The implementation and effectiveness of bat roost mitigation and compensation measures for *Pipistrellus* and *Myotis* spp. and brown long-eared bat (*Plecotus auritus*) included in building development projects completed between 2006 and 2014 in England and Wales.

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SUMMARY

We investigated the implementation and effectiveness of bat roost mitigation in building developments completed between 2006 and 2014 in England and Wales. Common and soprano pipistrelle *Pipistrellus pipistrellus* and *P. pygmaeus*, brown long-eared bat *Plecotus auritus* and any of the *Myotis* spp. were selected for the study.

Building inspection and emergence/re-entry surveys were carried out at 71 sites during 2017 and 2018.

Implementation: 61% of new roosts/access points were implemented precisely as specified, 19% deviated, 11% were absent and 1% were damaged. The remaining 8% were enhancements rather than mitigation or compensation.

Effectiveness: 14% of sites did not retain roosting bats at all, 86% of sites had some bats post-development but only 13% maintained or increased numbers of all target species. Only 18% of *new* roosting provisions were occupied by bats post-development compared to 52% for adapted buildings and 25% for retained roosts. No bat lofts in new buildings were occupied in comparison to 55% of those in adapted buildings and 65% where bat loft roosts were retained after works. Breeding brown long-eared bats were least likely to return in similar numbers, particularly in roost destruction cases. Bat boxes mounted externally on buildings showed the highest occupation rate regardless of species. Common pipistrelle showed a preference for these over tree mounted boxes; the opposite was true for soprano pipistrelle. Only 8% of new, 8% of adapted and 21% of retained access points were used. These low percentages may be because most roosts were accessed from only one entrance point although multiple entrance points were provided at most sites. Significant relationships were observed between bat use and aperture width and height above ground level.

The findings give important insights into degrees of implementation and effectiveness and how these might be improved, through changes in the licensing process, associated policy and guidance, to serve bat conservation. Further investigation is necessary to drive greater improvements (for example, for other bat species).

BACKGROUND

The Conservation of Habitats and Species Regulations (2017) make it illegal to damage or destroy bat roosts in England and Wales. Where roosts are likely to be damaged or destroyed during building development projects it is necessary to gain a derogation licence permitting these activities from Natural England or Natural Resources Wales. The licence will only be granted if the works are in the public interest, there is no satisfactory alternative and there will be no detrimental impact on the favourable conservation status of the species concerned.

Licence applications therefore contain measures to avoid harm to bats, avoid disturbance at sensitive times of the year such as during breeding and hibernation and ensure the provision of roosts for the bats post-development. The latter includes retaining existing roosts (avoidance and mitigation), modifying alternative buildings to make them more suitable for bats (compensation) or providing entirely new roosts in new buildings (compensation).

However, only a handful of studies (e.g. Lintott & Mathews, 2018; Mackintosh, 2016; Stone, 2013) have been carried out investigating whether such measures are (a) implemented as proposed, and (b) effective in retaining the bats. Indeed, in Lintott and Mathews (2018) report on a survey of practitioners carried out in 2017, 19% of the 261 respondents reported that they are unable to make informed decisions about bat mitigation and compensation due to the lack of evidence and 70% reported that only partial evidence is available.

Three actions were found on the Conservation Evidence website for the key words ‘bat mitigation’: legally protect bats during development (3 studies, unknown effectiveness); provide bat boxes for roosting bats (39 studies, likely to be beneficial); and create alternative bat roosts within developments (10 studies, likely to be beneficial). The latter category showed varied outcomes for alternative roosts in studies in the UK, USA, Ireland, Portugal and Spain.

This study aimed to provide evidence about the implementation and effectiveness of bat roost mitigation and compensation measures applied during development projects in England and Wales. All projects were subject to a derogation licence

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from the relevant licensing body and were completed between 2006 and 2014. Only projects involving common pipistrelle, soprano pipistrelle, brown long-eared bat or *Myotis* spp. (Natterer's bat *M. nattereri*, Daubenton's bat *M. daubentonii*, whiskered bat *M. mystacinus*, Brandt's bat *M. brantii* or Bechstein's bat *M. bechsteinii*) were included because these are the most common species arising in licence applications. However, where other species were present alongside those listed here they were also included, e.g. lesser horseshoe bat *Rhinolophus hipposideros*.

