Effectiveness of mitigation of the impacts of a new road on horseshoe bats *Rhinolophus ferrumequinum* in Wales, UK

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SUMMARY

The intervention described in this paper was designed to allow greater horseshoe bats *Rhinolophus ferrumequinum* to cross safely underneath a newly constructed road scheme in Pembrokeshire, Wales. The mitigation measures, consisting of bridges, culverts and underpasses, were designed and positioned to increase the likelihood that they would be used by bats. These features were then monitored to determine their effectiveness from the proportion of bats flying safely through the mitigation compared to over the carriageway. This was done using a combination of bat surveyors with hand-held detectors and night-vision equipment, and automated bat detectors. Effectiveness of the different mitigation features increased with increasing cross-sectional area, with a culvert of 1500 mm diameter used less frequently than a larger culvert of 1800 mm x 3000 mm. The larger mitigation measures were generally more than 85% effective. Position in the landscape and the presence of features to guide bats into the mitigation are also likely to be important. In order to assess the likely impacts of a new road scheme on a designated bat population this study also considers local bat population trends, the time of night when most bats cross the road and approximate traffic volumes at these times.

BACKGROUND

Under the Conservation of Habitats and Species Regulations 2017 (also referred to as the Habitats Regulations), planners of development projects are required to demonstrate 'beyond reasonable scientific doubt' that their proposals will not have a significant adverse impact upon any qualifying features associated with the Natura 2000 network of European designated sites. This usually requires appropriate mitigation to be incorporated into proposals and monitoring to be carried out to confirm the success, or otherwise, of these measures. However, published evidence for the effectiveness of many commonly applied mitigation techniques remains limited.

It is clear that roads pose a risk of mortality to bats through collision with vehicles, but they can also have a major negative impact on bat foraging activity and diversity (Berthinussen & Altringham 2012a). Mitigation to reduce the impact of roads on bats therefore needs not only to make the road more 'permeable' (through the use of effective crossings, such as underpasses and overpasses), but should also improve habitat within 1 km of major roads. Whilst there is some evidence that bats use underpasses preferentially, especially if installed on pre-construction commuting routes (Berthinussen & Altringham, 2012b), there is currently little or no evidence of the effect of diverting bats to safe crossing points using vegetation, except for a small percentage of lesser horseshoe bats *Rhinolophus hipposideros* in one controlled study (Berthinussen *et al*. 2018).

The A40 Penblewin to Slebech Park Improvement (Ordnance Survey grid reference SN083154) in Pembrokeshire is a Welsh Government road scheme, which was completed in 2011. Approximately half of the 6 km scheme comprised a new bypass of the village of Robeston Wathen, crossing through an agricultural landscape known to be used by both greater horseshoe bats *Rhinolophus ferrumequinum* and lesser horseshoe bats. Both are qualifying species of the Pembrokeshire Bat Sites and Bosherston Lakes Special Area of Conservation (SAC), and both were considered to be at potential risk of increased mortality as a result of vehicle strikes on the new road, owing to the proximity of a roost at Slebech Park, approximately 3 km to the south-west. For this reason, comprehensive mitigation measures were incorporated into the scheme design.

A number of 'safe crossings' (most deliberately positioned on known bat flight paths) were incorporated into the scheme design, including clear-span bridges, underpasses and over-sized drainage culverts, and landscape planting was designed to create natural features to 'funnel' the bats towards the crossings.

This study describes the results of monitoring the rate at which horseshoe bats used these mitigation features to cross the road. This required a monitoring regime that recorded the proportion of bats that flew under bridges and through culverts and underpasses, relative to those that flew across the carriageway at vehicle height (i.e. 'unsafely'). Annual changes in the local horseshoe bat population were then examined, to consider if any decreases in the local population might be attributable to the Scheme. The focus of this paper is on greater horseshoe bats, partly because this is the rarer of the two species (and the primary qualifying feature of the SAC of greater conservation interest), but also because this was the species that was recorded most frequently during the surveys.

