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Changes in roost occupancy and abundance in attic-dwelling bats during decreasing roost availability in Burgenland, Austria

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Abstract. In the course of two consecutive (1990–1997 and 2004–2008) surveys of potential bat roosts in 312 attics of large buildings in Burgenland, Austria, changes in attic occupancy by bats and in the abundance of adult bats in maternity roosts were determined. We located 308 bat roosts in 228 attics and found nine species of roosting bats, six (mouse-eared bats pooled) of them occurring on a regular basis, the other three only accidentally. Our results provide evidence that a continuous, steep and rapid decrease of roosts of attic-dwelling bats took place over the study period. In 110 attics bat occupation persisted, and in almost the same number (107 attics) former roosts were found to be abandoned during the second survey period. Roost occupancy and utilisation as a maternity or solitary roost were highly fluctuating. Also, the composition of species sharing one roost changed frequently between the two surveys. Decreasing roost availability influenced abundance trends of the six species differently. Over the course of the two surveys, the numbers of adults in maternity colonies increased in the mouse-eared bats (*M. myotis* + *M. blythii* pooled) and in *M. emarginatus*, and decreased in *Rhinolophus hipposideros*, *Eptesicus serotinus* and *Plecotus austriacus*. The conservation status of three attic-dwelling bat species listed in the Annexes II and IV of the Habitats Directive has deteriorated since Austria became member of the European Union.

Attic-dwelling bat species, changes in roost occupation, abundance trends, Austria

Introduction

It is widely accepted that the species-specific quality of attics as roosts for maternity colonies and solitary individuals is one of the main factors determining the reproductive success of temperate attic-dwelling bat species. Optimal attics provide shelter from weather and predation, adequate microclimates, reduced commuting costs to foraging sites and possibilities of information transfer among the inhabitants (Kunz 1982, Altringham 2011). If undisturbed, attics may be used by one or more bat species for centuries. In the last decades, however, new roof building regulations, renovation works and – above all – active exclusions of bats from the attics have constantly led to destructions of roosts (e. g. Briggs 2004, Hutson et al. 2001) and presumably to changes in numbers of attic dwelling bats. Although the protection of attics containing bat roosts is considered to be a crucial issue in bat conservation, the utilisation of a particular attic by one or more bat species over time (Kunz & Reynolds 2003) and the reaction of different species to increasing shortage of roosts are poorly understood.

In order to evaluate the role of roosts for the conservation of attic-dwelling bat species, we studied the changes in roost availability, in the occupancy of a particular roost and in the abundance of six (mouse-eared bats pooled) attic-dwelling bat species over the course of two surveys on a regional basis.

Monitoring the status of bat populations is an obligation anchored in the Habitats Directive (92/43/EEC) of the European Union. We chose an Austrian Province (Bundesland) as a study area because Austria, being an EU member state with federal structure, vested the provincial authorities with the integration of environmental legislation issued by the European Community into national legislation. As Austria became member of the EU in 1995, the results of the two surveys (1990–1997 and 2004–2008) contribute to an assessment of changes in the conservation status of bat populations in Austria before and after the EU Habitats and Species Directive became national law.

Material and Methods

Study area and study periods

Two surveys of bats roosting in attics of buildings were carried out in Burgenland, the easternmost province (Bundesland) of Austria. Burgenland occupies an area of 3970 km²; it forms a long and narrow belt located between 48° 06' and 46° 50' N and 16° 00' and 17° 50' E. In the east it has borders with Slovakia, Hungary and Slovenia. The landscape is very diverse, including the eastern foothills of the Alps (highest summit 884 m a. s. l.) and parts of the Little Hungarian Plain in the north of the country. Unique features of this lowland in the north are Lake Neusiedl and the adjacent Seewinkel, a flat area with salt lakes and small remnants of steppe vegetation. Here the climate is characterised by hot summers, cold winters and an annual precipitation of 450–700 mm. To the south the climate becomes more humid. While large streams are missing, numerous small rivers and brooks lined with narrow belts of riparian forests drain south-eastward into the Danube. One third of the country is covered by forests which consist mainly of oak, hornbeam and pine; spruce and beech dominate at higher elevations. Cultivated land is comprised of 153,000 hectares of arable land and 12,000 hectares of grassland, of which 11,000 hectares are extensive meadows and pastures. The main agricultural crops are corn, wheat and other cereals, wine and rape oil seed.

