Performance of artificial maternity bat roost structures near Bath, UK

Lincoln Garland[1]*, Mike Wells[1] & Steve Markham[2]

[1] *Biodiversity by Design Ltd, Waterhouse, Waterhouse Lane, Monkton Combe, Bath, BA2 7JB, UK*
[2] *Marquis and Lord, 13 John St, Stratford-upon-Avon, CV37 6UB, UK*

SUMMARY

Surveys were undertaken in 2010 to assess the potential impacts on maternity roosts of brown long-eared bat *Plecotus auritus* and common pipistrelle bat *Pipistrellus pipistrellus* before the demolition and redevelopment of a converted farm house and associated outbuildings in the Cotswolds Hills near Bath, UK. As all bat species and their roosts are afforded statutory protection in the UK, a licence was required before the buildings could be demolished. This licence required the construction of two new purpose-designed bat structures in compensation, with the specific goal being the re-establishment of the displaced maternity colonies. Separate bat house and bat wall structures were completed by early spring 2011 with the primary purpose of attracting void-dwelling brown long-eared and crevice-dwelling common pipistrelle bats respectively. Roosting brown long-eared bats established in the Bat House from late 2012, with observed numbers peaking at 20-25 in summer 2013, indicating that a maternity colony had probably re-established. Although a common pipistrelle maternity roost had not established by 2017, small numbers of common pipistrelles were using features within both the bat house and bat wall.

BACKGROUND

Bats require different roosting conditions at different times of the year, therefore they typically move around during the year to find the conditions that satisfy their specific seasonal needs. A maternity roost is where female bats gather together into a maternity colony between late-spring and mid-summer to give birth, nurse and wean their pups. Maternity roosts are of particular conservation importance as they can be critical to the viability of a species' local population; female bats often congregate from across a wide area to form a single colony for this purpose.

Artificial bat roosts can be provided to enhance opportunities for roosting bats or to compensate for the loss of a roost as a result of development. Purpose-built maternity roosts (as opposed to roost modifications) require more care in their design and positioning than other artificial roost types, and they are often larger and more elaborate structures. Due to the greater challenges involved in re-creating maternity roosts, and perhaps because of the added cost, there have been few purpose built maternity roost successes (Mackintosh 2016). The UK study by Mackintosh, which investigated the success of maternity roost compensation measures, found that *'the majority of roosts provided for maternity colonies as compensation for loss and/or damage of a roost through development work were not being used (at least in the short-term)'*. Brown long-eared bats are particularly discerning in terms of roost site selection (Entwistle *et al*. 1997) and only limited success has been reported for this species with respect to the take-up of artificially constructed maternity roost structures (Bat Conservation Trust 2017).

Before the demolition and redevelopment of a former farmhouse and associated outbuildings in the Cotswolds Hills near the city of Bath in the UK, surveys were undertaken in 2010 assessing the potential impacts on bats known to be roosting within the buildings. In summary, pre-development bat surveys entailed day-time inspections of external and internal features to determine roost potential and identify physical evidence of bat presence; evening roost emergence / dawn roost re-entry surveys using hand-held detectors (data were also recorded and subsequently analysed for identification to species / species group level); and bat activity surveys (recording of active bats outside of roosts) to provide vital context (local bat foraging and commuting behaviour / distribution). Further information on pre-development survey methods and results is provided in Tables 1 and 2.

A brown long-eared bat maternity roost was identified in the loft of the inhabited former farm house, and a common pipistrelle maternity roost was found in an east-facing stone constructed gable wall (triangular portion of a wall between the edges of intersecting roof pitches) of an adjacent uninhabited cottage (Figure 1). There were at least 8-12 brown long-eared bats (two individuals recorded with pups) and 76 common pipistrelle bats. These are the two species most frequently encountered in households by Natural England (the government adviser for the natural environment in England) roost visitor volunteers according to records collated from 2013 (National Biodiversity Network 2017). A lesser horseshoe bat *Rhinolophus hipposideros* and greater horseshoe bat *Rhinolophus ferrumequinum* night roost was also found within a nearby carport structure.