ACTION

Mitigation design: During the detailed design of the proposed scheme, the implications for greater and lesser horseshoe bats were paramount, especially along the section of road that went through new countryside and traversed hedgerows and fields known to provide commuting and foraging habitat for these species. The most significant potential impacts were considered to be the risk of collision with vehicles, and the likelihood that the road would form a barrier preventing bats from the Slebech Park roost accessing their foraging habitat to the north.

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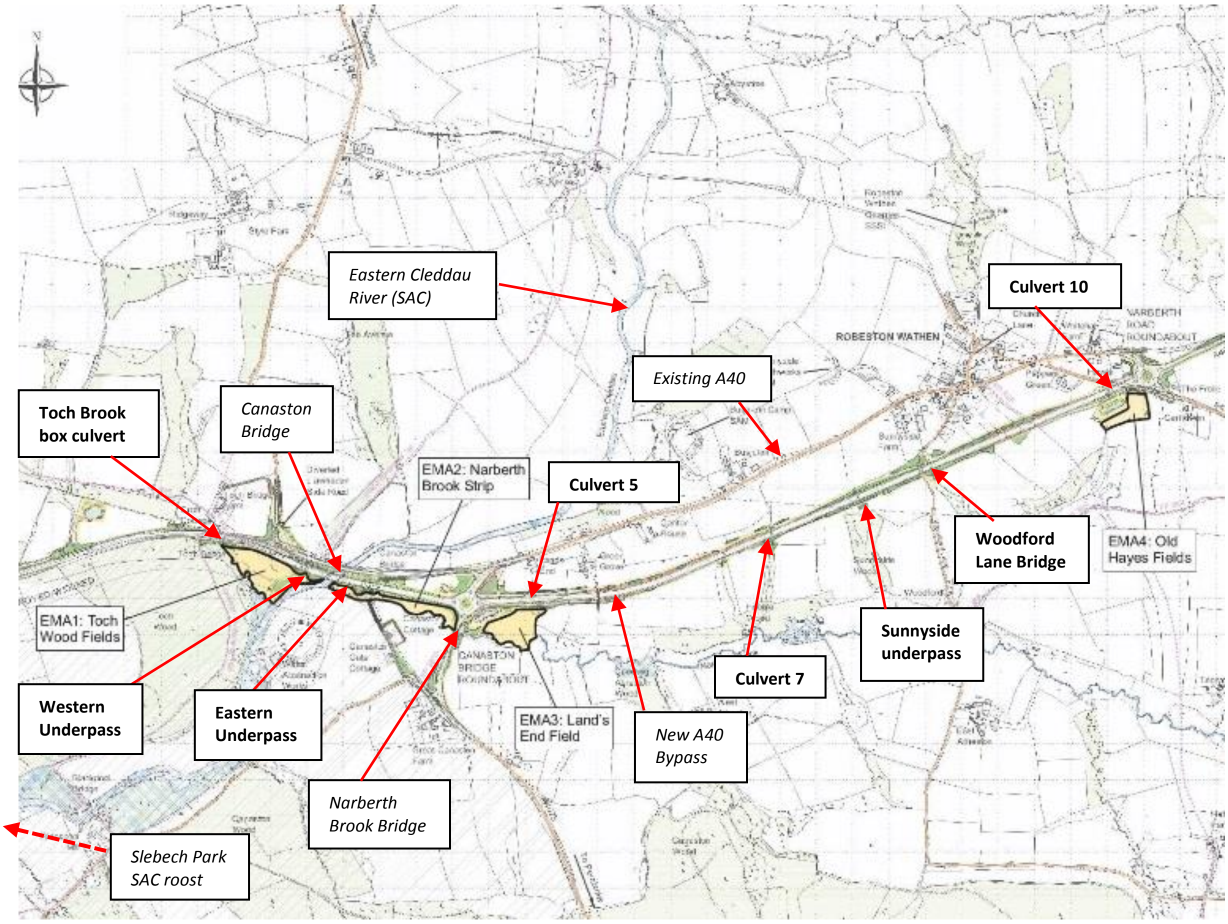

Figure 1. Locations of the eight 'safe crossings' monitored (in bold); see Table 1 for a description of the crossings. EMA = Essential Mitigation Area for bat foraging.

