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Massive population decline of the Critically Endangered Greater Horseshoe Bat, *Rhinolophus ferrumequinum* (SCHREBER, 1774), in Styria, south-eastern Austria, between the mid-1990s and 2009 (Mammalia, Chiroptera)

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Abstract: Between 1991 and 1995 a population survey of attic-dwelling bats by investigating the attics of 424 large, public buildings, i.e. churches, castles and monasteries, was conducted in the districts of Graz-Umgebung, Deutschlandsberg, Feldbach, Fürstenfeld, Hartberg, Leibnitz, Radkersburg, Voitsberg und Weiz. The study area covered an area of 6679 km² in the pre-alpine foothills and lowlands of western and eastern Styria in south-eastern Austria. During the first survey, a whole of 10 summer roosts of Greater Horseshoe Bats (*Rhinolophus ferrumequinum*) in the attics of large castles and in a monastery in the districts of Graz-Umgebung, Fürstenfeld, Hartberg and Weiz were found in summer 1994 and 1995. A second survey of all known roost-sites of the species which was conducted in July 2002, revealed that six formerly occupied roost-sites had been abandoned since 1994–95. Of four remaining roosts only one, in Herberstein Castle, has kept its former status as a maternity colony. Two additional maternity colonies were found in a formerly unoccupied roost and in a castle in the city of Graz which had been not investigated during the first survey. Of six roost-sites existing in 2002 two persisted till 2009 when a second monitoring survey was conducted. The status of the formerly occupied roost and the numbers of Greater Horseshoe Bats in Herberstein Castle cannot be considered in this publication, because we were denied access to the attic in 2009 and failed to obtain data on counts which were recently conducted by experts for the Styrian government. However, the species' population numbers declined from 50 spread over 10 summer roosts to 26 adult individuals in two roost-sites between 1994–95 and 2009, and the number of breeding females dropped from 40 to 25 during the same period. Since 2002 the Styrian metapopulation which may include adult bats of two adjacent maternity roosts in Burgenland, which are abandoned since 2008, seems to have contracted to a single maternity roost in Eggenberg Castle in the outskirts of the city of Graz. Possible reasons for the species' decline are discussed.

Zusammenfassung: Zwischen 1991 und 1995 wurde eine erste Erhebung der Bestände Gebäude bewohnender Fledermäuse in 424 Großgebäuden - Kirchen, Klöster und

Schlösser - in den Bezirken Graz-Umgebung, Deutschlandsberg, Feldbach, Fürstenfeld, Hartberg, Leibnitz, Radkersburg, Voitsberg und Weiz (zusammen 6679 km²) in der West- und Oststeiermark durchgeführt. Hierbei wurden im Sommer 1994 und 1995 insgesamt 10 Sommerquartiere der Großen Hufeisennase (*Rhinolophus ferrumequinum*) in den Dachböden von Schlössern und im Dachraum eines Klosters in den Bezirken Graz-Umgebung, Fürstenfeld, Hartberg und Weiz gefunden. Bei einer weiteren Kontrolle dieser Dachböden im Sommer 2002 wurden sechs Quartiere verlassen vorgefunden, von den restlichen vier Quartieren hatte lediglich eines, im Schloss Herberstein (Bezirk Hartberg), seinen ursprünglichen Status als Wochenstube behalten. Zusätzlich konnten aber in zwei neuen Gebäuden zwei weitere Wochenstuben von Großen Hufeisennasen gefunden werden. Im Jahr 2009 kontrollierten wir neuerlich alle bekannten Sommerquartiere mit Ausnahme des Schlosses Herberstein, wo uns der Zutritt verweigert wurde. Da auch alle Versuche scheiterten, die Ergebnisse eines vom Land Steiermark beauftragten Zählteams zu erhalten, finden der Status des Quartiers Herberstein und allfällig dort vorhandene Tiere in dieser Arbeit keine Berücksichtigung. Von fünf Quartieren im Jahr 2002 waren 2009 nur mehr zwei erhalten. Insgesamt hat zwischen der ersten Kontrolle 1994 bzw. 1995 und 2009 die Zahl von rund 50 adulten Tieren in ursprünglich 10 Sommerquartieren auf 26 adulte Tiere in zwei Quartieren abgenommen. Im selben Zeitraum ist die Zahl reproduzierender Weibchen von 40 auf 25 zurückgegangen. Die steirische Fortpflanzungspopulation und vermutlich auch jene Tiere, die bis 2007 in zwei burgenländischen Wochenstubenquartieren kontrolliert worden waren, hat sich bis 2009 in einem einzigen Quartier, im Schloss Eggenberg in Graz, zurückgezogen. Mögliche Gründe für den Zusammenbruch der Population seit 1995 werden diskutiert.