ACTION

Development projects meeting the criteria outlined above were initially identified by Natural England, Natural Resources Wales and ecological consultants. Site owners were contacted by these organisations/individuals to request their participation in the study and thus access to their sites for bat surveys. The sample was self-selected rather than random; results should be taken in this context.

From the information provided we documented 409 bat roosts that had been directly or indirectly affected by licensed bat mitigation schemes across 71 sites in England and Wales. Most were smaller domestic sites, 87% required planning permission and all were in rural or semi-rural locations.

We surveyed 117 buildings across the 71 sites between 23 May and 5 September 2017 (Year 1) and 9 May and 23 August 2018 (Year 2). Survey work was completed by a licensed bat worker and an assistant surveyor. Surveys included inspections to ground-truth how the bat roost mitigation and compensation had been implemented and search for evidence of bats, and at least one bat emergence or re-entry survey to cover potential bat access points. Procedures for both daytime and night-time surveys were based on current best practice guidance (Collins 2016). Species-level identification was restricted to cases confirmed by DNA analysis of droppings, confident identification of live and / or dead bats or non-ambiguous echolocation calls.

Data from baseline surveys (pre-construction), consultant's surveys (post construction) and our surveys (undertaken at least two years after completion of construction and up to 12 years after) were then analysed to investigate the implementation and effectiveness of the bat roost mitigation.

Implementation

Using information provided in the licence application we collated data on proposed roosting provisions, including the number, location, structural details (size, materials and design), environmental conditions (temperature, air flow, light levels, protection from the elements) and details relating to managing human disturbance. We also collected data on the number, location and design of access points. This information was transcribed onto tick sheets for comparison in the field between what was originally proposed and what was actually applied. Individual provisions were classified as: precisely as proposed; damaged (i.e. installed as proposed but subsequently damaged); deviating from proposed; or absent.

Effectiveness – at the site or scheme level

Table 1 provides definitions of potential conservation outcomes for bats post-development at the site level used during this study. The definitions are not ranked or hierarchical and therefore individual sites could meet one or more of the outcomes.

Most sites in the sample featured more than one target bat species. Therefore, to examine effectiveness per species, the 71 case studies were divided into 180 separate mitigation 'schemes' according to species. Schemes with species unknown or identified only to genus level were excluded. Of the remaining schemes, these were split into lower status or maternity roosts per species.

Data for brown long-eared bats were further examined by comparing baseline bat counts to monitoring bat counts, separated into schemes where roosts were completely removed (i.e. provisions were entirely new) in comparison to those where an alternative building was adapted to make it suitable for bats or those where roosts were retained *in situ*.

Effectiveness – by provision type

Each individual roosting provision and access point was classified according to whether it was entirely new, adapted (i.e. an existing building was adapted to house bats), retained (i.e. a roosting location was retained) or non-intended (i.e. bats moved in opportunistically to locations not intended for mitigation or compensation) and occupancy and use-rates respectively were calculated as a percentage.

New roosts were separated into sub-groups to assess the efficacy of different types of provisions in terms of presence or absence of bats (expressed as a percentage).

Effectiveness – bat lofts

Bat lofts were examined in more detail by dividing them into three sub-groups: 1) new bat lofts within new host builds; 2) new lofts within adapted builds (e.g. loft conversions); and 3) bat lofts where baseline roosts had been identified and the structure largely retained post works. Occupancy rates for voids (given as a percentage) were either obtained from bats roosting openly in the voids themselves or roosting in internal cavities inside them. The relationships between the maximum number of individuals recorded during a single survey, temperature, volume, height and number of different types of internal cavity were examined.

Effectiveness – bat boxes

Bat boxes were broadly classified according to their mounting location as follows: 1) tree-mounted boxes; 2) wall-mounted boxes; and 3) wall-integrated boxes. Wall-mounted boxes could also be external or internal (e.g. mounted inside loft voids or outbuildings). Presence rates were calculated as a percentage of the number of bat boxes at each mounting location with bats.

Presence rates were also calculated for the different bat box models and the exercise was repeated for the different species in the study.

