangered *R. ferrumequinum* and other large bats such as *Nyctalus* and *Eptesicus* species (BECK, 1995).

The impact of pesticides on *R. ferrumequinum* in Croatia has not been investigated so far. Therefore we propose a research project which would look at insect populations in two areas in the vicinity of large nursery colonies. One area should be with intensive agriculture (high usage of pesticides) and one with extensive agriculture. For this we would propose the colony in Tradanj as a one with extensive or no agriculture around the roost and the colony in Vištičina cave that is situated in the Neretva valley that is one of the most intensive and largest agricultural regions in Croatia.

Habitat changes and destruction

Forests are a key habitat for bats. The disappearance of forests and key landscape elements such as tree lines, hedgerows, and canals which bats use regularly during flight is a major problem (LIMPENS *et al.*, 1989; LIMPENS & KAPTEYN, 1991; VERBOOM, 1998). Forest management in Croatia is based on an acceptable forest regime with varied age classes within an area, but there are many improvements that could be made, in coordination with bat experts, to improve these habitats for bats. The destruction of aquatic habitats (i.e. backfilling and drainage) is also a problem because open-water drinking sites are vital to bats (RACEY, 1998). One of the problems becoming more and more pronounced in Croatia is waterflow regulation and especially destruction of river banks.

Another human activity resulting in habitat loss and fragmentation is intensive agriculture that is mostly widespread in the eastern part of the Continental region. Apart from deterioration of natural habitats (mostly forests), intensive agriculture increases the use of pesticides.

Proposal for research and conservation in Croatia

Further field investigations should concentrate on finding more nursery colonies of *R. ferrumequinum* in Croatia, especially in some areas. The results should help to clarify distributional borders in the litoral part, continental Dinaric part with the Hrvatsko Zagorje region, as well as the eastern Continental part of Croatia. Priority areas are the Hrvatsko Zagorje region, Istria, the slopes of the Slavonian mountains, the lower stream of the Drava river, the lower stream of the Sava river, areas by the Kupa, Dobra, Mrežnica, Una, Gacka, Lika and Zrmanja rivers as these areas are insufficiently explored.

Monitoring of both winter and nursery colonies is required to understand the general status of the species in Croatia..

The greater horseshoe bat is proposed for monitoring for several reasons. 1. For this species we know a fair number of their nurseries (over 30), and winter (over 20) colonies. 2. In most of the colonies it is possible to count a precise number of animals (from 20 to 500 animals). 3. This species is quite easily observed (hanging freely and not using crevices of any kind) and also easy to distinguish from other species.

For monitoring we recommend the following nursery colonies and winter colonies. Selection has been made based on the position of the roost, size of the colony, accessibility of the site and the colony inside and the overall importance and estimate of possible threats.

For summer monitoring we recommend: the Banovo brdo mine, Hrvatska Dubica abandon house, church in Hrvatska Kostajnica, Krka spring cave, Sveti Križ church, Tradanj cave, Vrbnik tunnel on island Krk, Zagorska cave, Barićeva cave, Golubinka cave (the island of Dugi), Medveđa ropa cave (the island of Lastovo), Miljacka II cave, Vištičina pit, Vilina cave and Rafova cave.

For winter monitoring we recommend: mine Banovo brdo, Veternica cave, Uviraljka cave, Rastik cave, Gradusa cave at Banija (Banovina), Matešića cave, Jopićeva pit, Zagorska cave, Medova buža marine cave (the island of Rab), Vištičina pit and mine Vora (the island of Vis). All colonies in houses and churches found in the future should immediately become part of the intensive monitoring programme.

The conservation of *R. ferrumequinum* in Croatia depends mainly on the protection of shelters and habitats in caves. It requires systematic protection of maternity roosts and winter roosts. Some of the caves need special protection at the time when females have their young. Along with caves, another important aspect of protection in the Continental region will be colonies in houses and, if any, in churches.

Caves that are used as both winter and nursery roosts represent a very valuable resource since the temperature conditions provide the optimal range for *R. ferrumequinum* and therefore they should be maximally protected.

Fear and prejudice from the presence of bats can result in roost destruction therefore it is necessary to raise awareness and educate the local population.

During the construction and reconstruction of buildings and churches it is required to leave an adequate space for bat to roost and not to seal all openings, also it should be forbidden to reconstruct at the time when females have their young. Illumination of church towers should be avoided or should be made following advice from bat experts and after detailed analysis of entrance usage.

Caving and tourism should be organised in a defined period with seasonal restrictions and restrictions of the number of visitors.

Further questions to be answered: Although *R. ferrumequinum* is one of the best known species in Croatia there are many questions about this species yet to be answered – where do animals from nursery colonies in Dalmatia (especially those from islands) go during winter? Related to that is the question of localities referred to as »migration« – could they possibly also be used as winter or nursery roosts? Of most importance for protection of the species is to find out how many nursery colonies are using abandoned houses and how to protect them?

For all the above reasons, *R. ferrumequinum* should be treated as a model species for establishing future monitoring and effective protective compensation and restoration measures for bats in Croatia.

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