Key words: population numbers, Greater Horseshoe Bat, *Rhinolophus ferrumequinum*, summer roosts, Styria, Austria, population decline, monitoring, Habitats Directive.

1. Introduction

Throughout its formerly almost continuous western and central European range, the Greater Horseshoe Bat (*Rhinolophus ferrumequinum*) belongs to the most endangered bats (SCHÖBER 1998). In Austria, besides the laws which are administered by the governments of federal states (Bundesländer), the species is protected under a number of international conventions which have been signed by the Republic of Austria. *Rh. ferrumequinum* is listed in annexes II and IV of the European Community's Directive 92/43/EEC (Habitats Directive). Under the Habitats Directive member states are responsible for regular monitoring, and for the maintenance or restoration of a favourable conservation status of the species and habitat types listed in both annexes.

On the basis of data which have been collected between 1970 and 1999, the Greater Horseshoe Bat was listed as Critically Endangered in the current edition of Austria's

Red Data Book (SPITZENBERGER 2005). Until the late 1990s a whole of 17 maternity colonies were known throughout the southern and south-eastern foothills of the Austrian Alps, i.e. in the federal states of Carinthia, Styria, and in Burgenland. The national population of adult bats which regularly aggregate in maternity roosts, was estimated at < 100 individuals by SPITZENBERGER (2002).

The majority of the Austrian population was found in Styria, where eight maternity colonies and four roost-sites of non-breeding individuals (ind.) have been recorded during the 1990s. Roost-sites were found in altitudes between 306 m up to 569 m a.s.l. in the sub-montane and sub-illyric zones in the foothills of the eastern Alps. Non-breeding and breeding Greater Horseshoe Bats were found in undisturbed attics of large castles and in one case in the attic of a monastery. With one exception, i.e. Eggenberg Castle in Graz which since 1939 is owned by the federal state of Styria and managed by the Universalmuseum (formerly Landesmuseum) Joanneum, all buildings, inhabited by the species, are in private property. In general, attics used by Greater Horseshoe Bats for breeding are characterized by very low light, the absence of almost any draught, and a wide range of ambient temperatures which provide adequate micro-climates for thermoregulation for bats of different age classes, as well as ample space for practising wing-flapping and exploratory flights for juveniles (RANSOME 1998, SCHÖBER 1998).

The present paper aims to document changes in the distribution and abundances of Greater Horseshoe Bats in summer roosts since a first survey, 1991–1995, of almost all larger, public and privately owned buildings in the pre-alpine foothills and lowlands of southern Styria, and two consecutive surveys of all already known and of some potential roost-sites of the species in 2002 and 2009. Hence, our results provide information on the species' conservation status before and following the implementation of the Habitats Directive in Austria in 1995.

2. Material and methods

During a first survey that was carried out in the years 1991–1995, the attics of 424 large, mainly public buildings in the political districts of Graz-Umgebung, Deutschlandsberg, Feldbach, Fürstenfeld, Hartberg, Leibnitz, Radkersburg, Voitsberg and Weiz were investigated for the presence of bats. The survey covered a total area of 6679 km² which is mainly covered by intensively used agricultural lands, deciduous and mixed-deciduous forests. The density of human population varies from 34 people/km² in the political district of Leibnitz, to 128 people/km² in the district of Graz-Umgebung. In total, more than 95 % of all churches, castles and monasteries which exist in the region between 208 m and 1274 m a.s.l. were investigated. Additionally, a few other large and medium-sized official buildings and some smaller private estates, where owners informed us about their bat colonies, were visited.