All three buildings were scheduled for demolition in late winter 2010-2011. In the UK all bat species and their roosts are legally protected under domestic and European legislation. A European Protected Species (EPS) development licence was therefore sought from Natural England before building demolition could be legally carried out. The licence was granted but required the construction of two new purpose-designed bat structures in compensation, recognising the specific requirements of the two main species (brown long-eared bats and common pipistrelles) which are primarily void-roosting and crevice-roosting species respectively. When designing

*To whom correspondence should be addressed: lincoln.garland@biodiversitybydesign.co.uk

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Table 1. Bat surveys of original roost structures.

Survey dates	Survey method	Summary results
Brown long-eared bat roost		
12/02/2010	Daytime inspection by 2 surveyors; N.B. survey by separate consultancy prior to author's involvement.	1000s droppings piled deep and of mixed age from long-eared bats and strong smell of urine/droppings suggesting presence of a maternity roost in loft.
17/06/2010	Dusk emergence survey undertaken by 2 surveyors prior to author's involvement.	Anecdotal report of brown long-eared bat roost but no written reports made available to authors.
23/06/2010	Ditto survey of 17/06 but 4 surveyors present.	Ditto results of 17/06.
21/07/2010	Daytime inspection by 2 surveyors.	In loft 1000s of droppings piled deep and of mixed age from long-eared bats and strong smell of urine/droppings. 7 brown long-eared bats counted but probably more present; included 2 nursing brown long-eared bats with their pups.
21/07/2010	Dusk survey using time expansion bat detectors (Pettersson D240X®); calls recorded to minidisk and later analysed using Batsound 3.3 software; 4 surveyors + Anabat.	2 brown long-eared bats recorded emerging.
05/08/2010	Ditto survey of 21/07.	7 brown long-eared bats recorded emerging.
02/09/2010	Ditto survey of 21/07.	8 brown long-eared bats recorded emerging.
03/09/2010	Ditto survey of 21/07 but undertaken at dawn.	8-12 brown long-eared bats returning including swarming behaviour.
Common pipistrelle roost		
12/02/2010	Daytime inspection by 2 surveyors; N.B. survey by separate consultancy prior to author's involvement.	Anecdotal report of pipistrelle droppings on external stonework but no written reports made available to authors.
27/05/2010	Dusk survey by 2 surveyors; N.B. survey by separate consultancy prior to author's involvement.	Anecdotal report of a common pipistrelle maternity roost but no written reports made available to authors.
21/06/2010	Ditto 27/05.	Ditto 27/05.
22/06/2010	Ditto survey of 27/05 but undertaken at dawn.	Ditto 27/05.
21/07/2010	Internal; 2 surveyors.	Two fresh pipistrelle droppings on external stonework.
21/07/2010	Dusk survey using time expansion bat detectors (Pettersson D240X®); calls recorded to minidisk and later analysed using Batsound 3.3 software; 2 surveyors.	76+ common pipistrelle bats emerged from gaps in stonework. Majority flew into or along nearby wooded bank (adjacent to the subsequently constructed artificial bat structures). Due to confidence in presence of maternity roost subsequent survey effort was concentrated elsewhere around farm complex.

N.B. surveys before 21/07/2010 were undertaken by a separate consultancy, full results from which have not been made available to the authors.

Figure 1. A brown long-eared bat maternity roost was originally present in the inhabited former farm house loft void (image left), while a common pipistrelle maternity roost was present in the cavities/crevices of an adjoining stone constructed cottage wall (image right).

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Table 2. Bat activity surveys undertaken across landowner's owner's estate to provide context prior to the roost demolitions.

