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Occupation of crevice-type nest-boxes by the forest-dwelling western barbastelle bat *Barbastella barbastellus* (Chiroptera: Vespertilionidae)

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Abstract. We studied the occupation of crevice-type roosting boxes developed especially for barbastelle bats *Barbastella barbastellus* (Schreber, 1774). Some 290 of the boxes were installed (in groups of five) in six study areas located in Poland in forests of different tree species composition. Colonization of boxes took place in the first summer season after installation. Two years after installation, a high rate of occupancy was recorded (up to 100 % groups of boxes, depending on the area). The total number of bats involved was 478, 72 % of which was the target species. Occupancy rates were highest in oak stands and lowest in those dominated by Scots pine. In all but one of the study areas, barbastelles founded colonies (and in part at least breeding colonies) in the boxes of this type. The overall ratio of the number of barbastelle colonies to the observation of individuals/small groups is 32.4 % to 67.6 %, respectively. The use of such boxes thus provides the active protection of the bat in question, and the effective study of its populations.

Key words: bats, crevice bat-boxes, forest type

Introduction

The loss of trees with holes and other types of natural cavities (like trunk and bark crevices) is a key factor in habitat deterioration for many forest-dwelling animal species, including bats (e.g. Marsden & Pilgrim 2003, Lindenmayer et al. 2010, Cockle et al. 2011). Tree holes excavated by woodpeckers (*Picidae*), as well as other cavities provide typical summer shelters utilized by bats in temperate-zone forests. Thus the loss of such places of shelter as well as the loss of food resources are key factors threatening the persistence of bat populations, given that the cavities in question offer protection against predators, as well as breeding and rearing sites (Kunz & Fenton 2003).

Unfortunately, the process by which cavities in trees form naturally is an extremely protracted one (Gibbons et al. 2000, Vesk et al. 2008), while forestry practice (even if sympathetic to the retention of some cavity-trees in the stand) is less sympathetic to leaving in place standing dead trees that represent the source of many natural holes (e.g. Referowska-Chodak 2014).

The standard method by which to achieve at least a short-term increase in numbers of available shelters for bats involves the installation of bat boxes in tree stands. These may be constructed in a variety of different ways (Issel & Issel 1955, Zaborowski 1976, Stebbings & Walsh 1991). However, specific requirements as regards places of shelter and concealment have thus far ensured that the protective measure in question does little or nothing to improve habitat for barbastelle bats.

The barbastelle tends to find shelter in old broadleaved stands, mainly in oaks, beeches and hornbeams. It eschews the cavities excavated in trees by

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woodpeckers, instead making use of natural splits and crevices in the trunks of broadleaved trees, as well as gaps behind patches of bark detaching gradually from dying trees, and crevices formed in the forks of trunks (Spitzenberger 1993, Kowalski et al. 1996, Rydell & Bogdanowicz 1997, Sierro 1999, Hermanns et al. 2003, Russo et al. 2004, Manias & Ignaczak 2008, Hillen et al. 2010, 2011). It is quite common for such shelters to be found in dead trees, which in fact have the potential to ensure far more places of concealment of the required type. In beech forests in central Italy, 20 out of 33 day shelters noted for barbastelles were in dead trees, while eight were in trees with half-dead boughs, and a further five were in trees whose boughs were largely dead (Russo et al. 2004). During summer, barbastelles are sometimes found in wooden buildings, behind shutters, or in crevices in bridges (Rudolph et al. 2003, Sachanowicz et al. 2004, Wojtaszyn et al. 2008, Kühnert et al. 2016, Gottfried et al. 2017). However, the results obtained in the Białowieża Forest (the largest remnant of natural lowland European forests) suggest that barbastelle use of this type of shelter is secondary, and results from a shortage of natural shelters. This confirms the status of this species as originally a typical forest bat (Rachwald et al. 2017b).

Barbastelle often change their shelters during the summer. During pregnancy and lactation, shelters are changed, on average, from every 3.5 days (Russo et al. 2005) up to every 7.4 days (Kühnert et al. 2016). Barbastelle colonies usually are divided between several sub-colonies spread across the surrounding forest (Willis & Brigham 2004), although the main colonies also move (Russo et al. 2005). In general, the flexibility of colonies may be associated with both avoidance of predation, with parasite load and with the instability of the shelters themselves, because hiding places under the bark do not last too long. According to Russo et al. (2005), a single group of barbastelles used ca 18 different trees for one month.