Surveys were conducted in 10–18 days periods during the main breeding season of bats between June and late July. With the help of torches and binoculars, inside the attics all accessible roof-timbers and roof chambers were controlled for the presence of bats and/or accumulations of bat droppings. In the case that we encountered single bats or colonies, survey protocols included information on visual identification of the species, reproductive status (non-breeding ind. or maternity colony) and counts of non-breeding ind., adult females and juveniles.

A second survey of all buildings which had harboured Greater Horseshoe Bats in the early 1990s, was conducted between July 8th–13th, and on August 1st, 2002. In addition to already known roost-sites, Eggenberg Castle in Graz, where a maternity colony was reported to exist since at least 1958 by KEPKA 1961, was visited, and one breeding female was found in another building that had not contained Greater Horseshoe Bats during the first survey. A third, and the most recent survey was conducted between July 21st and August 13th, 2009. We managed to visit eleven out of 12 buildings which during former surveys had harboured Greater Horseshoe Bats. Regrettably, in July 2009 the owners of Herberstein Castle in Stubenberg a. See (district of Hartberg) refused permission to enter the castle. Because our efforts to obtain data from a team which was appointed by the Styrian government to count bats in Herberstein Castle have failed, the status and population numbers of Greater Horseshoe Bats for this roost-site cannot be considered in the present paper. However, FRIESS (2004) mentions that the breeding colony of the Greater Horseshoe Bat in Herberstein Castel is no longer existing.

3. Results

3.1. Roost occupancy

During the early 1990s, the presence of Greater Horseshoe Bats was recorded in ten from a whole of 424 buildings (2,4 %) which we had investigated between 1991–1995. All positive sites were found in summer 1994 and 1995, in the districts of Graz-Umgebung, Fürstenfeld, Hartberg and Weiz. In three roost-sites only non-breeding adults were found, while seven buildings contained maternity colonies (Tab. 1).

In 2002, i.e. 7–8 years after the first survey, the number of active roosts had declined to four. Five out of a total of six roost-sites which had been abandoned by 2002, were maternity roosts (Tab. 1). In only one, i.e. Herberstein Castle, of the four roosts which remained till 2002 adult females and juveniles were present. During the same survey two additional maternity roosts were found: One inside the attic of a building which had not been used by *Rh. ferrumequinum* in 1994–1995, and a second in Eggen-

berg Castle, Graz, which we had not visited during the first survey (Tab. 1). Thus, until 2002, the number of known maternity colonies had decreased from seven to three.

From a total of six occupied roost-sites 2002, only two persisted in 2009. Of these, one harboured a solitary adult, while in Eggenberg Castle a maternity colony which in late July contained 51 adult and juvenile bats, was noted. Hence, in the course of the last 15 years the number of known summer roosts had declined from 12 to two in 2009 (Tab. 1).

3.2. Population numbers

3.2.1. Numbers of adult bats per roost-site

As shown in Tab. 1, between 1994 and 1995 the numbers of adult non-breeding bats per roost varied between 1–3 ind., from 2–4 ind. 2002, while 2009 only a single non-breeding animal was found. In total, the mean of non-breeders in summer roosts since 1994, is calculated with $2,0 \text{ adults} \pm 1,0 \text{ SD}$ ($n = 11$). For comparison, the total mean of adult ind. in maternity colonies amounts to $6,7 \pm 8,2 \text{ SD}$ ($n = 11$). In 1994 and 1995 the numbers of breeding females per maternity colony varied from 1 ind. (in three roosts) to 19 females, from 1–4 females 2002, while a total of 25 females was counted in the remaining breeding colony in Eggenberg Castle which we managed to visit 2009.

