The effects of the illumination of buildings on house-dwelling bats and its conservation consequences

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As the illumination of buildings at night increases, light pollution and negative impacts on wildlife also increase. In order to assess the effect of direct lighting on house-dwelling bats, we examined colonies of *Rhinolophus ferrumequinum*, *Myotis emarginatus* and *M. oxygnathus* in illuminated and non-illuminated buildings found in close proximity to each other. We investigated the onset and timing of nocturnal emergence and measured the body mass and the forearm length of juvenile bats. Results show that bright artificial lighting delays the onset or significantly prolongs the duration of emergence and, in the worst cases, may destroy the whole colony. Juveniles are significantly smaller in illuminated buildings than in non-illuminated ones. The differences in length of the forearm and in body mass may suggest that the parturition time starts later and/or the growth rate is lower in bats living in illuminated buildings. Thus, the illumination of buildings could have serious implications for the conservation of house-dwelling bat colonies.

Key words: light pollution, bat, conservation, artificial roost, *Myotis oxygnathus*, *M. emarginatus*

INTRODUCTION

Light pollution resulting from the increasing illumination of the planet by mankind is having an increasing influence on wildlife (Longcore and Rich, 2004; Rich and Longcore, 2006). The ecological consequences of artificial night lighting are becoming increasingly clear (e.g., Fedum, 1995; Borg, 1996; Harder, 2002; Eisenbeis, 2006; Frank, 2006; Montevecchi, 2006). Scientific data shows that this artificial disturbance also influences nature conservation policy and activities (e.g., Eisenbeis and Hassel, 2000; Health Council, 2000; Le Corre *et al.*, 2002; Salmon 2003, 2006).

Ecological light pollution has obvious effects on bats as well as many other diurnal, crepuscular and nocturnal species. Many groups of insects, of which moths are the most well-known, are attracted in large numbers to lights, and bats are quick to take advantage of these concentrations of prey (Rydell, 1991, 2006; Blake *et al.*, 1994; Rydell and Baagøe, 1996a, 1996b; Gaisler *et al.*, 1998; Swensson and Rydell, 1998). However, artificial illumination not only affects the hunting-ground but may also influence roosts and emergence behaviour (Downs *et al.*, 2003). In 2003, we observed that bats did not emerge after dusk from a church which was directly illuminated by

floodlighting. In another case, a colony disappeared after lights had been installed by the local council. If bats can be restricted or deterred by illumination, this must have important implications for bat conservation. The floodlighting of buildings (mainly churches) was not a common practice in villages in Central and Eastern Europe 10 years ago, but recently it has become increasingly common. The aim of such lighting is to emphasize the attractiveness of the buildings. The abundance of house-dwelling bat colonies in Hungary (see Dobrosi, 1996; Matis *et al.*, 2002; Boldogh, 2006) and the many different practices of lighting make the study particularly relevant.

MATERIALS AND METHODS

Emergence Activity

House-dwelling bat colonies were surveyed in the north and south-east of Hungary (Table 1). The species composition and the size of the roosting colonies were determined beforehand by day.

Firstly, to test whether bright lighting causes any differences in emergence activity, we examined the timing of the nightly onset of emergence and the characterics of the emergence behaviour in illuminated (roosts 4 and 6) and non-illuminated buildings (roost 7 — Table 1).

Secondly, we disconnected the lights at the illuminated buildings (roosts 4 and 6 — Table 1) for several days (1–3) so the roost-buildings remained dark and examined the onset of nightly emergence and the duration of emergence behaviour. The temporary elimination of lighting was carried out during the days immediately following the basic investigation, in order to avoid and/or reduce the effect of the lunar cycle and the natural shortening of daylength. The investigations were carried out on days with calm weather to avoid the influence of meteorological factors (strong wind, clouds) on the emergence behaviour. During the investigation bats were counted and identified visually and with the help of an ultrasound bat detector (Mini-3 Bat Detector®).

The Growth of Juveniles

To investigate the effect of lighting on the growth of juveniles, the length of the forearm and body mass of bats in the illuminated and the non-illuminated control buildings were compared (Table 1). Control buildings with the same species and similar condition (same type of roof) were selected. The data were collected in the paired colonies on the same day. To minimize disturbance the young bats were usually measured after their mothers had left the roost at dusk; only one parallel measurement was taken in the daytime on warm days (roosts 1 and 4). Random sampling of juveniles was carried out by hand catch. Measurement of pups was carried out immediately after they were captured. The pups of *R. ferrumequinum* were not investigated considering the sensitivity of this species.