The barbastelle is an endangered species that enjoys species protection in EU countries and requires active conservation measures if it is to persist. This reflects its ecological links with a type of forest environment that is itself threatened and is thus subject to protection in Natura 2000 areas. On the IUCN Red List (2017 and 2018 – 3.1), this species is assigned to the Near-Threatened (NT) category. In Poland, this bat is not very common, has an uneven distribution, and is in general of DD ("data deficient") status (Głowaciński 2002, Gottfried et al. 2015). For all of these reasons, it is very much indicated that protective measures be devised and put into effect to ensure an improvement in the quality of suitable habitat, and hence an improved conservation status for the barbastelle.

To this end, work began in 2014 as part of a project implemented jointly by the Forest Research Institute (Poland) and the University of Wrocław. This entailed the installing of a new type of bat box specifically for the barbastelle, given that it is considered to better imitate the natural cracks the species favours. The project drew on solutions arrived at in the United Kingdom by F. Greenaway (see Greenaway & Hill 2004). The project thus sought to determine if colonization by barbastelles of this new design of box would take place, and if the barbastelles would found breeding colonies in these artificial shelters. A further aim was to determine whether boxes of the type on trial might be applied as an active conservation measure for barbastelle.

Material and Methods

The research made use of boxes that were a simplified version of those designed by F. Greenaway. The dimensions of the boxes were as follows: height 80 cm, width 16 cm, roof 17 × 17 cm, board thickness 2.5 cm, the distance between vertical elements (crevice) 2 cm (Fig. 1).

Areas in which different types of forest are present were selected for the trials. Specifically, these forests were of oak, beech, and pine, as well as mixed. The boxes were put up in the August 2014-March 2015 period in six areas in Poland (Fig. 2). They were (in SW Poland): Uroczyska Płyty Krotoszyńskiej (i.e. Krotoszyńskie Oaks – a site in Krotoszyn Forest District); Wrzosowiska Przemkowskie (in Przemkowski Landscape Park, and administered by Przemków FD); Muszkowicki Forest (in Henryków FD); Czeszowska Plain (in Oleśnica Śląska FD); as well as areas in central Poland (Mazowsze region) – i.e. Chojnowski Landscape Park (south of Warsaw, in Chojnów FD) and Naruszewskie Oaks (east of the River Wisła, Naruszewo Area of Protected Landscape). In terms of their dominant tree species, the study areas are as follows: 1) Krotoszyńskie Oaks – oak, 2) Przemkowski LP – Scots pine, 3) Muszkowicki Forest – beech, 4) Czeszowska Plain – mixed forest with no clearly-dominant species, 5) Naruszewskie Oaks – oak, 6) Chojnowski LP – mixed forest with no clearly-dominant species.

A feature of all the areas selected was that barbastelles had been recorded in them previously (by means of ultrasound recording or netting). Boxes were installed in forest on the basis of consent given by the forestry

administration, as well as the authorities associated with nature conservation management within the Landscape Parks and Natura 2000 sites.

In each area, 50 boxes were installed – in groups of five arranged as a quincunx, with side lengths of around 15 m (adjusted in line with actual conditions in the field). This denoted that each area received ten groups of boxes (or had ten "points"), with these, 200-600 m distant from each other. An exception was the Muszkowicki Forest area, in which just 40 boxes (eight groups of five) were located. Boxes were attached to trees at a height of four meters, usually along forest compartment boundary roads, though at some distance (up to 30 m) in from the road edge.

The idea to group boxes arose from the fact that barbastelles (like such other species as Bechstein's bat *Myotis bechsteinii* (Kuhl, 1817) make frequent changes of location of their breeding colonies (Russo et al. 2005, Kühnert et al. 2016). The assumption was thus that a larger number of extra roost sites in close proximity would be required by the bats. This had further consequences for the processing of results, given that the unit (or point) under consideration is most often the group of five boxes rather than the single box.