The relationships between the height of bat boxes and bat counts, and orientation of bat boxes and bat presence (there were not enough boxes with more than one bat to compare orientation and bat counts) were also examined.

Effectiveness – access points

The use-rate of access points was investigated in relation to the number of access points available, aperture width, height of access points and the presence of features such as overhangs.

Effectiveness – time

Using consultant's and our own monitoring data we assessed whether roosting provisions became more effective over time since installation, where possible (installation date was not always known).

Statistical analysis

Data were analysed using mixed models with random terms for sites and, where applicable, structures within sites, in order to account for the correlation between observations from the same site or the same building. Presence-absence data (use rate) were analysed using a Generalized Linear Mixed Model (GLMM) with a logistic link function and binomial error distribution. Count data were analysed with a log-normal mixed model (taking the log of counts+1), which was preferred to a Poisson GLMM due to the high level of over-dispersion in the count data. All mixed models were fitted using Residual Maximum Likelihood (REML) in order to avoid the bias in variance components that can arise from Maximum Likelihood estimation with small sample sizes (Welham et al. 2015). Continuous variables such as height were fitted using both linear and quadratic terms, log-transforming where the distribution was skew, but only the linear test is reported where the quadratic term was non-significant. All statistical analyses were completed in Genstat for Windows (19th Edition).

Depending on the research question, one or more of the following measures were used as outcome / response variables in statistical models: potential conservation outcomes; presence-absence; and abundance counts. Structural attributes were used as the explanatory variables in each model including: type of compensation measure; bat box mounting location; access point type; height; and temperature.

CONSEQUENCES

Implementation

The implementation of 2,333 proposed new roosts and access points was assessed: 61% of these were installed precisely as proposed, 1% were damaged, 19% deviated from what was proposed, 11% were absent, and enhancements accounted for the remaining 8% of the sample.

When looking at causes for poor implementation (both deviation and absence), no relationship was found with the number of different provisions proposed on an individual site or the ecological consultant working on the project. Our results suggest that the *type* of mitigation proposed was likely to be the main influence on implementation rates. More complex structures (e.g. loft voids) were more likely to *deviate from what was proposed* (65% deviated, n=48) than less complex structures such as access points and bat boxes. However, larger features such as loft voids were *less likely to be absent* (8% absent) than smaller features such as bat boxes and external cavities (15%, n = 254 and 14%, n = 333 absence respectively). In particular, 35% of externally wall-mounted bat boxes (n = 87) and 26% of wall top crevices (n = 78) were absent. Bat tiles were the most frequently absent access point type (46%, n = 56).

Effectiveness – at the site or scheme level

Table 1 shows the percentage of the 71 sites meeting the different conservation outcomes. Overall, 14% of sites did not retain roosting bats at all, 86% of sites had some bats post-development but only 13% maintained or increased numbers of all target species.

Figure 1 shows the percentage of the 180 'schemes' that retained or increased numbers of bats post-development per species and separated into lower status and maternity roosts. In all cases, fewer than 50% of sites retained or increased pre-development numbers. Of particular note is the low proportion of sites retaining pre-development numbers for maternity roosts of brown long-eared bat. Lesser horseshoe bat schemes showed the highest rates of retention for both types of roost.

Looking in further detail at brown long-eared bat, Figure 2 shows paired dot plots comparing baseline and monitoring counts for maternity roosts and for roost removal schemes (i.e. where roost provisions were entirely new) compared to schemes where alternative buildings were adapted for use by bats or roosts were retained. The latter two scenarios were more effective at maintaining or increasing numbers.

Table 1. Potential conservation outcomes

Potential conservation outcome		%
Roosting bats not retained at all		14
Site retained the presence of roosting bats	*Any* species	86
	Any target species	79
	All target species	34
Site maintained or increased overall bat abundance levels (via direct counts)	*Any* species	35
	Any target species	49
	All target species	13
Site maintained or increased bat species richness on site		49
Site maintained or increased the value of baseline roost(s) with the highest conservation status		44