We used callipers for measuring the length of the forearm to the nearest 0.1 mm and a spring scale (Pesola Light-Line 50®) for measuring body mass. The body mass was measured to the nearest 0.1 g. The analysis of the data was performed with SPSS 12.0®.

RESULTS

Emergence Activity

Differences in the emergence activity of the bats in the illuminated and non-illuminated buildings were remarkable. Almost all the bats left the undisturbed roosts in the first 30 minutes after dusk, whereas there was a considerable delay in the onset of emergence in the illuminated buildings where most of the bats remained in the roof until the disconnection of the lights (Fig. 1). Some bats flew out but never totally left the site whilst the lights were on. They re-entered repeatedly, flew back into the darkness of the roof and fluttered inside for a long time. The evidence suggests that we can separate the species by their sensitivity: while several *R. ferrumequinum* and *M. oxygnathus* departed when the lights were on, the great majority of *M. emarginatus* remained behind until it was totally dark.

During the first unlit night, the majority of the colony of *M. emarginatus* emerged at the same time as they had done during the previous illuminated nights whilst the

TABLE 1. The details of investigated roosts and colonies

Roost No.	Locality	Roosting species	Date of experiment	Description of illumination	Measured species
1	Kelemér (N Hungary), church	*Myotis oxygnathus, M. myotis, Plecotus austriacus*	29.06.2006, 16.08.2006	No lights	*M. oxygnathus*[b, c]
2	Alsószuha (N. Hungary), church	*Rhinolophus hipposideros, R. ferrumequinum, M. oxygnathus, M. myotis, M. emarginatus*	27.06.2006, 16.08.2006	All night[a]	*M. oxygnathus*[b, c]
3	Ragály (N Hungary), church	*M. emarginatus*	30.06.2005, 27.06.2006	All night from 01.11.2005[a]	
4	Szőlősardó (N Hungary), church	*M. oxygnathus, R. ferrumequinum*	29.06.2006, 16.08.2006, 17.08.2006	1 hour (after dusk)	*M. oxygnathus*[b, c, d]
5	Komádi (SE Hungary), castle	*M. emarginatus*	16.07.2005		*M. emarginatus*[b, c, d]
6	Geszt (SE Hungary), church	*R. ferrumequinum, M. emarginatus, Myotis dasycneme, P. austriacus*	07–17.07.2003, 15.07.2005	From dusk until 23:30	*M. emarginatus*[b, c, d]
7	Geszt (SE Hungary), castle	*R. ferrumequinum, M. emarginatus, P. austriacus*	07–17.07.2003	No lights	All species[d]
8	Tatárszentgyörgy (E Hungary), church	*M. oxygnathus, Eptesicus serotinus*	13.07.2006	From dusk until 23:00	*M. oxygnathus*[b, c]
9	Mezőberény (SE Hungary), church	*M. oxygnathus, Nyctalus noctula, P. austriacus*	13.07.2006	No lights	*M. oxygnathus*[b, c]

[a] – from dusk until dawn
[b] – body mass
[c] – length of the forearm
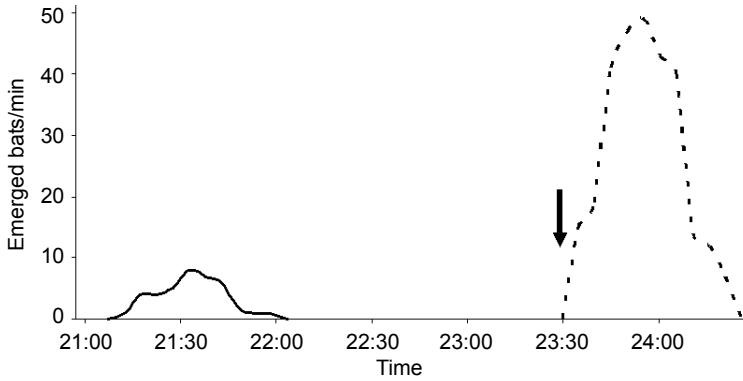[d] – emergence activity

FIG. 1. The nightly emergence activity in *M. emarginatus*, in an illuminated (dashed line, roost number 6, $n = 1460$) and a non-illuminated roost (continuous line, roost number 7, $n = 200$) at the same night (07.07.2003). Arrow shows the time when lights were switched off at the illuminated roost

other species (*M. oxygnathus, R. ferrume-quinum*) flew out earlier. During the second period after the lights had been disconnected, *M. emarginatus* also flew out earlier than they had during the illuminated nights (Fig. 2). *M. emarginatus* was the slowest to adjust to the modified circumstances; *M. oxygnathus* and *R. ferrumequinum* reacted more quickly to the change.