In south-western Poland, the boxes were installed in the field in autumn 2014, with checks initiated in 2015; while in the central part of the country the boxes were installed in spring 2015, with checks beginning in 2016. Checks were carried out three times in the course of a season (in June, August, and October), with the monitoring effort beginning in the calendar year following the one in which boxes had been installed. Each of the six areas was checked for the subsequent two years.

The division of reports adopted for the purposes of analysis involved the two categories of: 1) colonies of bats (5 or more animals in a box); 2) lone individuals or small groups (< 5 in a box).

Thus groups of five or more bats present in a box were categorized as colonies, though with precise status not determined in most cases, with the possibilities being bachelor groups (Ruprecht 1976), or groups of individuals that would not go on to breed at all. To try and verify the status of such groups, one further evening examination of each box in which a group of barbastelles had been noted was made in the Czeszowska Plain area (in June). Such observations, made when adults had left for their night flights allowed the presence of non-flying young remaining behind to be observed. The status of groupings as breeding colonies was confirmed in this way.

As summary results from more than one check are given, the terms "recorded" or "observed" are resorted to (as opposed to "number of bats"), because consecutive monitoring sessions during one season most probably re-recorded the same individuals and groupings of bats to a great extent. This leaves it more correct to refer to recording or observation than to an absolute number of animals in a given area by simply summing up the individuals observed during subsequent inspections.

Boxes were checked from the ground, with the aid of a hand-held lamp plus binoculars or a camera with a telephoto lens. This made it possible to identify barbastelles to species level, and other bats to the level of the species, a group of species or genus, without any major disturbance of the bats in the boxes. The results presented derive from two years of work in the case of each study area. Statistical analyses were carried out using the R 3.5.1 programme, as well as Python Statistic.

Fig. 1. Crevice bat-box in its natural habitat.

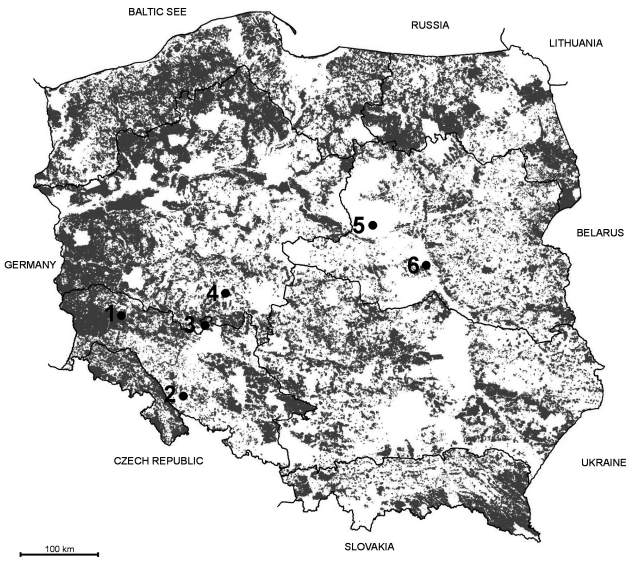

Fig. 2. Research areas on the background of the map of forestation of Poland. 1 – Muszkowicki Forest, 2 – Czeszowska Plain, 3 – Krotoszyńskie Oaks, 4 – Przemkowski Landscape Park, 5 – Naruszewskie Oaks, 6 – Chojnowski Landscape Park.

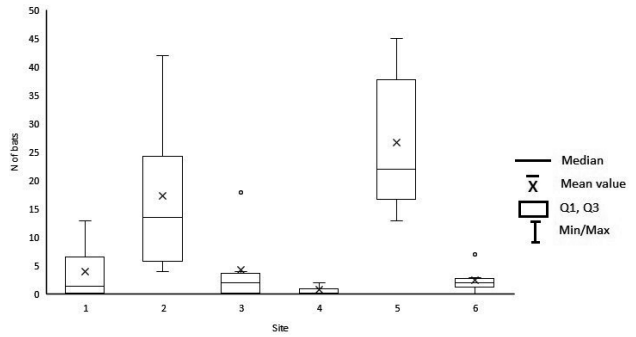

Fig. 3. Comparison of the occurrence of barbastelles in different areas, with data from the two seasons taken together, and with overall reports of all animals in each area being compared. 1 – Muszkowicki Forest, 2 – Czeszowska Plain, 3 – Krotoszyńskie Oaks, 4 – Przemkowski Landscape Park, 5 – Naruszewskie Oaks, 6 – Chojnowski Landscape Park.