Site-wide activity surveys	• To characterise species and identify key foraging and commuting habitat. • Survey dates: 27/5/2010; 17/6/2010; 28/7/2010; 29/7/2010; 10/8/2010; 11/8/2010; 27/9/2010; & 28/9/2010. • 2 surveyors on each occasion; 2 Anabat detectors used during final three surveys. • Pre-defined transects walked including all woodland edges and connecting features such as hedgerows and vegetated banks/ditches.
Site description:	• Farm building complex lies just below the 200 m contour and is set in a c. 30 ha private estate on a north-facing valley slope. • Most of estate managed under a Countryside Stewardship Agreement aimed at conserving/enhancing limestone grassland. • Mostly semi-improved cattle-grazed pasture, a few small pockets of which are reasonably species-rich. • Most fields enclosed by mature and relatively species-rich hedgerows. • Recently planted broadleaved woodland has enlarged a long-standing narrow band of woodland wrapping around southern side of the farm complex. • Estate is bounded by Ancient woodland and secondary broadleaved woodland on north-eastern and eastern sides respectively. • Stream emerges from a spring near the farmhouse and flows down to the estate's northern boundary.
Summary of bat activity	• 186 bat passes from six most recent surveys. • Band of woodland directly to south of the farm complex was a key commuting route, being heavily used by bats radiating out from the farm complex at dusk; ultimately the artificial roost structures were positioned adjacent to this feature. • Recorded species along this particular corridor were common pipistrelle, soprano pipistrelle, brown long-eared bat and serotine *Eptesicus serotinus* bats. • Various myotid *Myotis* spp. bats were recorded commuting towards the farm complex from the valley bottom at dusk. • In valley bottom pipistrelles, serotine, noctule *Nyctalus noctula* and various myotid bats were frequently recorded foraging in cattle grazed fields. Myotid species, lesser horseshoe bat and brown long-eared bat activity was also concentrated along treelines and hedgerows.

N.B. surveys before 28/07/2010 were undertaken by a separate consultancy, full results from which have not been made available to the authors.

Figure 2. New purpose-designed 'L' shaped Bat House including a sloping gable roof (longest section is east-west aligned); visible roost features include bat tiles, ridge beam access points, wall-integrated 2FR Schwegler Bat boxes, hanging tiles, and wall mounted climber planting.

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Figure 3. New purpose-designed Bat Wall constructed on the east-facing gable wall of an existing hay barn; includes multiple crevices between the stonework leading to internal cavities and five wall integrated 1FR Schwegler Bat boxes.

structures for these species, the needs of the other bat species recorded on site also had to be carefully considered and accommodated. The two new roost structures were completed in early spring 2011. This paper describes the design features of the two structures and the results of monitoring surveys undertaken to determine their success in re-establishing the displaced maternity colonies.

ACTION

Under EPS licence two new purpose-designed bat structures were built to compensate for the loss of the two maternity roosts. These were:

- A Bat House with the primary purpose of attracting void-dwelling brown long-eared bats (Figure 2).
- A Bat Wall with the primary purpose of attracting crevice-dwelling common pipistrelle bats (Figure 3).

The structures are 20 m apart and located 30 m from the original roost location. The Bat House is a free-standing structure while the Bat Wall is built onto the east-facing gable facade of an existing hay barn. The structures are directly adjacent to a wooded bankside, which was identified from activity surveys as a key destination for bats emerging from the original roosts (Table 2 and Figure 2).

The key considerations when designing the new structures were: ensuring close proximity to the original roosts; replication of their shape, aspect and size as far as practically possible; re-use of materials; provision of artificial heating; and provision of the structural complexity needed to maximise micro-climatic variation. The various design features of the two structures that reflect these considerations are described in Tables 3 and 4.

Given the local presence of foraging / commuting horseshoe bats and due to the loss of a horseshoe bat night roost caused by the redevelopment, features were also incorporated into the new Bat House to specifically accommodate their requirements, and ideally achieve overall enhancement for these species. These features and others included to attract other species of bat are also described in Table 3.

Monitoring: The EPS licence committed the landowner to undertake five monitoring sessions over a ten-year period to determine the success of the new Bat House and Bat Wall in re-establishing the brown long-eared and common pipistrelle bat maternity roosts. The authors are continuing to undertake additional visits (early afternoon daytime inspections) to supplement the findings. Survey work undertaken in each year typically includes three separate day-time inspections of the structures; one winter visit checking for evidence of hibernating bats - principally horseshoe bats, and two evening emergence surveys using hand-held detectors (duration 2.5 hours, starting 15 minutes before sunset). During emergence surveys, a single surveyor using a hand held detector has been able to comprehensively cover the Bat Wall. The Bat House is covered by two surveyors, but this does not provide full coverage of potential exit points. Surveyor positions have been varied between visits to partly compensate for this. Funding limitations have prohibited more comprehensive emergence surveys, though it is the internal inspections which constitute the key means of determining whether a brown long-eared bat maternity roost has re-established in the Bat House. Survey dates and further information on survey protocols are provided in Table 5; an additional 1.5 monitoring years will be completed before 2021.