The locations and details of the features of the eight safe crossings monitored in this study are illustrated in Figures 1-6 and Table 1. The design of these features is likely to affect the effectiveness of the crossings; landform and habitat features that 'funnel' the bats toward the mitigation entrance are likely to increase usage, and the closer a feature is to the roost, the more often the bats are likely to encounter it, increasing the likelihood that they will become accustomed to it.

Horseshoe bats generally fly quite low to the ground, and therefore are best encouraged to fly under rather than over roads. The Scheme's three bridges (Canaston Bridge, Narberth Brook Bridge and Woodford Lane Bridge; Figure 1) were designed as open-span structures, rather than more restricted box structures;the aim was to increase the volume of available space through which the bats could safely fly. A number of drainage culverts were 'oversized' for the same reason. The location of the three underpasses was also positioned to increase the likelihood of being used by bats, by locating them on existing flightpaths and/or adjacent to valuable foraging habitat.

Monitoring design: Surveys were undertaken using both automatic detectors and surveyors for one night each month between May and September for four years after the mitigation was implemented (from 2011 to 2015, excluding 2014). Bat monitoring was carried out in the same locations surveyed

Figure 2. Culvert 10, showing line of trees (known horseshoe bat flight-line) leading towards southern entrance, marked by white wing-walls. Tree guards indicate the planting around back and sides of the culvert to guide bats into the structure.

Figure 3. Culvert 5, a 1.5 m diameter drainage ring (with steps leading down into the entrance for otters).

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Table 1. Description of mitigation features/safe crossings, in order of increasing crossing size.

Crossing	Description/ dimensions	Positioning within landscape, and relative to roost
Culvert 7	750 mm pipe	Positioned within large embankment perpendicular (but poorly connected at the time of the monitoring) to occasional commuting route alongside Hobble Wood. Landscape planting likely to improve the link over time. Approximately 5.4 km from roost.
Culvert 10 (Figure 2)	1000 mm pipe	Reasonable linear features to north and south that needed strengthening at time of the monitoring. Landscape planting likely to improve the link over time. Approximately 6.5 km from roost.
Culvert 5 (Figure 3)	1500 mm pipe	Good linear feature to the north, but area of scrub (and no clear linear route) to the south (the direction of the roost). Approximately 4.7 km from roost.
Toch Brook box culvert (Figure 4)	1800 x 3000 mm box culvert	Located on stream used as commuting route by greater horseshoe bat. Approximately 4.3 km from roost
Sunnyside Underpass (Figure 5)	2660 x 2370 mm cattle underpass	Positioned within large embankment perpendicular to occasional commuting route alongside Sunnyside Wood. Landscape planting likely to improve the link over time. Approximately 5.6 km from roost
Eastern Underpass	3500 x 4000 mm equestrian underpass	Located approximately 70 m east of Eastern Cleddau river and 20m north of Narberth Brook (both used as significant commuting routes by greater horseshoe bats), though lacking clear linear links to either entrance. Approximately 4.3 km from roost
Western Underpass (Figure 6)	3500 x 4000 mm equestrian underpass	Located 15 m west of Eastern Cleddau river (a significant commuting route by greater horseshoe bats) and adjacent to Essential Mitigation Area 1, one of four specially created foraging habitat areas along the Scheme. Approximately 4.3 km from roost.
Woodford Lane Bridge	Open span bridge: 8950 x 3500 mm	Located on sunken lane running underneath the Scheme, used as occasional commuting route by greater horseshoe bats. Approximately 5.9 km from roost

during the construction phase (from west to east): Toch Brook box culvert, the Western Underpass, the Eastern Underpass, Narberth Brook Bridge, Culvert 5, Culvert 7, Sunnyside Underpass, Woodford Lane Bridge, and Culvert 10 (Figure 1, Table 1). In 2013, only three survey visits were carried out (at the request of the employer and following agreement with consultees); no surveys were undertaken in 2014.