3.2.2. Population numbers

Because we miss data for Eggenberg Castle for the early 1990s and for Herberstein Castle in 2009, we are not able to assess the change of total population numbers since the 1990s in absolute numbers. However, between 1994 and 1995 total numbers of adult Greater Horseshoe Bats in 10 summer roosts amounted to 50 ind. By including a presumably incomplete count during a visit of the attics of Eggenberg Castle (5–8 ind.) on July 21st 1998, 11 occupied roost-sites which harboured a minimum of 55–60 adult ind., may be a more adequate estimate for the period 1994–1998. In contrast, 2002 six occupied roost-sites (including Eggenberg and Herberstein Castle) hosted a total of 20 adult ind., while only two active summer roosts which harboured 26 adult bats (Herberstein Castle excluded), remained in 2009 (Tab. 1). During the same period the number of breeding females dropped from a minimum of 50 ind. in the mid-1990s to 25 ind. in 2009 (cf. Tab. 1).

The only currently known maternity colony which exists since at least 1958 (KEPKA 1961), inhabits the extensive attics of Eggenberg Castle in the outskirts of the city of Graz. During the study period the numbers of adult bats increased from six ind., 2002, to 25 in 2009. According to published data of older counts, the colony experienced a severe decline till 2002: 1958 the colony consisted of approximately 100 adult and juve-

nile ind. (KEPKA 1961), of around 80 adults and juveniles in 1966 (KOCHSEDER 1968), and decreased to 35 adult and juvenile bats in 1984 (SPITZENBERGER 2002). For the year 1985 13 adults were reported by SPITZENBERGER l.c., while 2002 six adults were present in the colony.