CONSEQUENCES

The results of the monitoring to date are summarised in Table 5. Roosting brown long-eared bats and/or fresh brown long-eared bat droppings were observed each year from 2012, with observed numbers peaking at 20-25 individual bats in August 2013 (Figure 4). No clearly identifiable juveniles were observed. While observed brown long-eared bat numbers were lower in 2014-2017 (Table 5), during each visit substantial numbers of fresh droppings / dropping clusters were recorded (up to c. 1000+ droppings). During the last two years the strong distinctive odour associated with a well-used roost was also evidnt.

Small numbers of common pipistrelle bats were found to be utilising the Bat House three months after its completion and then the Bat Wall from 2012. Bats have been observed emerging from the hanging tiles, integrated bat boxes, roof tiles and crevices in the stonework.

As of the end of winter 2016-2017 there was no evidence to show that any bat species had used the new structures for hibernation. No horseshoe bats have been recorded to date within or emerging from the Bat House.

Figure 4. Probable brown long-eared bat maternity roost in the roof void of the Bat House of 20-25 individuals (2013).

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Table 3. Bat House design features

Design feature	Bat House
Shape	• Single storey windowless structure with a sloping gable roof. • 'L' shaped building arrangement replicates the original roof/loft space and associated microclimatic variations (Figure 2); longest section east-west aligned. • Ground floor partitioned into two compartments including a Bat Summer Roost and a Horseshoe Hibernation Roost, covering a third and two-thirds of ground-floor area respectively.
Dimensions	• Length 15 m and 12.5 m (two length measurements given because loft is 'L' shaped); height 2.25 m; width 6 m. • Loft void slightly larger than the original as the former contained water tanks, chimneys and trusses, all of which inhibited open flying space favoured by brown long-eared bats.
Heating	• Includes two thermostatically controlled heaters, one within loft and on one on ground floor. Temperature of loft heater set (from May to August inclusive) to 25^0C. • Sustainably sourced energy used for heating the Bat Wall and the Bat House; the owner generates energy from various non-fossil fuel sources.
Re-use of materials	• Re-used timber materials include rafters, ridge beam, tie beam, purlins and battens. • The original fibre insulation and associated droppings were rolled up and installed in the new roost. • Roof is mostly covered using tiles from the demolished farm buildings (Figure 2), although some additional asphalt tiles have been included to make up for a short-fall.
Access points and specific roost features for brown long-eared bats within loft void	• 5 access gaps at the eaves and 10 ridge tile access points; each hole 15-20 mm (high) x 20-50 mm (wide) (Figure 2). • Timber framework of loft provides key roost features for brown long-eared bats.
Access and roost features for horseshoe bats	• Horseshoe hibernation roost on ground floor consists of a thickly insulated chamber. Chamber designed to achieve humid conditions (no damp proof course is included) and stable winter temperatures. Heater set to activate heating on cold days between May and September inclusive. • Boards attached to interior walls for bats to hibernate behind; a rock pile for bats to shelter in; wind-break netting (with holes 5x8 mm) stretched and attached across the ceiling for horseshoe bats to hang from; and 2 rough untreated timbers installed on the roof for bats to hang from. • A large 50 cm x 50 cm entrance installed on the east wall including an interior partition/screen to prevent drafts and light intrusion; N.B. horseshoe bats typically fly straight into their roosts without landing and thus require larger access points.
Access and roost features for other bats	Interior features: • 11 lattice-like bricks (holes c. 20 mm [wide] x 60 mm [high]) on the interior walls (ground floor and Loft House) for crevice-dwelling bats. • 8 rough-surfaced timber boards bolted to the wall leaving a 20-25 mm enclosed bat roost space between the board and wall; board dimensions ca. 30 cm x 30 cm. • Four rough untreated timber baffles installed on the walls for bats to hang from; dimensions – 5 m x 0.1 m x 0.1 m. • Cavity wall installed on one gable end of building. Exterior features: • Ivy and other climbers planted up the external walls to serve as night perches (Figure 2). • 9 Schwegler 1FR and 3 Schwegler 2FR Modular bat boxes embedded into outside walls at varying heights between 2.5 m and 4.5 m to attract various bat species; potential to be used for maternity or hibernation (Figure 2). • Ten bat tiles installed in the tiled roof allowing access beneath tiles and roofing felt (Figure 2); access into the loft space provided via cut sections in the roofing felt. • Hanging tiles installed on the north and east facing walls (Figure 2).