Automated Anabat SD1 and SD2 detectors were positioned within and above all features, to pick up bats flying through the safe crossings and also over the road. On the same night, the entrance to each crossing (on the south side, where the bats flying north from the Slebech roost would be expected to enter) was also observed from dusk until it was too dark to see by a surveyor with a Pettersson D240X bat detector. Although this method did not record bat activity throughout the night, it provided important contextual information about bat behaviour around the culvert and underpass entrances.

Changes to monitoring methodology: Whilst consideration was given to employing the original survey methods throughout, to allow comparison across the five years, it was decided to improve the methods over time. This was because the aim of the monitoring was to determine the effectiveness of the mitigation as accurately as possible, not to compare change in effectiveness over time.

During 2011 and 2012, surveyors were positioned at the entrance of each safe crossing, in order to observe the bats' behaviour and confirm that they were indeed flying into it. However, in 2013 it was decided that visual monitoring should focus on the bats that were *not* using the mitigation, to monitor whether these bats were at risk of collision with vehicles.

Consequently, the survey approach was modified in 2013 and 2015, with surveyors instead positioned at carriageway level with night-vision equipment, to establish whether passes recorded on the automated detectors 'above' the mitigation were due to bats crossing the carriageway (either at vehicle height or

Figure 4. Toch Brook box culvert.

Figure 5. Southern entrance to Sunnyside Underpass (for cattle), located within a retaining wall created within the road embankment to avoid loss of habitat from Sunnyside Wood.

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Table 2. Total number of greater horseshoe bat passes recorded on Anabat detectors within and above crossing point locations along the scheme in May-September from 2011 – 2015. No monitoring was carried out in 2014.

	May		June		July		August		September		Annual Total	
	Within	**Above**	**Within**	**Above**	**Within**	**Above**	**Within**	**Above**	**Within**	**Above**	**Within**	**Above**
2011	13	1	5	0	8	2	7	1	2	0	**35**	**4**
2012	6	4	91	124	31	43	18	3	6	0	**152**	**174**
2013	17	4	158	95	13	7	No data	No data	No data	No data	**188**	**106**
2015	17	6	25	9	13	4	9	5	7	0	**71**	**24**

above), or flying along the verge, parallel with the road. Observations were carried out by a surveyor with both a Pettersson bat detector and night-vision equipment for approximately two hours after dusk and two hours before dawn at each location. These were the two periods when peak activity was recorded during the earlier surveys. Night-vision equipment was used by the surveyors once conditions became too dark to see with the naked eye, particularly in locations where bats had previously been seen crossing the road at carriageway level. This provided qualitative information describing observations of bat behaviour, to complement the quantitative data provided by the automated Anabat recordings.

In 2015, where detectors were located above features, they were positioned to best detect horseshoe bats travelling to and from Slebech Park roost (i.e. on the north side of the carriageway facing south during the dusk survey, and on the south side of the carriageway facing north during the dawn survey).

Analysis: Recordings were made of all bat species, but analysis focused upon greater horseshoe bats. All recordings were analysed using BatSound software (for Pettersson recordings) and Analook (for Anabat automatic recordings).

Anabat files can be up to 15 s long; thus, in continuous bat noise, four files will be created per minute. However, this does not necessarily represent four separate bat passes; for example, four separate files would be recorded if a single bat were circling a culvert mouth for a minute. Therefore, recordings were identified as separate passes only where there was a time delay of more than 15 s between Anabat files. For files with shorter delays between them, the pattern of echolocation calls was assessed. If a sequence of bat calls continued from one Anabat file onto the next, this was counted as one pass.