An unfortunate example of the direct effect of illumination was when the largest known *M. emarginatus* colony, consisting of approximately 1,000–1,200 females, left the roost after lights had been installed by the local council; the floodlights poured light directly through the wide exit-hole and completely flooded the loft (roost 3).

The Growth of Juveniles

The forearm length of juvenile bats was significantly shorter in illuminated than in non-illuminated colonies (Table 2). The difference was greatest during the lactation period (Mann-Whitney *U*-Test, $P < 0.001$) and disappeared by mid-September (Mann-Whitney *U*-Test, $P > 0.05$ — Table 2).
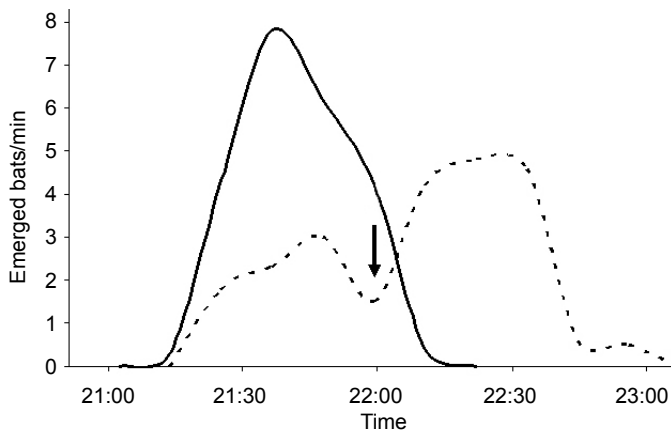

FIG. 2. The nightly emergence activity in *M. oxygnathus* ($n = 230$), during an illuminated (dashed line) (16.07.2006) and the following first non-illuminated night (continuous line) (17.07.2006) at the same roost (roost number 4). Arrow shows the time when lights were switched off during the illuminated nights

The body mass of juveniles was also different between illuminated and non-illuminated colonies. Young bats were larger in dark roosts (Mann-Whitney *U*-Test, *P* < 0.001) and this difference persisted until late summer (Mann-Whitney *U*-Test, *P* < 0.015 — Table 2).

DISCUSSION

Bright artificial illumination negatively affects bats, therefore, the illumination of roosts has serious implications for the conservation of house-dwelling bat colonies. The highest abundance of aerial insects usually occurs around dusk (e.g., Nyholm, 1965; Jones and Rydell, 1994; Rydell *et al.*, 1996); hence bats, especially aerial-hawking bats, emerge from their roosts soon after sunset (e.g., Gaisler, 1963; Herreid and Davis, 1966; Kunz, 1974; Kunz and Anthony, 1996). Our study is consistent with other studies (Erkert, 1982; Kunz and Anthony, 1996) in showing that most bats synchronize the onset of their nightly emergence with sunset. However, we found — correspondingly with Downs *et al.* (2003) — that bright artificial lighting affects the number of bats emerging. Our results even show that lighting delays the onset and the duration of the emergence of bats. Due to such delayed emergence bats miss the highest abundance of aerial insects and lose a significant proportion of their foraging time. In one instance we found that artificial lighting forced the whole colony to leave the roost.

The difference in the length of the forearm may show that the parturition time starts later and/or that the growth rate is slower in bats living in illuminated buildings. Our field observations suggest that both effects occur. The exact time of parturition was not known, therefore, the disparity in age could only be estimated. The length of the forearm can be used for

TABLE 2. The development stages of juvenile bats measured by the length of the forearms (mm) and body mass (g) in the different roosts; *n* — sample size (Mann-Whitney *U*-test)