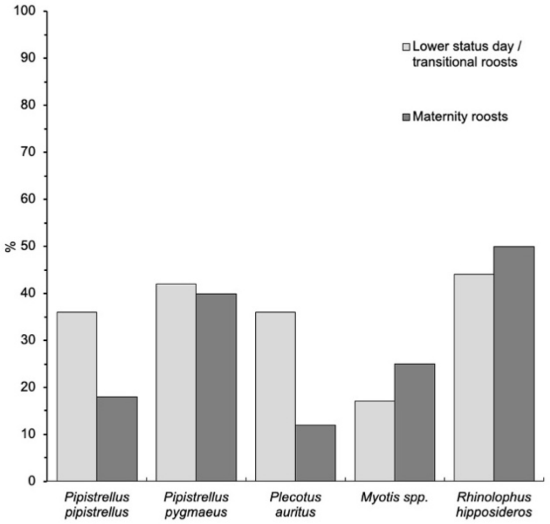

Figure 1. Percentage of species-specific mitigation schemes that retained or increased abundance of the target bat species post-development.

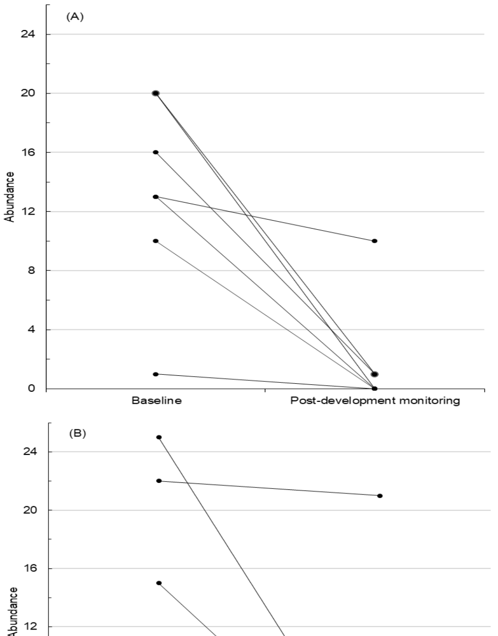

Figure 2. Comparing the baseline and post-development monitoring bat counts for brown long-eared maternity roosts within roost removal schemes (A) and modification/retention schemes (B).

Effectiveness – by provision type

Overall, across the 71 sites we surveyed 849 roosting provisions and 1736 access points. These are broken down in Table 2 according to whether they were new, adapted, retained or non-intended (see ACTION for definitions). Table 2 shows gross occupancy and use rates for roosts and access points respectively, illustrating that only 18% of new roosts and 8% of new access points were actually used by bats. Adapted buildings were occupied more frequently by bats than either retained or new roosts and retained access points were used more frequently by bats than new access points or those built into adapted buildings.

Table 2. Gross frequency (GF), gross occupancy (GO), gross use-rate (UR) for roosts and access points.

Provision	**Roosts**		**Access points**	
	GF	GO	GF	UR
New	698	18%	1,629	8%
Adapted	64	52%	12	8%
Retained	36	25%	34	21%
Non-intended	51	100%	61	100%

Figure 3 shows bat occupancy rates for entirely new provisions according to roost sub-group (n=698). Crevices built into the tops of walls, underneath the roof covering, showed the highest occupancy rate (40% occupied) followed by wall mounted bat boxes (36%) then bat lofts (33%). The least frequently used provisions were internal boards and panels (10%) and gaps in stone and brick walls (2% occupied). Bat occupancy rates varied significantly between sub-groups ($\chi^2 = 25.50$ with 10 d.f., $p = 0.004$).

Effectiveness – bat lofts

Table 3 shows bat occupancy rates for the different bat loft sub-groups, with the total sample size of 70. None of the new lofts in new buildings showed any evidence of occupancy in contrast to 55% of new lofts in adapted buildings and 65% of retained lofts. Of these, 88% were due to the presence of brown long-eared bats.

There was no significant relationship between temperature (°C) and bat abundance counts (F= 1.36 with 1 and 21 d.f., p = 0.257), but the number of small internal cavity types inside voids showed a highly significant positive relationship with counts (F = 10.79 with 1 and 24 d.f., p = 0.003). Similarly, internal height (m) and volume (m^3) both displayed highly significant positive relationships with bat counts (height F = 12.44 with 1 and 26 d.f., p = 0.002; volume: F = 11.20 with 1 and 19 d.f., p = 0.003). However, since internal loft height and volume (and to some extent, the number of cavity types) were strongly correlated, it was impossible to determine which displayed the strongest influence. This analysis was for adapted loft voids only; no count data were available for new loft voids. The highest bat loft recorded was 6m; no bats were recorded in lofts in which the highest internal point was lower than 1.5m.