Figure 6. The Western underpass, showing the wet grassland habitat of Essential Mitigation Area 1, adjacent to the southern entrance. The new road runs along the top of the embankment.

Corpse searching and traffic counts: Corpse searches were undertaken at each crossing from May to September 2015. Surveyors searched the carriageway and adjacent verge within 50 m each side of the mitigation features immediately after the dawn surveys, to maximise the chance of finding bat corpses.

Traffic counts were also undertaken in 2015 to determine the frequency of vehicles passing on the carriageway during periods of peak bat activity. These were particularly relevant in September, when sunset and sunrise correspond more closely to periods of peak traffic movement. Traffic counts were made at the same time as bat monitoring (i.e. one count/crossing/month between May and September). It was not always possible to reliably record both the quantity of traffic and the behaviour of bats when the two happened at the same time. In these instances, observation of bats' behaviour took precedence.

CONSEQUENCES

Number of bat passes: Results from automated detectors, recording the total number of greater horseshoe bat passes from May to September each year across all sites showed that, in three out of four survey years, significantly more bats were recorded within the crossings than above them (Table 2). This suggests that in these years more bats were crossing the road safely than were crossing above the carriageway. In 2011, 90% of bats used the crossings; in 2012 the figure was 47%, in 2013 it was 64%, and in 2015 it was 75%. Bats used all the underpasses to some extent, with crossings with larger diameter being used more often than smaller crossings (Table 4).

Corpse Searches and Traffic Counts: No bats of any species were found during the corpse searches. The results of traffic counts in 2015 showed that the average time for 10 vehicles to pass the crossing point from either direction was 3.7 min for the dusk survey and 17.6 min the dawn survey. This equates to

Table 3. Total number of greater horseshoe bat passes observed by surveyors at the crossing point locations along the scheme for each month 2011 – 2015. Note that in 2011 and 2012 surveyors observed the safe crossing entrances, whilst in 2013 and 2015 they observed bats over the road.

	May	**Jun**	**Jul**	**Aug**	**Sep**	**Annual Total**
2011	0	0	0	0	0	**0**
2012	0	1	1	0	0	**2**
2013	1	23 (at least)	2	No data	No data	**26 (at least)**
2015	0	5	0	0	0	**5**

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Table 4. Percentage of the total number of greater horseshoe bats detected at each crossing point that used the underpass based on Anabat data. Results presented in order of increasing crossing size. Results for 2015 are presented separately from the combined results, as these used a more reliable monitoring methodology (see 'Changes to monitoring methodology' for more details).

Crossing	Dimensions	% passes in 2015 (total passes)	% passes in 2011-2015 combined (total passes)
Culvert 7	750 mm pipe	0% (1)	15% (117)
Culvert 10	1000 mm pipe	15% (11)	26% (23)
Culvert 5	1500 mm pipe	42% (12)	40% (155)
Toch Bridge	1800 x 3000 mm culvert	86% (21)	88% (85)
Sunnyside Underpass	2660 x 2370 mm underpass	100% (5)	86% (226)
Eastern Underpass	3500 x 4000 mm underpass	50% (14)	87% (135)
Western Underpass	3500 x 4000 mm underpass	82% (32)	97% (348)
Woodford Lane Bridge	8950 x 3500 mm bridge	82% (11)	68% (167)

average traffic rates of approximately 2.7 vehicles/min after dusk and 0.57 vehicles/min prior to dawn.