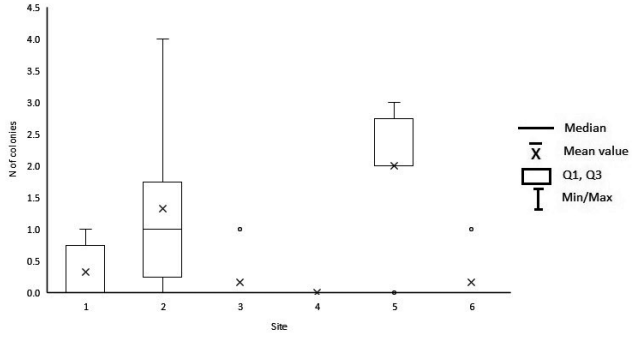

Fig. 4. Numbers of observations of colonies of barbastelles in different study areas, as noted in the course of six checks during the two first seasons of study following the one in which boxes were placed out in the forest. 1 – Muszkowicki Forest, 2 – Czeszowska Plain, 3 – Krotoszyńskie Oaks, 4 – Przemkowski Landscape Park, 5 – Naruszewskie Oaks, 6 – Chojnowski Landscape Park.

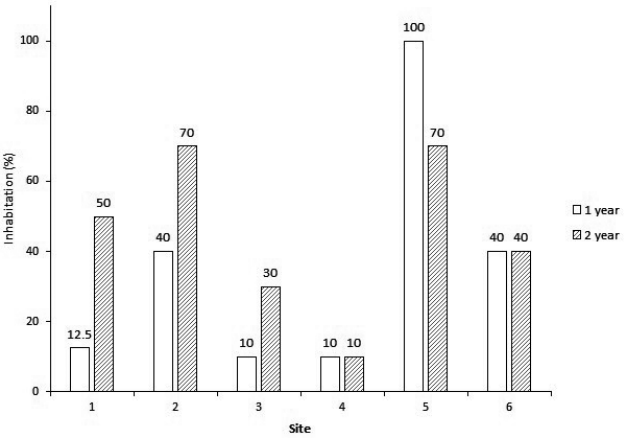

Fig. 5. Year-on-year (percentage) change in the occupation of points in the different study areas by barbastelles. Data are combined for occupation through the season as a whole. 1 – Muszkowicki Forest, 2 – Czeszowska Plain, 3 – Krotoszyńskie Oaks, 4 – Przemkowski Landscape Park, 5 – Naruszewskie Oaks, 6 – Chojnowski Landscape Park.

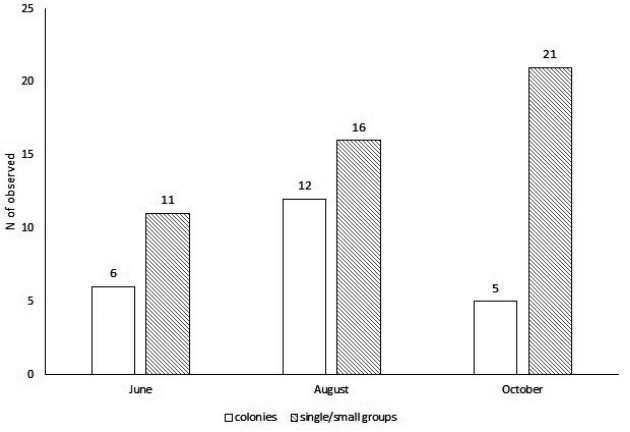

Fig. 6. Comparison of season-to-season variability (between checks) in terms of the occurrence in boxes of colonies of barbastelles and of specimens in the single/small group category, in the course of the two research seasons (summed data from the separate reports made each month).

Results

The type of box on trial was occupied by barbastelles in the first season of activity following installation in forests. However, the process of occupation was not uniform, with differences noted most likely associated with dominant tree species present. The result of the Kruskal-Wallis H-test was h = 20.792 ($p < 0.005$), with the post-hoc Dunn-Bonferroni test, revealed significant results for the Czeszowska Plain/ Przemkowski LP comparison ($p < 0.05$), as well as that between Naruszewskie Oaks and Przemkowski LP ($p < 0.005$). Remaining pairings did not differ significantly (Fig. 3).