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Table 4. Bat Wall design features

Design feature	Bat Wall
Aspect & dimensions	• East-facing. • Depth 0.45-0.60 m; Width 8 m; Height 3-7 m (dimensions approximately replicate the dismantled wall previously occupied by common pipistrelles).
Heating	• Two thermostatically controlled heaters installed at back of wall set to 25^{0}C between May to August inclusive. • Very thick wall with large thermal mass. • Same aspect as the original roost to replicate, as far as possible, the previous solar regime.
Re-use of materials	• Much of wall consists of re-used Cotswold stone from the demolished farm buildings.
Roost features	• Multiple crevices installed between the stone work with access dimensions of 15-20 mm (high) and 20-50 mm (wide); these are of similar size to those that were being used by the bats within the original wall roost (Figure 3). • 5 artificial wall integrated bat boxes (1FR Schwegler) (Figures 3). • The thickness of the new wall has allowed for the creation of an insulated void space (connected to the crevice entrances) near the rear wall heaters.

Table 5. Summary monitoring results for the Bat House and Bat Wall between 2011 and 2017

Date	Survey method	Bat House			Bat Wall
		Brown long-eared bat[♈]	**Common Pipistrelle**[♉]	**Other evidence of bat occupation**	**Common Pipistrelle**[♉]
28/06/2011	Daytime inspection & evening emergence[¥]	0	3	No	0
08/08/2011	Daytime inspection & evening emergence	0	2	No	0
28/09/2011	Daytime inspection	0	NS	No	NS
27/01/2012	Winter daytime internal inspection[❅]	NS	NS	No	NS
17/06/2012	Daytime inspection & evening emergence	0	2	No	2
06/08/2012	Daytime inspection & evening emergence	0	1	No	0
25/02/2013	Winter daytime internal inspection	NS	NS	Yes (BD)	NS
28/08/2013	Daytime inspection & evening emergence	20-25	1	Yes (BD)	3
18/02/2014	Winter daytime internal inspection	NS	NS	Yes (BD)	NS
08/07/2014	Daytime inspection & evening emergence	3	0	Yes (BD & CD)	0
13/07/2015	Daytime inspection & evening emergence	1	1	Yes (BD & CD)	0
16/06/2016	Daytime inspection	4	NS	Yes (BD & O)	NS
25/05/2017	Daytime inspection & evening emergence	11	2	Yes (BD & O)	1

NS – not surveyed
BD – fresh brown long-eared bat droppings in loft
CD – fresh common pipistrelle droppings at entrance of external wall integrated bat boxes
O – strong bat odour
[¥]Emergence surveys – Structurally complex Bat House covered by two surveyors who varied positions between visits to better cover multiple exit points; Bat Wall covered comprehensively on each occasion by a single surveyor; surveyors in position for 2.5 hours using hand-held detectors.
[♈]Directly observed during internal inspection
[♉]Detected emerging from evening survey; no checks made for roosting common pipistrelles during daytime inspections other than for droppings
[❅]Primary purpose of winter daytime building inspection was to check for hibernating horseshoe bats; none have been recorded to date

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DISCUSSION

Reasons for the failure of artificial bat structures: The reasons for the failure of artificial bat structures to attract maternity bat roosts are not well-documented but the limited literature on the subject and anecdotal reports suggest that failing to consider the following factors can be important:

- Structure complexity. Some structures are not sufficiently complex in design. Within a roost, bats can regularly move position in response to varying metabolic and social requirements (Entwistle *et al.* 1997). In particular, more complex roost structures allow bats to respond more readily to excessive heat or cold.
- Building dimensions and shape. Insufficient space within new bat houses is blamed for many failures (Mitchell-Jones 2004). Large internal flight spaces (c. 20 m length x 4 m width x 2 m height) are considered critical for facilitating social interactions in the case of brown long-eared bats (Briggs 2004).
- Thermal regime. Failure to provide a favourable thermal regime has also been cited as a possible reason for artificial roost structures not being used. For maternity sites, ensuring roost zones with high internal temperatures is critical (typically 25ºC to 40ºC) to minimise energy expenditure by pregnant and nursing females (Speakman & Thomas 2003; Lourenço & Palmeirim 2004; Swift 2004).
- Re-use of existing roost features. Failure to incorporate physical elements of the bats' existing roost site (and their associated odours) is considered a key factor in artificial roost failure (Mitchell-Jones 2004).
- Adjacent habitat. Unsuitable surrounding habitat can also influence occupation of a newly provided roost structure (Entwistle *et al.* 1997; Burland *et al.* 2007).
- Distance to original roost. Siting a replacement bat roost feature too far away from the original site is often cited as another potential cause of failure (Mitchell-Jones 2004).

The new roost structures in this case were designed with these considerations specifically in mind (Tables 3 and 4).

Interpreting uptake by bats of the Bat House and Bat Wall: The monitoring revealed that brown long-eared bats probably first colonised the roof void of the Bat House in the latter half of 2012 (approximately 18 months after the structure was completed) and were then present annually until spring 2017, at least outside the hibernation season. The large number of droppings, distinctive odour and the regular presence of bats (up to 20-25 in summer 2013) indicate that a brown long-eared bat maternity roost has probably re-established.

There is only one documented case in the UK where brown long-eared bats displaced from their maternity roost have re-established in a newly constructed purpose-built bat house nearby (Bat Conservation Trust 2017). While this would also colonisation of bat boxes increased over time, indicating that occur it is often by fewer individuals than counted in the original maternity roost. In the present study the maximum count of brown long-eared bats in the compensatory Bat House is higher than the maximum recorded in the original roost in 2010.bats may take years rather than months to discover and become familiar with potential new roost sites. When colonisation does seem to have been achieved over a short timescale, long term studies by McAney & Hanniffy (2015) and Poulton (2006) (undertaken over 16 and 20 years respectively)

While observed brown long-eared bat numbers were lower in the subsequent four inspections (2014-2017) following the 2013 peak, the direct observation of bats and other evidence of occupation support the likelihood that a maternity roost has re-established. The lower numbers of directly observed bats during this period might be due to brown long-eared bats roosting between the roofing felt and tiles or in other inaccessible crevices at the time of survey. Roost-switching during lactation might also have occurred, although female brown long-eared bats are thought less likely to do this than other species such as pipistrelle bats (Burland *et al.* 2001; Bartonička & Řehák 2007). Other factors such as climate may also explain variations in numbers.

While emergence surveys recorded occasional brown long-eared bats in flight around the Bat House at around the time of their typical emergence (c. one hour after sunset), only one individual was ever confirmed emerging. This could be explained by survey effort limitations, fading light inhibiting direct observations, and because brown long-eared bat echo-locations are difficult to detect.

Small numbers of common pipistrelles rapidly discovered both the new Bat House and Bat Wall, and made use of various roosting features (Table 5). A common pipistrelle maternity roost had not formed as of 2017, but these bats usually have many more opportunities within their home range to establish maternity roosts following displacement compared with brown long-eared bats. Funding limitations have prohibited monitoring of micro-variations in temperature and humidity within the Bat Wall which might have helped explain the results to date.

In conclusion, it can take many years for both brown long-eared bats and common pipistrelles to re-establish a maternity colony following displacement (if they re-colonise at all). However, the results from seven years of monitoring from the present site suggest that brown long-eared bats have probably re-established their maternity roost within the new Bat House, while small numbers of common pipistrelles are making use of both structures. The interim results from this study suggest, for brown long-eared bats at least, that careful consideration in the design process of all the reasons cited for the failure of artificial maternity roosts is critical to the success of mitigation efforts.

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