DISCUSSION

To determine whether or not mitigation measures have been effective, it is necessary to set some 'criteria for success'. The Statement to Inform Appropriate Assessment stated: "*The mitigation measures in relation to bats would be considered to be successful if the monitoring demonstrates that a statistically significant proportion of the bats crossing the Published Scheme utilise the underpasses rather than flying over the newly constructed carriageway*". This was a relatively vague target, and Criteria for Success for more recent schemes tend to be more quantitative (for example, a percentage effectiveness target for all crossings might be set). Nevertheless, the results of the bat monitoring demonstrate that the safe crossings provided have largely been successful. A greater proportion of greater horseshoe bats were recorded using the safe crossings than crossing the scheme at carriageway level in three out of the four survey years, and bats were shown to use all eight safe crossings. Whilst there were Anabat failures in certain locations and years, and some surveys were cancelled in bad weather, these limitations were not significant, and were not biased to any particular crossing.

The installation of culverts and underpasses underneath new roads is never likely to be 100% successful (i.e. all bats encountering the road choosing to fly through them rather than over the carriageway). However, it is key that enough of the local bat population uses them to ensure no significant increase in annual mortality. Prior to this scheme opening, greater horseshoe bats from the Slebech Roost had only one safe crossing point available on this stretch of the existing A40, underneath the old Canaston Bridge along the Cleddau River. Therefore, the scheme has significantly increased the number of safe crossings available. The assessment of the individual crossings demonstrated significant variation in their effectiveness, and this is likely due to a variety of factors. The most important appears to be the cross-sectional area of the structure (Table 4). A threshold appears to occur somewhere between the 1500 mm diameter of Culvert 10 (effectiveness of 40%, for an area of 1.77 m^2) and the 1800 x 3000 mm dimensions of the Toch Bridge box culvert (effectiveness of 88% for an area of 5.4 m^2). Whilst the detail should be treated with caution, this result suggests that the cross-sectional area provided for greater horseshoe bats needs to be closer to the latter than the former to be effective. Whether it needs to be as big as 1800 x 3000 mm requires further research. The nature of each crossing and its position within the landscape, particularly in relation to linear features that greater horseshoe bats use for commuting and foraging, are also likely to be relevant.

The relatively lower effectiveness of the Woodford Lane Bridge can readily be explained. Over the course of the aftercare and maintenance period, it was noted that the hedge vegetation either side of the bridge was not being cut as part of the landscape contract, and appeared to be encouraging bats to fly up and over the bridge. This vegetation was cut in early 2015, so that bats flying along the field side of the hedgerows could now readily access the space between the bridge deck and the ground level, and effectiveness for 2015 was 82% compared with the combined 2011-2015 figure of 68%. Whilst the maximum height of the bridge above Woodford Lane was 3.5 m, this was only the part that spans the sunken lane; where the bridge deck is over the field on either side, the clearance is little more than a metre. A proportion of the bats encountering the structure were observed to be flying up the sunken lane, but others followed the hedgerows running along the top of the banks either side of the lane, and it was these bats that flew up and over the bridge when the hedgerow was unmanaged.

There are also lessons to be learnt from the results for Culverts 5, 7 and 10, which were used less than other crossings. This was most likely due to their size and positioning within the surrounding landscape, as well as the availability of linear features to guide bats to the headwall. All three culverts were smaller than the other mitigation measures and suffered from sub-optimal linkages to strong linear features, along which the bats might be expected to be moving.

Table 5. Total number of greater horseshoe bats from three nearby roost counts from 2013-2015 (provided by NRW).

Site	2013			2014			2015		
	Count 1	Count 2	Peak	Count 1	Count 2	Peak	Count 1	Count 2	Peak
Slebech	**254**	**276**	**276**	**343**	**361**	**361**	**357**	**369**	**369**
Felin Llwyngwair	363	355	363	395	390	395	446	438	446
Stackpole			637	729	710	729	718	754	754