Species (roost number)[a]	Length of forearm						Body mass					
	Non-illuminated roost		Illuminated roost		U-value	P-level	Non-illuminated roost		Illuminated roost		U-value	P-level
	n	x̄ ± SD	*n*	x̄ ± SD			*n*	x̄ ± SD	*n*	x̄ ± SD		
M. emarginatus (5, 6)[b]	53	35.62 ± 4.13	76	31.43 ± 5.14	906.0	0.001	53	6.07 ± 0.95	76	5.27 ± 1.03	1032.0	0.001
M. oxygnathus (8, 9)[b]	19	54.95 ± 4.72	23	46.28 ± 7.56	67.0	0.001	18	14.65 ± 4.65	23	10.74 ± 3.41	112.5	0.013
M. oxygnathus (1, 4)[b]	18	46.40 ± 8.31	23	36.46 ± 7.84	82.0	0.001	19	20.37 ± 2.77	23	14.01 ± 3.16	29.0	0.001
M. oxygnathus (1, 2)[c]	18	57.57 ± 1.26	14	56.79 ± 1.63	92.5	0.203	18	22.96 ± 1.68	14	19.6 ± 1.47	20.5	0.001

[a] — See Table 1 for roost details and date of measurements
[b] — in the lactation period
[c] — post-weaning period

estimating the absolute age of juveniles during the rapid and linear phase of growth in the first two weeks (Tuttle and Stevenson, 1982; Anthony, 1988; Kunz and Stern, 1995; Reiter, 2004; Sharifi, 2004*a*); correct estimation is more difficult for older juveniles (De Paz, 1986; Kunz and Hood, 2000). Since our research involves data from the initial phase, and the gross growth rate in the initial phase is known in *M. oxygnathus* (Sharifi, 2004*b*) we were able to make a relatively good estimation. However, as Sharifi's (2004*b*) study was conducted at an undisturbed maternity roost, his results could only be used for estimations at the non-illuminated roosts in our research. Another problem is that there is nothing known about the degree of asynchrony at birth in the different roosts which results in an even more complicated and questionable estimation. Regarding these experiences, we used the detected differences in the length of the forearm only for a rough estimation of disparity in age between the illuminated and non-illuminated colonies. The estimated disparity is at least 7–10(11) days. We had one concrete observation at the early stage of the parturition, when only pregnant females and neonates were found at the illuminated roost while the undisturbed roost had well-developed young. This apparently indicated that birth had been delayed in illuminated buildings.

In natural conditions the growth rate of the forearm in *M. oxygnathus* reaches the plateau about 35–40 days after birth (Sharifi, 2004). Similar rapid progress has also been reported in other free-ranging and captive insectivorous bats in the temperate zone (e.g., Kleiman, 1969; O'Farrell and Studier, 1973; Burnett and Kunz, 1982; Kunz and Anthony, 1982; De Fanis and Jones, 1995; Kunz and Stern, 1995; Swift, 2001; Reiter, 2004). Since we did not find significant differences in the length of forearms between the two different roosts at the end of

summer, it suggests that the individuals at the light-disturbed roosts had also already reached the normal length of the forearm by that time. This equalization may be caused by compensatory growth which has also been reported in other studies (Hoying and Kunz, 1998; Kunz and Hood, 2000). The question of how much the variation is due to different dates of birth and how much to the different rates of growth, is one which deserves further investigation.

In young bats body mass growth rate reflects environmental conditions more responsively than the growth rate of forearms (Kunz and Robson, 1995). The lower availability of insects to lactating females owing to the illumination of roosts, directly leads to lower body mass in juveniles. This is a similar effect to that of bad weather during the maternity period (Kunz and Robson, 1995; Hoying and Kunz, 1998; Kunz and Hood, 2000; Reiter, 2004). The present study shows that in illuminated colonies the body mass remains reduced even after the weaning season. The juvenile bats concerned could probably not compensate for their early disadvantage and/or they had deposited less fat by mid-September. Since hibernation success mainly depends on the body mass achieved, the illumination of maternity roosts may reduce the hibernation success of young bats. Whereas, the earlier born individuals have higher survival rates compared to the ones were born later (Ransome, 1998), the bats born in unlit roosts may have an advantage over those who were born in the illuminated ones.

The conservation strategy for maintaining important house-dwelling colonies is clear: to eliminate direct illumination totally during the whole reproductive season. According to our results, reducing the hours of illumination in the night has little effect: even a one-hour long lighting period after dusk causes significant disruption in behaviour and growth. Summer nights are short in

the temperate zone and even shorter further north, so any artificial reduction in foraging time is disadvantageous.

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