Burgenland is predominantly a rural country. Beside the capital Eisenstadt (104,000 buildings) there are 57 small and 15 somewhat larger towns in 171 municipalities.

The first survey was conducted between 1990 and 1997, the second between 2004 and 2008. The median record date for the first period is 1994 and for the second period 2006, thus the mean distance between the surveys is 12 years.

Survey design

We searched for attic-dwelling bats in nearly all large public buildings across the 171 municipalities of Burgenland. If informed by the owners, we also included bat roosts in smaller private houses into our sample. During both surveys we visited the same 312 buildings. They consisted of 90% churches and chapels, 7% castles, the rest were monasteries, barracks, custom houses, one mill and two private houses. Each attic was visited at least once per period, some were surveyed annually. During the first survey 87%, during the follow-up survey 75% of all buildings were visited only once. The attics were surveyed predominantly between May and July. Inside the attic we searched all accessible rooms for bats and/or accumulations of bat droppings, using torches and binoculars. Ten maternity colonies of the greater mouse-eared bats were found to be mixed with a varying number of the lesser mouse-eared bat. As it was impossible to distinguish their droppings, we pooled these two species. The database encompasses 558 records of the first and 504 of the second survey.

To assess the changes in abundance we used maternity roost counts. This acknowledged monitoring method provides more or less accurate and reliable estimates of the actual number of gregarious bat species (Battersby 2010, Dietz & Simon 2005, Hayes et al. 2009). Counts of bats in maternity roosts made during April and August were excluded from the assessment of abundance trends. We differentiated between the following three roost types: Maternity roost (m); roost of solitary individual (s); attic without signs of bat occupation and/or without living bats and fresh droppings (0). Roosts of solitary individuals contained a small number of single individuals of unknown sex, age and reproductive status.

The survey and counting protocol included: (1) in case of living bats present – visual determination of the species; deciding on the status of the bats encountered (solitary individuals or maternity colony); visual counts of solitary animals and members of the maternity colony; distinguishing between pregnant, adult and young individuals. In very large colonies we assessed the orders of magnitude by counting 10 or 20 bats and extrapolating the total number by estimating how often the square area occupied by the counted bats was included in the area occupied by the whole cluster; (2) in case of accumulated bat droppings – determination of the species and age (this year, last year, older, very old), deciding on the status of the accumulation (solitary animals, maternity colonies).

Data analysis

Attic occupancy during the two consecutive surveys was categorised as follows: (1) no occupation – neither living bats nor fresh droppings present in the first and second period; (2) ongoing occupation – living bats and/or fresh droppings present in the first and second period; (3) abandoned – living bats and/or fresh droppings present in the first period, living bats and/or fresh droppings missing in the second period. Roosts were also categorised as abandoned when the bats became exterminated over the course of the second period; (4) newly established – living bats and/or fresh droppings missing in the first period, living bats and/or fresh droppings present in the second period.

If more than one species occupied one particular attic, the categories 2–4 were treated separately for each species. For example, one particular attic could be categorised as "abandoned" for one species, and "newly established" for another species.

For assessing abundance trends of a certain species, we summed the numbers of adults counted across all maternity roosts occupied by this species per survey period and compared the total sums of the two periods. In case of multiple counts of the same colony during one survey period, the arithmetic mean was considered in the subsequent analyses.

Results

Changes in attic occupancy

More than one quarter (N=84) of the monitored attics (N=312) was not inhabited by bats during the first and second survey period. Accumulations of old bat droppings indicated, however, that 44.5% (N=37) of these 84 attics had been inhabited by bats before the beginning of the first survey in 1990. Of the 228 active attics, bat occupation persisted in 110 roosts (48.2%), and nearly the same number (N=107; 46.9%) of attics which had contained bats during the first period was found to be abandoned during the second period. Only in less than 5% (N=11) of those attics that had not been used as roosts during the first period, new bat colonies were found to be established during the second survey.

Bat species roosting in attics of large buildings

In the 228 active attics we found bats and/or their droppings of the following nine species: *Rhinolophus ferrumequinum*, *Rh. hipposideros*, *Myotis myotis*, *Myotis blythii*, *Myotis emarginatus*, *Eptesicus serotinus*, *Plecotus austriacus*, and very rarely *Myotis mystacinus* and *Barbastella barbastellus*. At the beginning of the first period in 1990, skeletal remains of *Miniopterus schreibersii* were detected in the church attics of Mischendorf and Jennersdorf.