Effectiveness – bat boxes

Bat boxes were the most frequently deployed roosting provision, being installed at 64% (n = 71) of sites as a compensation or enhancement measure. Box frequencies ranged from 1 to 41 at sites where they were installed, with an average of 6.6 boxes per site (n = 270). Bats, or evidence of bats, were recorded in 20% of these.

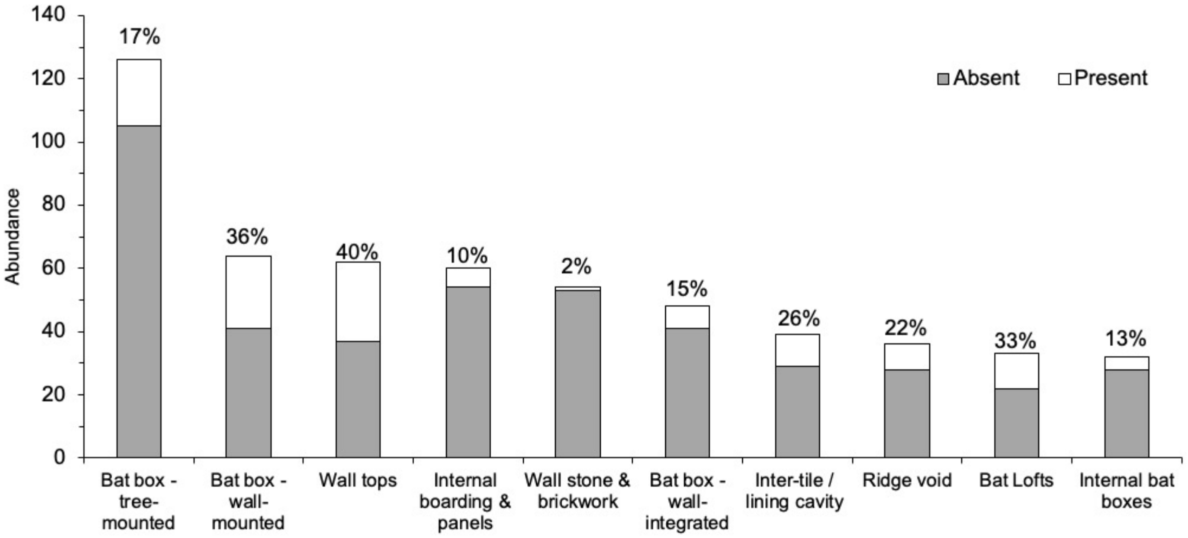

Figure 3. Total number of new roosting provisions by type and percentage of those occupied by bats.

Table 3. Occupancy rates for bat loft sub-groups

	Occupancy rate (presence)	Occupancy rate (live bats only)	Min. bats	Max. bats	Mean no. bats (roosts with live bats only)
New lofts in new builds (n = 13)	0 (0%)	0 (0%)	N/A	N/A	N/A
New lofts in adapted builds (n = 20)	11 (55%)	0 (0%)	N/A	N/A	N/A
Retained lofts (n = 37)	24 (65%)	12 (32%)	1	21	5
Totals (n = 70)	35 (50%)	12 (17%)	1	21	5

Bat presence was highest in external wall-mounted boxes (36%, n = 64). Bat presence in tree-mounted, wall-integrated and internally-mounted boxes was recorded in 17% (n = 126), 15% (n = 48) and 13% (n = 32) respectively.