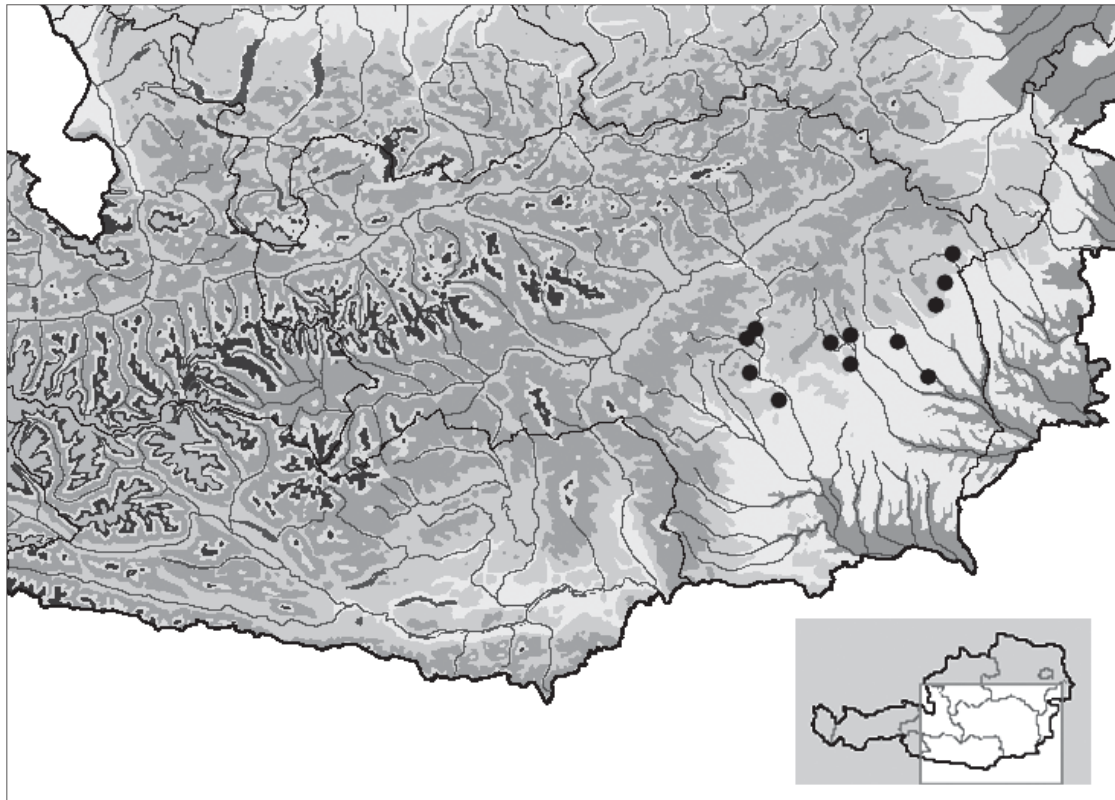


Fig. 1: Distribution of 12 summer roosts of Greater Horseshoe Bats (*Rhinolophus ferrumequinum*) in Styria, south-eastern Austria, recorded between 1994 and 2009. – Verbreitung der Sommerquartiere der Großen Hufeisennase (*Rhinolophus ferrumequinum*) in der Steiermark, Südost-Österreich, zwischen 1994 und 2009.

Locality	year of visit	indet. adults	ad. females (pregnant or with young)	indet. young	status
used as maternity roost					
1	1995	0	1	1	breeding confirmed
maternity roost until 1995	2002	2	0	0	breeding not confirmed
	2009	0	0	0	extinct
2	1995	1	1	1	breeding confirmed
maternity roost until 1995	2002	0	0	0	extinct
	2009	0	0	0	extinct
3	1995	3	5	5	breeding confirmed
maternity roost until 1995	2002	0	0	0	extinct
	2009	0	0	0	extinct
4	1995	0	1*	0	breeding confirmed
maternity colony until 1995	2002	0	0	0	extinct
	2009	0	0	0	extinct
5	1995	0	2	0	breeding confirmed
maternity roost until 1995	2002	0	0	0	extinct
	2009	0	0	0	extinct
6	1995	0	11	1	breeding confirmed
maternity roost until 2002	2002	2	4	4	breeding confirmed
	2009	?	?	?	?
7	1995	0	0	0	not present
maternity roost only in 2002	2002		1	1	breeding confirmed
	2009	0	0	0	extinct
8	1994	0	19	12	breeding confirmed
maternity roost until 1994	2002	0	0	0	extinct
	2009	0	0	0	extinct
9	2002	2	4	4	breeding confirmed
maternity roost since 1958	2009	0	25	26	breeding confirmed

Locality	year of visit	indet. adults	ad. females (pregnant or with young)	indet. young	status
used as roost of non-breeding individuals					
10	1995	3	0	0	breeding not confirmed
maternity roost until 1994 (Freitag 1996)	2002	4	0	0	breeding not confirmed
	2009	1	0	0	breeding not confirmed
11	1995	2	0	0	breeding not confirmed
non-breeding roost until 2002	2002	1	0	0	breeding not confirmed
	2009	0	0	0	extinct
12	1995	1	0	0	breeding not confirmed
non breeding roost until 1995	2002	0	0	0	extinct
	2009	0	0	0	extinct

Tab. 1: Status of summer roosts (no. 1–12) and population numbers of Greater Horseshoe Bats (*Rhinolophus ferrumequinum*) in Styria, south-eastern Austria, during the first survey in 1994 and 1995, and subsequent monitoring surveys 2002 and 2009. – Status der Sommerquartiere (Nr. 1–12) und Bestände der Großen Hufeisennase (*Rhinolophus ferrumequinum*) in der Steiermark 1994–1995 und während nachfolgender Kontrollen 2002 und 2009.

4. Discussion

4.1 Has the Styrian metapopulation contracted in a single maternity roost?

With a maximum age of 35 years and slow reproduction, in comparison to other Western Palearctic bats of the family Vespertilionidae, *Rh. ferrumequinum* is a very long-lived, mainly k-selected species (GAISLER 1989, RANSOM & HUTSON 2000). According to recoveries of individually marked animals, the species appears to be largely sedentary by using the same maternity roosts and hibernacula for many years (SCHÖBER 1998). In a recent analysis of the species' ranging behaviour in southern England, however, FLANDERS & JONES (2009) found evidence that some individuals move via transitional roosts between different maternity colonies. Hence, the increase of population numbers in Eggenberg Castle may indicate the contraction of the Styrian metapopulation in a single

maternity roost. Additionally, it may be speculated that the small population which existed in the mountains of adjoining northern Burgenland until 2007 (SPITZENBERGER 2002, unpubl. data), has joined the Styrian population in Eggenberg.