The greater and lesser mouse-eared bats, grey long-eared bat, lesser horseshoe bat, serotine and Geoffroy's bat were the most frequently recorded species in the monitored attics. They were found in different compositions in 227 attics (Table 1). The remaining three species constituted only a small fraction of the roosting bats and were excluded from further analysis.

The most active attics contained roosts of only one species and others were shared by two or three species (Table 2). Most frequently, mouse-eared bats and grey long-eared bats occupied the same attic; in 13 attics we encountered mouse-eared bats and serotines simultaneously, and grey long-eared bats and serotines were recorded together in seven attics. Rarely, the lesser horseshoe bat shared an attic with other species. The composition of the species assemblages rarely remained stable: only in 13 attics we found the same species composition during both surveys, whereas in 60 attics the species assemblages differed between the two periods.

Table 1. Numbers of attics containing roosts of the six most abundant species during both surveys

number of active attics		*Myotis myotis + M. blythii*	*Plecotus austriacus*	*Eptesicus serotinus*	*Rhinolophus hipposideros*	*Myotis emarginatus*
N	227	158	71	37	33	9
%	100	69.6	31.2	16.3	14.5	4.0

Table 2. Species composition of continuous and temporary assemblages in one attic

species	number of attics periods 1+2	one period only
Myotis myotis + *M. blythii* and *Plecotus austriacus*	6	25
Myotis myotis + *M. blythii* and *Eptesicus serotinus*	2	11
Myotis myotis + *M. blythii* and *Rhinolophus hipposideros*	2	7
Myotis myotis + *M. blythii* and *Myotis emarginatus*	1	0
Plecotus austriacus and *Eptesicus serotinus*	0	7
Plecotus austriacus and *Rhinolophus hipposideros*	0	3
Rhinolophus hipposideros and *Myotis emarginatus*	2	0
Myotis myotis + *M. blythii*, *Plecotus austriacus* and *Eptesicus serotinus*	0	4
Rhinolophus hipposideros, *Plecotus austriacus* and *Myotis emarginatus*	0	1
Myotis myotis + *M. blythii*, *Plecotus austriacus* and *Rhinol. hipposideros*	0	2

Changes in roost occupancy in regard to species

The changes in roost occupancy between the first and second period varied strongly among species (Table 3).

Myotis myotis and *Myotis blythii*

The greater mouse-eared bat was by far the most widespread and abundant species in the attics of large buildings in Burgenland. Together with the lesser mouse-eared bat which was far less common, it occupied almost 70% of the active attics identified between 1990 and 2008 (Table 1). During the second survey, mouse-eared bats were found to be absent from 77 previously inhabited attics, and in 15 attics new roosts were found to be established, amounting to a net roost loss of 39.2%. Only 15 maternity colonies persisted in the same roost over both surveys. Seven former

Table 3. Changes in roost occupancy of *Myotis myotis+M. blythii* (Mymy+bl), *Plecotus austriacus* (Plaus), *Rhinolophus hipposideros* (Rhhi), *Eptesicus serotinus* (Epse) and *Myotis emarginatus* (Myem) of the surveyed attics (N=227) between the first and second period
Legend: nao = number of attics occupied; m-m=maternity roost during both the first and second period; 0-m = empty roost in the first period, maternity roost in the second period; s-m = roost of solitary individual(s) in the first period, maternity roost in the second period; m-s = maternity roost in the first period, roost of individual(s) in the second period; m-0 = maternity roost in the first period, abandoned in the second period; s-s = roost of solitary individual(s) during both the first and second period; 0-s = empty roost in the first period, roost of solitary individual(s) in the second period; s-0 = roost of solitary individual(s), abandoned in the second period

species	nao	m-m	0-m	s-m	m-s	m-0	s-s	0-s	s-0
Mymy+bl	158	15	2	10	2	7	39	13	70
%	100	9.5	1.3	6.3	1.3	4.4	24.7	8.2	44.3
Plaus	71	8	4	1	2	8	7	15	26
%	100	11.3	5.6	1.4	2.8	11.3	9.8	21.1	36.6
Epse	37	5	2	–	1	7	1	2	19
%	100	13.5	5.4	–	2.7	18.9	2.7	5.4	51.4
Rhhi	33	9	1	1	2	12	1	1	6
%	100	27.3	3.0	3.0	6.1	36.4	3.0	3.0	18.2
Myem	9	6	–	–	1	2	–	–	–
%	100	66.7	–	–	11.1	22.2	–	–	–

maternity roosts were found to be abandoned during the follow-up survey, and two maternity roosts were established in new attics. Two former maternity roosts were occupied by solitary individuals in the second period, whereas 12 former solitary roosts turned into maternity roosts. Thus, the number of maternity roosts rose from 24 in the first period to 27 in the second period. In contrast to maternity roosts, a big loss occurred in the solitary roosts of the mouse-eared bats. The numbers of this roost type decreased from 119 in the first, to 54 in the second survey (Table 3).