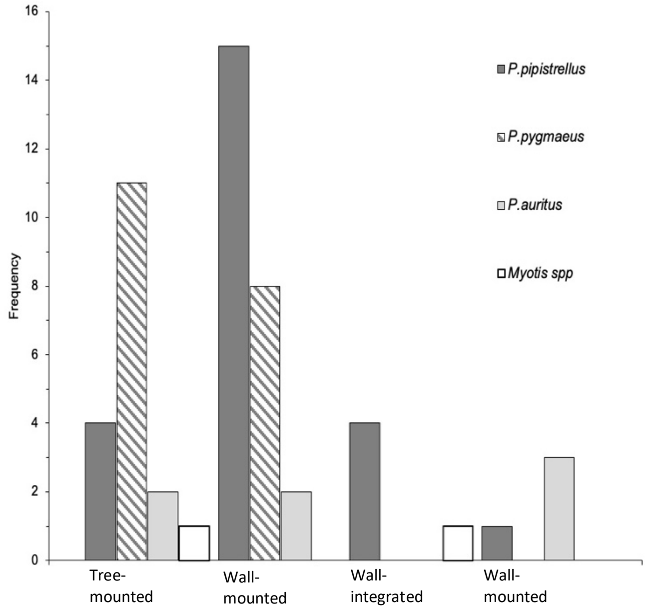

Figure 4. Frequency of different species in bat boxes on different mountings.

As shown in Figure 4, common pipistrelle was most frequently recorded in external wall-mounted boxes, being found in 71% (n = 23) of occupied wall-mounted boxes compared to soprano pipistrelle (38% n = 23). By contrast, tree-mounted bat boxes were more frequently occupied by soprano pipistrelles (52% n = 21) compared to common pipistrelle (19% n = 21).

We compared the four most popular bat box models used by consultants in the study (all Schwegler). Bat presence was highest in the 1FF (32%, n = 53) and lowest for birds (8%). The tree-mounted 2F and wall-integrated 1FR/2FR models both demonstrated similar bat presence rates of 23% (n = 43) and 25% (n = 32) respectively. The 2FN tree-mounted model showed the lowest presence rate for bats (11%, n = 19) and the highest for birds (58%). There were also 26 timber bat boxes, none of which were used by bats. No evidence of birds was found in bat box designs where access point apertures were ≤17 mm. Similarly, box models with the highest bird presence featured access apertures at least 25mm wide.

Ninety-two percent of 1FF boxes that were occupied on external walls were occupied by common pipistrelles, compared to just 8% occupied by soprano pipistrelle. Only one tree-mounted 1FF box was occupied at a single site, and this was by soprano pipistrelle. Furthermore, despite soprano pipistrelles being recorded at three sites where alternative tree-mounted models had been installed alongside the 1FF design, this species was only recorded once in the 1FF model. Although this may suggest a difference in bat box preferences between common pipistrelle and soprano pipistrelle, it must be noted that both were recorded using the 2F and 1FR / 2FR designs in equal proportions.

Average bat box heights above ground level were 4.6 m; tree-mounted boxes were slightly lower at 3.8 m and wall-mounted / integrated boxes were slightly higher at 5.4 m. The lowest occupied box was at 1.8 m and the highest at 11 m. However, fitting height in mixed models indicated that it did not have a significant impact on either bat presence (F = 0.31 with 1 and 128 d.f., p = 0.577), or on counts (F = 0.02 with 1 and 232 d.f., p = 0.894). Likewise, there were no significant differences between boxes on different orientations (north, north-east etc., χ^2 = 4.69 with 8 d.f., p = 0.790 for presence, F = 1.56 with 8 and 237 d.f., p = 0.139 for counts). There were insufficient bat count data to assess the relationship between bat counts and orientation using this method.

Only five heated bat boxes were surveyed and no evidence of bats was found. Despite close examination and discussions with site personnel, it was not possible to confirm whether the heating elements were functioning.

Effectiveness – access points

Of 1,629 new access points provided, only 8% were used (see Table 2). Of these, 94% involved bats using a single roost access point despite more being available. The remaining 6% involved bats using 2 - 3 access points into a roost. No relationship was found between the number of access points and either use-rate or maximum bat counts (χ^2 = 0.18 with 1 d.f., p = 0.671 and F = 0.23 with 1 and 69 d.f., p = 0.632, respectively).

When examining external access points in isolation, apertures leading into bat boxes had the highest use-rate (20%, n = 232) followed by those leading into adapted crevices at wall tops (11%, n = 351). Other external access points with lower use-rates were those at the bases of boarding and panels (7%, n = 70), and ridge tile access (4%, n = 162). The least effective access points were stonework gaps (1%, n = 94) and bat tiles (0%, n = 45).