Among the six study areas, two had boxes with colonies of barbastelles in the first research season, while four areas yielded positive reports in the second

Table 1. Breakdown by species and number of reported bats occupying boxes through the study period in the different study areas. "Indet" denotes an unidentified bat (albeit with the possibility of it being *B. barbastellus* excluded).

	Muszkowicki Forest	Czeszowska Plain	Krotoszyńskie Oaks	Przemkowski LP	Naruszewskie Oaks	Chojnowski LP	Total
Barbastella barbastellus	24	111	26	5	160	19	345
Pipistrellus nathusii	2	11	9	2	0	0	24
Myotis mystacinus/ brandtii	6	1	7	12	0	0	26
M. nattereri	0	0	0	1	0	0	1
Nyctalus noctula	0	5	0	1	0	0	6
Pipistrellus pipistrellus/P. pygmaeus	0	27	2	0	0	0	29
Pipistrellus spp.	0	11	0	0	4	7	22
Eptesicus serotinus	0	1	0	0	0	0	1
M. daubentonii	1	6	7	1	0	0	15
Plecotus auritus	0	0	0	1	2	3	6
Myotis spp.	0	0	0	0	2	6	8
Indet	0	1	0	0	0	0	1
Total	33	174	51	23	168	35	478

season. Observations made once adults had flown from boxes on the Czeszowska Plain allowed the presence of the young in the shelters to be confirmed, which supported the view that boxes contained breeding colonies.

While groupings were observed in forests of various different site types, most colonies over the two research seasons were associated with boxes in the Naruszewskie Oaks area (n = 12). The only habitat in which no colonies of barbastelles were found in the boxes was pine forest (in Przemkowski LP). In these circumstances, differences between areas in terms of the distribution of colonies achieved statistical significance (Kruskal-Wallis H-test, h = 16.5875, $p < 0.05$; post-hoc Dunn-Bonferroni test, $p < 0.05$ for the Naruszewskie Oaks/Przemkowski LP pairing. Other combinations did not reveal statistically significant differences (Fig. 4). The year-on-year comparison did reveal differences (typically greater numbers of bats in the second season). Only in the Naruszewskie Oaks area was the reverse trend noted, though here the overall level of occupancy was anyway very high (Fig. 5).

Across the different study areas taken together, there were no significant changes in occupancy from one year to the next, with the August t-test figure (coinciding with the highest level of occupation) being t = 1.581 ($p = 0.175$). Given this lack of significant differences, further comparisons were based on data for the two years combined.

At least nine bat species were found in the boxes (some of them unidentified to the species level, Table 1) with a total of 478 bats (individual specimens and from colonies altogether) with 72.2 % of these (n = 345) identified as barbastelles. The only area in which the species in question accounted for a minority of the bats found was Przemkowski Landscape Park (Fig. 1). This was also the area in which the smallest overall number of bats was reported from the boxes (Table 1).

In most cases, single bats were recorded in the boxes. Larger groups of individuals or colonies consisted solely of barbastelles, or else individuals of *Pipistrellus* species (though with no more than five bats present together in the latter case). The progression of the summer season was characterized by certain differences between the appearance of colonies and single specimens of the barbastelle. Over two seasons, observations showed that the latter species was most likely to be present in colonies at the beginning or middle of the season (peaking in August), with a decline noted subsequently. In contrast, the number of single specimen observations rose uninterruptedly through to October (Fig. 6). The overall ratio of the number of barbastelle colonies to the observation of individuals/small groups is 32.4 % to 67.6 %, respectively.

The observed differences did not achieve statistical significance in this case (t-test, t = –2.301, $p = 0.08$),

perhaps because the sample size was too small. However, significant differences in the level of occurrence of all barbastelles taken together were noted over the season, i.e. between checks (one-way ANOVA, $f = 3.947$, $p < 0.05$).