4.2 Decline of the Austrian population

Since the 1970s summer roosts of Greater Horseshoe Bats have been recorded only along the south-eastern edge of the Austrian Alps in Burgenland and Styria, westwards to eastern and central Carinthia (SPITZENBERGER 2002). Following the largely restricted distribution of summer roosts to the south-east of the country, the Austrian population appears to represent the northern edge of the species' core distribution area in Italy and Slovenia (LAPINI et al. 1996, KRYŠTUFEK & REŽEK DONEV 2005, PRESETNIK et al. 2007). Although seasonal migrations from western Slavonia (Croatia) to a hibernaculum in Aflenz a.d. Sulm in southern Styria, close to the border to Slovenia, have been confirmed by the recovery of a banded bat (KEPKA 1960), according to the species' apparent avoidance of lowland areas during the breeding season, the Austrian breeding population may have been never closely connected to populations in the north-western Carpathian Basin in Hungary (BIHARI et al. 2007) and Slovakia (UHRIN et al. 1996).

Simultaneously to the decrease of the Styrian population, population numbers as well as the species' summer range in Carinthia and Burgenland have declined dramatically. In Carinthia during a five year study (1985–1989) in the attics of 975 large buildings six active maternity colonies (0,6 %) were found (SPITZENBERGER 1993, 1995). In accordance with later results obtained by KRAINER et al. 2007, by 2001 the majority of maternity roosts in Carinthia had been abandoned and the numbers of adult Greater Horseshoe Bats have decreased distinctly (unpubl. data). In the same way in Burgenland where annual surveys of two recognised maternity colonies of the species are established since 2004, pregnant or lactating females which were seen in 2005 and 2007, were no longer present in 2008 and 2009.

On the basis of our data, we estimate that the Austrian population has lost almost 90 % of its former summer range. Following the abandonment of the majority of maternity colonies whose numbers have dropped from 17 to two colonies during the last 15 years, the total of adult individuals in summer roosts has declined by approximately 70 % of its former numbers. Consequently, the Austrian remnant population appears to be heavily susceptible to isolation, restricted gene flow, and to fluctuations of population numbers following stochastic events.

4.3 Possible reasons of the decline

Data which are available for the maternity colony in Eggenberg Castle since 1958 (see 3.2.2.) and results of winter counts for a number of underground hibernacula since the

late 1960s (P. SACKL et al., in prep.) indicate that the Styrian population has already undergone a serious long-term decline before our first survey in 1994 and 1995. However, in regard to the species' longevity, the sudden and almost simultaneous decline of the Austrian population since 1995 is striking and cannot be explained on the basis of currently available count data.

4.3.1. Weather conditions

According to RANSOME & HUTSON (2000), in *Rh. ferrumequinum* recovery from population crashes following a series of severe winters and cold springs is slow and will take several years. Tab. 2 shows the monthly means for ambient air temperatures for the years 1996–2008, in comparison to respective mean temperatures during the period 1971–2000. Data in Tab. 2 indicate that the period between January and March 1996 was unusually cold. In particular, in February and March 1996 temperatures $> 3^{\circ}\text{C}$ below long-term means have been measured which were followed by periods of comparably low temperatures in April and July, and extremely high precipitation in May 1996. We have no data for testing, if the unusual combination of unfavourable weather conditions in late winter and spring 1996 has affected the population. However, in regard to the series of mild winters (with the exception of the slightly colder winter 2005/06) and particularly warm summer months since 1997, weather conditions appear to be inadequate to explain the steep decline of *Rh. ferrumequinum* since 1995.