Figure 5 details the aperture widths for all access points in use during post-development monitoring surveys (ours and consultant's). The GLMM showed there was a highly significant quadratic relationship between bat use and aperture width (χ^2 = 34.22 with 1 d.f., p < 0.001 for the quadratic term). When active access points within the 10 - 35 mm range were examined in more detail, the most frequently used for all species were those with aperture widths of 13 – 22 mm (84%, n = 143).

Figure 6 shows the height above ground-level (m) for all new access points (including access points into bat boxes) confirmed as being used by bats during our monitoring surveys. The GLMM showed a significant quadratic relationship with bat presence (χ^2 = 7.43 with 1 d.f., p = 0.006).

It was observed during both the baseline and monitoring stages that 47% (n = 401) of confirmed access points were located directly adjacent to some form of corner or overhang at 90° to the opening. When new access point provisions were examined in isolation (excluding bat box access points), it was also recorded that openings adjacent to overhangs or corners were twice as effective (bat-use rates of 8%, n = 571) compared to those that were more exposed (3%, n = 723). The GLMM also indicated that this relationship varied significantly between species (χ^2 = 12.34 with 3 d.f., p = 0.006), being more evident for soprano pipistrelle and brown long-eared bats compared to common pipistrelle and *Myotis* spp.

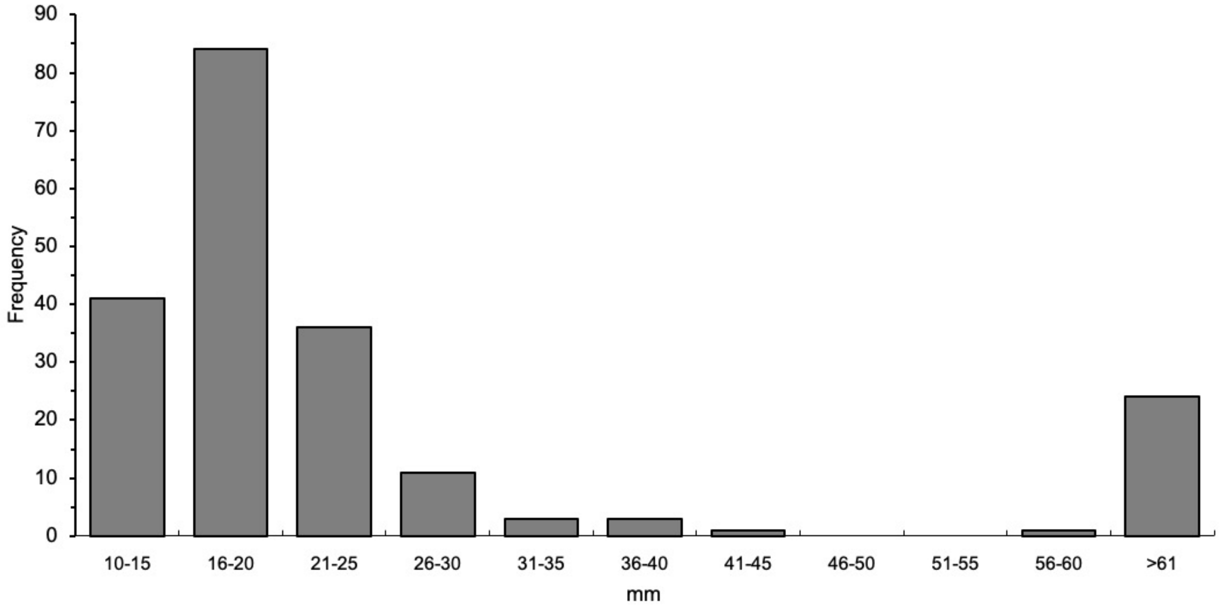

Figure 5. Frequency of different aperture widths (mm) for all new access points that were used by bats