Plecotus austriacus

This species occupied less than one third of the active attics identified between 1990 and 2008 (Table 1). During the second survey, grey long-eared bats were found to be absent from 34 previously inhabited attics, but 19 roosts were established in new attics in the second period, amounting to a net roost loss of 21.1%. Eight maternity colonies persisted in the same roost over both surveys and the same number of former maternity roosts was found to be abandoned during the second survey. Four maternity roosts were established in a new attic. Two former maternity roosts contained only solitary individuals in the second period, and one former roost of solitary animals turned into a maternity roost. Thus, the number of maternity roosts decreased from 18 in the first period to 13 in the second period.

The numbers of solitary roosts decreased from 34 in the first, to 24 in the second survey. The grey long-eared bat managed to establish 15 new solitary roosts (Table 3).

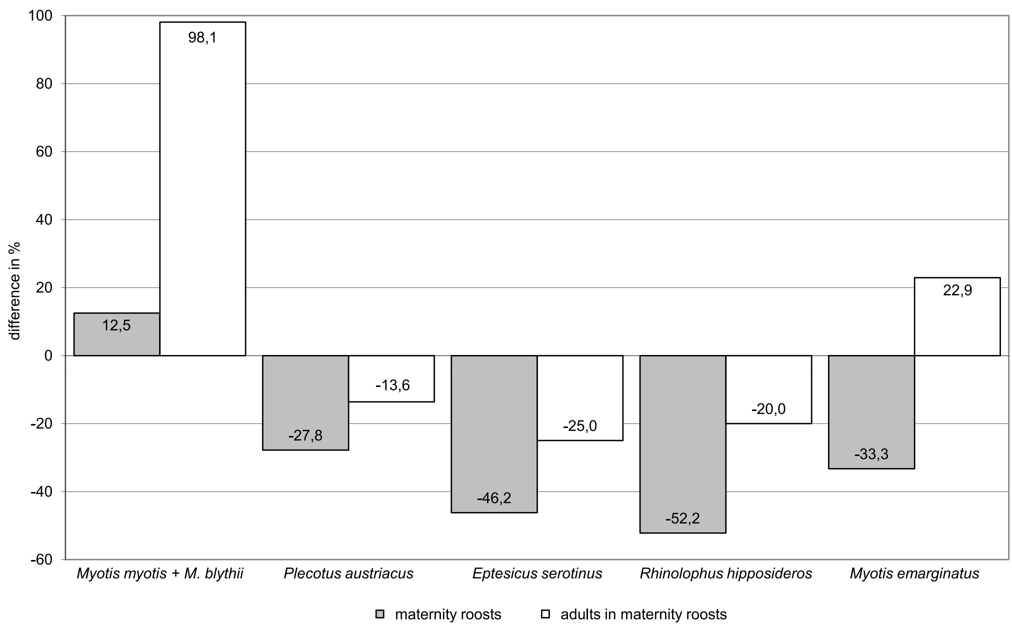

Fig. 1. Changes in the numbers of occupied maternity roosts and numbers of adult individuals in maternity roosts between the first and second survey period (in %).

Table 4. Changes in numbers of adults in maternity roosts and in numbers of maternity roosts between the first and second survey period

	Myotis myotis + M. blythii		*Plecotus austriacus*		*Eptesicus serotinus*		*Rhinolophus hipposideros*		*Myotis emarginatus*	
survey period	1	2	1	2	1	2	1	2	1	2
numbers of adults in maternity roosts	4328	8575	165	143	175	131	434	347	1120	1376
numbers of maternity roosts	24	27	18	13	13	7	23	11	8	7

Eptesicus serotinus

The serotine occupied 16% of the active attics identified between 1990 and 2008 (Table 1). During the second survey, serotines were found to be absent from 26 previously inhabited attics, and only in four attics new roosts were found to be established, amounting to a net roost loss of 59.5%. Five maternity colonies persisted, seven former maternity roosts were abandoned, one was inhabited by solitary individuals and two were newly established in the second period. Thus, the number of maternity roosts decreased from 13 in the first to seven in the second period. The numbers of solitary roosts decreased from 22 in the first, to four in the second survey (Table 3).