	Jan	Feb	Mar- ch	April	May		June		July	
1996	- 2.6	- 3.8	0.8	9.7	15.6	125	19.0	75	18.3	57
1997	- 3.0	2.1	5.1	7.4	15.9	63	18.2	141	18.8	222
1998	0.5	3.8	4.4	10.7	14.9	48	19.3	129	20.3	143
1999	- 1.7	0.6	6.8	10.9	15.4	122	18.5	144	20.6	145
2000	- 3.4	3.1	6.2	13.3	16.6	86	20.2	99	19.0	147
2001	0.3	3.0	7.4	9.4	17.3	48	18.0	96	21.3	61
2002	- 1.5	4.0	7.0	9.8	17.4	47	21.1	52	21.7	102
2003	- 3.4	- 2.9	5.8	9.0	18.0	40	22.7	75	22.1	145
2004	- 1.9	0.9	3.8	10.5	13.6	98	18.1	223	20.0	82
2005	- 0.5	- 2.5	3.0	10.4	16.1	61	19.2	99	20.3	154
2006	- 4.6	- 0.8	3.2	11.0	14.9	104	19.5	99	20.6	69
2007	2.8	4.7	6.9	12.9	16.8	84	20.7	76	21.8	100
2008	1.1	3.4	6.1	10.7	16.6	59	20.0	133	21.2	150
1971–2000	- 2.3	- 0.1	4.3	9.0	14.2	82	17.4	120	19.1	123

Tab. 2: Monthly mean of air temperature in $^{\circ}\text{C}$ [calculated: (7 a.m. + 7 p.m. + Max. + Min.)/4] and monthly sum of precipitation in mm [calculated: (7 a.m. + 2 p.m. + 7 p.m.)/3] at Graz Airport (340 m a.s.l.) in the years 1996–2008 and the long-term mean value for the period 1971–2000 (Source: Annals of the Central Institute for Meteorology and Geodynamics Austria, www.zamg.ac.at). – Monatsmittel der Temperatur ($^{\circ}\text{C}$) und die monatliche Niederschlagsmenge (mm) für die Station Flughafen Graz (340 m NN) für die Jahre 1996–2008. Am Ende der Tabelle sind die entsprechenden, langjährigen Mittelwerte, 1971–2000, angeführt (Quelle: Zentralanstalt für Meteorologie und Geodynamik, www.zamg.ac.at).

4.3.2. Habitat quality and roost conditions

With the exception of Herberstein Castle, during our last survey in July 2009 we found conditions in all formerly used attics unchanged. We noted no recently finished renovation works or any indication of reconstruction in tracts formerly inhabited by Greater Horseshoe Bats. There is also no evidence for a substantial change of land-use in the immediate surroundings of roost-sites with the potential to affect the foraging areas of all roosting colonies, more or less simultaneously, since 1995.

5. Conclusions

Despite the already critical conservation status of the Styrian breeding population in the mid-1990s, to our knowledge, so far no Action Plan or other measures targeted at the protection of Greater Horseshoe Bats have been adopted. During the evaluation of the network of Natura 2000-sites which had been proposed by the Styrian conservation authorities, between 1999 and 2000, bat species, listed in the annexes of the Habitats Directive, were not included (ERNET & ADLBAUER 2000). However, two breeding sites, in Herberstein and Gutenberg Castle, are situated within Natura 2000-sites which have been implemented since 2005: Feistritzklamm/Herberstein (AT2218000; 554,5 ha) and Raabklamm (AT2233000; 124,8 ha). By considering an average of 148 ha, recently measured for individual foraging areas of a transitional roost in southern England by FLANDERS & JONES 2009, and maximum distances of foraging trips ranging between 5–10 km (mean distances 2,1–5 km) which are reported for maternity colonies in western Europe, Switzerland, southern Germany and Bulgaria (cf. DIETZ et al. 2007), both SPAs appear to be too small for adequately protecting and managing the species' potential foraging areas of the (former) breeding colonies in Herberstein and Gutenberg Castle. According to the recent concentration of the Austrian metapopulation in Eggenberg Castle, i.e. within the limits of the densely populated and heavily urbanized city of Graz, the breeding population appears to be even more vulnerable.

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