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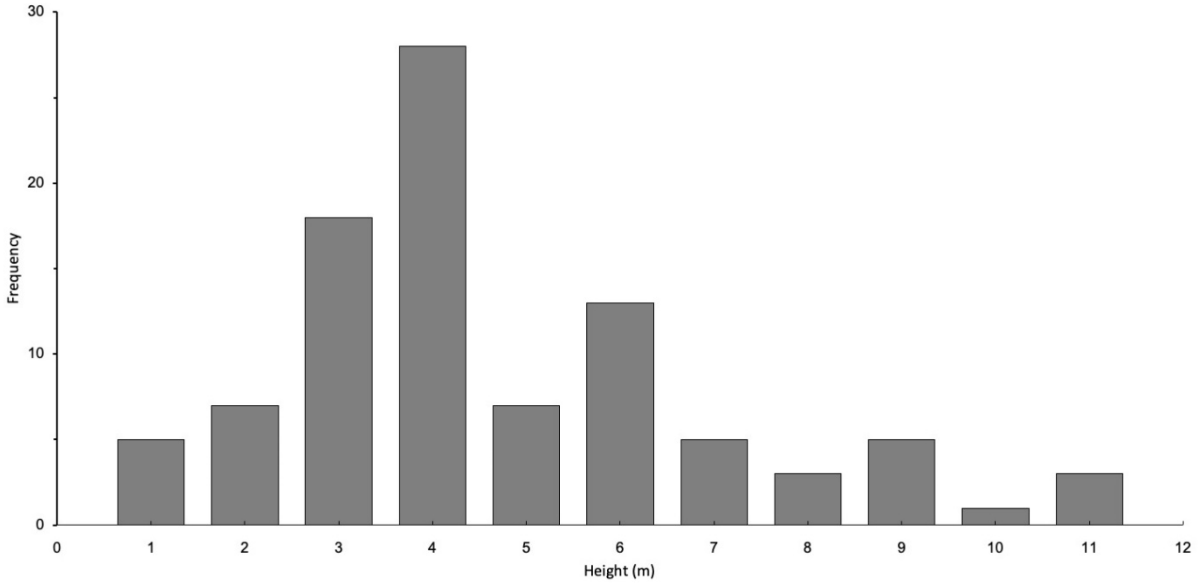

Figure 6. Frequency of different heights above ground level (m) for all new access points (including access points into bat boxes) that were used by bats

Effectiveness – time

Results indicated that overall roost occupancy rates increased over time. In particular, analysis demonstrated that bats started occupying new provisions very soon (within six months) after installation, and that most effective provisions had become occupied within two years. This result may be slightly biased towards smaller day roosts of *Pipistrellus* spp., which accounted for the majority of active roosts in this project.

DISCUSSION

This study adds to the evidence to inform and improve future practice, in particular with respect to bat lofts, bat boxes and bat access points. Our findings are consistent with other studies regarding the variability in efficacy of bat roost mitigation/compensation and the importance of prioritising roost retention or modification over roost loss and compensation (Mackintosh 2016, Lintott & Mathews 2018).

Further work is needed to investigate all aspects of mitigation and compensation provision but in particular it is important to further our understanding with respect to providing suitable roosts in new buildings for brown long-eared bats. Again, our findings are consistent with Mackintosh (2016), who found only low levels of use by this species in new bat lofts despite the structures themselves being positioned near optimal habitat and constructed from similar materials to roosts that were removed. Similarly, Briggs (2004) assessed the effectiveness of numerous bat lofts but reported that none effectively compensated for the *P. auritus* roosts that had been removed despite their volume and height meeting standard requirements.

It is important to bat conservation to continue to learn from experience by feedback mechanisms which allow a greater understanding of which mitigation and compensation measures are the most effective at retaining populations of the target species. This information should be used to update the Bat Mitigation Guidelines (Mitchell-Jones, 2004). Licensing of these activities provides an opportunity for data to be systematically collected, collated, stored and analysed to provide a feedback loop to improve practice over time.

Focus should also be given to improving implementation rates and understanding the impacts of habitat and lighting changes on bats at development sites. It was not possible in this study to accurately determine the extent of any habitat- or lighting-related impacts in the immediate vicinity of roosts using the baseline information. However, all sites were located in rural or semi-rural locations surrounded by good habitat for bats so wider habitat losses were unlikely to have played a significant role in our results.

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