Rhinolophus hipposideros

Between 1990 and 2008, the lesser horseshoe bat occupied 14.5% of the 227 active attics (Table 1). During the second survey, we found 18 previously inhabited attics to be abandoned, and only in two attics newly established roosts were found, amounting to a net roost loss of 48.5%.

Nine maternity colonies persisted, twelve former maternity roosts were abandoned and two were inhabited by solitary individuals; one former roost of solitary individuals turned into a maternity roost and another one was newly established in the second period. Thus, the number of maternity roosts declined from 23 in the first to eleven in the second period. The numbers of solitary roosts decreased from eight in the first, to four in the second survey (Table 3).

Myotis emarginatus

Only 4.0% of the active attics were occupied by the Geoffroy's bat between 1990 and 2008 (Table 1). Two attics having contained maternity colonies were found to be abandoned (net roost loss = 22.2%) and one former maternity roost contained only solitary individuals during the second survey. Thus, the number of maternity roosts declined from nine in the first to six in the second period. The six remaining maternity roosts persisted in their respective attics (Table 3).

Assessment of trends in the maternity colony size

Between the two surveys, the numbers of adults in maternity roosts increased only in the mouse-eared bats (*M. myotis* + *M. blythii*) and Geoffroy's bat (*M. emarginatus*) (Table 4). The numeric gain amounted to almost 100% in the mouse-eared bats and to less than one quarter in the Geoffroy's bat. During the same time, the numbers of maternity roosts increased only by 12.5% in the mouse-eared bats and decreased by 33% in *M. emarginatus*.

In the remaining three species, the numbers of adults in the maternity roosts declined (Table 4). The grey long-eared bat lost 14%, the lesser horseshoe bat one fifth, and the serotine one quarter of the numbers counted during the first survey period. The concurrent loss of maternity roosts was biggest in the lesser horseshoe bat (more than 50%), in the serotine almost as big (46%) and comparatively small (28%) in the grey long-eared bat (Fig. 1).

Discussion

Although our study area is defined by political borders and does not represent a natural geographic unit, we chose the province of Burgenland because it is the responsible governmental body for the legal and physical protection of bats and their roosts within its borders according to Austrian law. As we surveyed the majority of potential buildings, we assume that the colony counts provide a sound basis for assessing population trends.

We tried to minimise census biases caused by shifting of colonies to alternate roosts by exploring (almost) all large public buildings existing in Burgenland, but we are aware of the fact that not all five attic-dwelling bat species choose large buildings for breeding exclusively. Data on more than 1500 maternity roosts obtained in the course of former large-scale surveys in different parts of Austria (e. g. Spitzenberger 1993) indicated that only the greater mouse-eared bat (*M. myotis*) breeds mainly in large buildings (but see Rudolph & Liegl 1990), whereas for *Myotis emarginatus*, *Rhinolophus hipposideros* and *Plecotus austriacus* it is unknown to what extent attics in small private houses are also used as maternity roosts. Another drawback is that the counts of adult individuals in the maternity colonies were not conducted at regular intervals and the duration of the two survey periods was not equal.

In spite of this, we are confident that the data obtained provide a useful basis for a rough assessment of changes in roost occupancy and maternity colony sizes between 1994 and 2006 (mean record dates of the two surveys).

Our study confirms that attics of large public buildings are favourite roosting sites for several bat species. Before the onset of the first survey (1990), 85% of the 312 attics in large buildings in Burgenland had been occupied by bats, a figure very similar to the results of a comparable study conducted in Carinthia (area 9533 km^2) between 1985 and 1989, where 84% of 975 buildings were inhabited by bats (Spitzenberger 1993).

The loss of suitable roost sites is one of the key threats to attic-dwelling bat species (Entwistle et al. 1997). Our results provide evidence that a continuous, steep and rapid decrease of roost sites of attic-dwelling bats has been taking place in Burgenland over the course of only 18 years. Already before the year 1990, 12% of all surveyed attics had been abandoned, and between 1990 and 2008 another 107 attics (34%) became deserted. The small number of newly established roosts in 3.5% of the attics can be taken as indication that the availability of adequate attics was limited.