Discussion

As has been alluded to, there are very few reports of barbastelles being found in bat boxes of any kind in forests. Exceptions relate to reports of these bats in boxes reported as "very similar to the Stratmann FS1 type" installed in Czech forests, which were once even found to support a breeding colony of barbastelles (Chytil 2014). Relevant data published in Poland include only one report of the species being present in a typical bat-box (Błachowski 2011).

The results detailed here confirm unambiguously that the boxes of the crevice types tested are readily occupied by barbastelles. Furthermore, the findings for the two years of trials attest to a marked preference for boxes of the new design being shown specifically by barbastelles, as opposed to the other species present in the same study areas (Table 1). This is a desirable result, given that remaining species colonize boxes of other designs. In several decades of observations on the summer colonization and occupation by bats of bat boxes as well as bird boxes, reports of the barbastelle have tended to be at best incidental and at worst absent altogether, in favour of other species of bats, e.g. from the genera *Pipistrellus* and *Myotis* (e.g. Stebbings & Walsh 1991, Błachowski 2011).

It is further important that, even in the first season, barbastelles occupying the crevice-type boxes establish colonies in them – a fact that must be considered to augur well for the effective longer-term conservation of the species in question. The level of occupation of boxes by the bats was higher in most areas in the second year of monitoring than in the first (Fig. 5). Given that bats are usually quite slow to colonize boxes – to the extent that these often remain unoccupied even several years after installation (or are in fact never colonized, e.g. Krzanowski 1961) – the results obtained here indicate that the boxes used in this trial represent highly-attractive shelters for barbastelles.

Notwithstanding the rather short duration of the trial described here, it was possible to observe differences in the colonization of boxes between forest areas of differing stand composition (Fig. 3), as well as differences between the study areas where the tendency to found colonies was concerned (Fig. 4). Furthermore, these differences can be regarded as a genuine reflection of habitat preferences known for the species under study, in particular its preference for old deciduous, especially oak forests (np. Sierro 1999, Hillen et al. 2010, 2011). Though it is interesting to note that barbastelles were even reported from boxes placed out in the species' least-preferred habitat of pine forest (Przemkowski Forest). The pine forest is still the main economic woodland type in continental Europe, but is characterised by a relatively small number of dead standing trees and natural bat shelters. Our data confirm results of Greenaway & Hill (2004) and suggest a role for the new-design boxes in raising the level of attractiveness (and potentially, therefore, barbastelle population sizes) in habitat sub-optimal for the species on account of tree species composition or the young age-classes characterizing stands. This is obviously a key matter warranting further study.

The differences in the sizes of bat groupings in boxes observed in the course of the season probably reflect a phenological phenomenon. Larger groupings (of more than five individuals) are probably mainly breeding colonies. Before the beginning of October, larger groups have usually splintered, with the result that the proportion of all reports involving single individuals is greater in the third period (Fig. 6). This implies that barbastelles use the available shelters, not only to found breeding colonies but also as a shelter through the whole period over which they remain active. This idea is supported by the observation that single bats may be present in the boxes as late as in November (Rachwald et al. 2017a).

The main aim of the deployment of bat boxes in trees is to achieve bat conservation in transformed forests that lack old trees, and hence natural places of shelter. The work presented here makes it clear that, if boxes of the crevice type are placed out in the habitat, an increase in the number of places of shelter suitable for barbastelles can be achieved. The use of boxes constructed in this way is, therefore, proposed as a conservation measure, given that it brings about an improvement in habitat conditions for barbastelles where the natural shelters for which individuals of this species show a preference is lacking. Action of this kind may, for example, be undertaken in forest areas included within the Natura 2000 network, where barbastelles are the subject of protection measures, and where other suitable means of active protection are lacking.

The boxes trialled here also represent an instrument favourable to scientific research, given that a great deal of information on the presence of other species of bats in Europe's forests is gained by studying those

individuals occupying standard boxes designated for either bats themselves or birds (e.g. Heise 1983, Rachwald 1992, Meschede et al. 2002, Ciechanowski 2005, Chytil 2014). Barbastelles have been largely excluded from these findings up to now, so the discovery of a kind of box they inhabit will not only help protect the species but will also – finally – facilitate more in-depth research of an ecological or ethological nature, as well as allowing for more generalized summer monitoring.

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