Possibly as a reaction to the increasing roost shortage, we observed a remarkable flexibility in roost selection. In only one third of the 308 roosts established in the remaining 227 attics, the occupying species and the status as maternity or solitary roost persisted over the course of both surveys, and almost 20% of the roosts were established in new attics or changed their status during this period. Also, the composition of species roosting together in one attic fluctuated between the two surveys remarkably. The fact that the mouse-eared bats, grey long-eared bat and the serotine were often observed to share the same attic, seems to indicate that of the common factors influencing roost selection (morphology of the bat species, roost microclimate, proximity to suitable foraging areas and the landscape surrounding the roost – Jenkins et al. 1998), mainly morphological and behavioural constraints limited the utilization of attics as roosts. These species do not need large exit holes, but can crawl through narrow fissures when entering or leaving the roost (authors' observations).

As can be expected, the flexibility in roost selection and thus the degree of roost fidelity was not equal among the species. The most flexible species was the grey long-eared bat, a result that is in accordance with observations compiled by Horáček et al. (2004). The lowest flexibility was exhibited by the Geoffroy's bat. Likewise, remarkable specific differences could also be observed in the population trends occurring between the two surveys.

Population trends can be influenced by many factors such as climate (Horáček 1984), food supply, change of landscape structures in the vicinity of the roosts, and of course by the availability of adequate roosts. The fact that different species were not equally affected by the increasing roost shortage can probably be best explained by different roosting strategies and social structures. At least for the greater mouse-eared bat (*Myotis myotis*) whose roosting strategy in Central Europe has been extensively studied (Horáček 1985), the observed abundance trends can be securely related to the roosting strategy of this species.

The mouse-eared bats were the only species (group) for which a (small) increase in numbers of maternity roosts as well as a huge increase in numbers of adult maternity colony members could be reported. Their numbers almost doubled over the course of 18 years. This obvious success can be explained by the fact that during the reproductive season, males are spread widely over the area inhabited by a regional population, whereas females concentrate in optimal roosts. A good knowledge of all available roosts shared among all population members enables the bats to colonize suitable roosts swiftly (Horáček 1985). The ability to cover long distances between the roost and hunting areas allows the mouse-eared bats to exploit large foraging areas and thus form large maternity colonies, as long as suitable conditions of the roost and sufficient food supply are available (Spitzenberger 1993). It cannot be excluded that the huge increase in numbers of adults in the maternity roosts was caused by the loss of good roosts outside the study area, but our results are in accordance with observations in some neighbouring countries (e. g. Czech Republic – Benda et al. 1996) and thus may mirror a wider trend.

Myotis emarginatus was the only species whose population numbers grew in spite of a decrease in the numbers of maternity colonies. Although increasing in numbers, and being the second most abundant species after the mouse-eared bats, it inhabited only few maternity roosts which probably met the high demands of this species. The habit of forming tight clusters (Zahn & Henatsch 1998) enables the females of this middle-sized species to form large maternity colonies even in small attics. High numbers of Geoffroy's bats in few maternity roosts were also observed by Gombkötő (1998) in the NW of Hungary.

The grey long-eared bat forms small maternity colonies (Horáček 1975), which accounts for the low total population numbers. Compared to the brown long-eared bat it exhibits lower roost fidelity (Horáček et al. 2004) and therefore was able to colonise new roosts for solitary individuals, which resulted in a net roost decrease of only 21%.

Until the 1990s, numerous metapopulations of the lesser horseshoe bat have inhabited the traditionally used rural landscapes of Burgenland (Spitzenberger 2002). Through agricultural intensification, urbanisation of the settlements and exhaustive renovations of buildings occurring between the two surveys, this species lost or abandoned many maternity roosts (–52%). Nevertheless, the decrease in numbers of adults in maternity roosts was moderate (–20%), because the lesser horseshoe bat maintained mainly its few large maternity colonies occurring in Burgenland.

The reasons why the serotine suffered the highest net roost decrease (almost 60%) and lost almost a half of its former maternity roosts as well as one quarter of the number of adults in maternity roosts, remain unclear. The trend observed in Burgenland is typical for large parts of Austria where the populations have declined sharply during the last decades for unknown reasons.

The species is listed as vulnerable in the last Red List of endangered mammals in this country (Spitzenberger 2005).

Of the six bat species occurring in the attics of large buildings in Burgenland on a regular basis, four are listed in the Annexes II and IV and two species are listed in Annex IV of the Habitats Directive. Our results provide evidence that the conservation status of three species (*Rhinolophus hipposideros*, *Plecotus austriacus* and *Eptesicus serotinus*) has deteriorated in Burgenland since Austria became member of the European Union.

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