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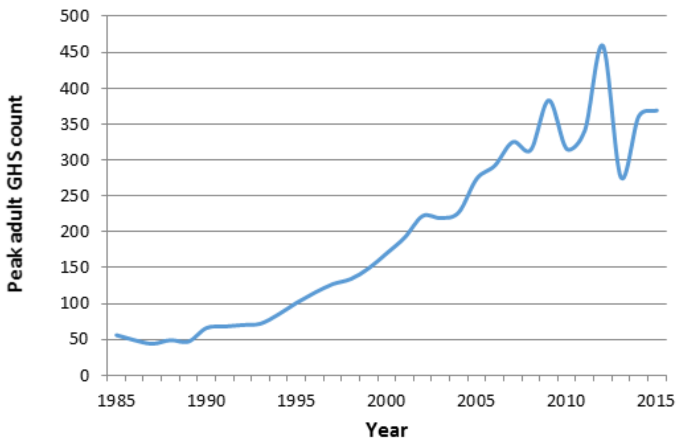

Figure 7. Peak adult greater horseshoe bat (GHS) counts at the Slebech Park roost, 1985-2015 (courtesy of NRW).

Fewer greater horseshoe bats encountered the scheme in 2015 compared with 2012 and 2013 (Table 2), although the latter results were skewed as a result of a very high encounter rate in June for both 2012 and 2013. This could have been the result of favourable weather conditions for foraging, and/or the temporary occurrence of a particularly attractive food resource during the week the detectors were deployed. Whilst the number of passes is only indicative of the levels of bat activity and is not representative of the true number of bats, the results demonstrate how dramatically the encounter rates of this species at a new road scheme can vary, both between months and years. The particularly low numbers in 2011 were probably because the road had only just opened, and the scheme remained much like a construction site.

The automatic detectors were left out all night and recorded many more bat passes than the surveyors, who were present for approximately two hours around dusk and two around dawn. For example, in 2015 there were five greater horseshoe bat surveyor observations above the safe crossings across the scheme across all observations (Table 3), whilst the Anabat detector captured 24 passes above the mitigation (Table 2). Although surveyor observations were generally much less frequent, they did provide important qualitative information, showing that the majority of 'above the mitigation' bat passes (a) were the result of foraging back and forth by a small number of bats rather than commuting by a large number, and (b) comprised bats foraging over the grass verges and therefore in areas where they were less at risk of collision with vehicles.

To determine whether mitigation has been truly effective in population terms, it is necessary to review the status of the nearby SAC roost over the last five years. The population of greater horseshoe bats at Slebech Park has increased steadily since 1985, but declined dramatically between 2012 and 2013 (Figure 7). This decline coincided with a particularly bad summer for the species in 2012 (L Wyatt, Welsh Government, pers. comm.), resulting in lower than normal recruitment.

Two other nearby roosts in the SAC, the Felin Llwyngwair roost and the Stackpole roost, saw rises in greater horseshoe bats numbers of 22.9% and 18.4% respectively between 2013 and 2015 (Table 5) (M. Chadwick pers. comm.). This suggests that the fall in numbers recorded at Slebech could have due to some bats moving to these other roosts, rather than a result of the new A40 road scheme. It is considered more likely that building works at the Slebech roost temporarily forced some bats to leave the maternity roost and find an alternative. The population at Slebech recovered in 2014 and 2015, with an increase of 34% between the low in 2013 and the figures for 2015 (Figure 7). The construction of the road does not therefore appear to have led to significant declines in the local greater horseshoe bat population.

No bats were found during the corpse counts carried out in 2015. Although the grass of the adjacent verge was short in May and July, in June the long, dense grass sward may have obscured any bat corpses that were present. For a number of reasons, any bat hit by a vehicle could be very difficult to find; for example, it could be stuck to the vehicle, swept a considerable distance from the verge, or picked up by a scavenger during the night, before the corpse search was conducted. An absence of corpses should not therefore be considered to confirm a lack of vehicle collisions.

However, bats were most frequently recorded crossing the carriageway of the new road when traffic levels were very low, between approximately 2300 h and 0100 h for bats heading off to forage in the evening; and between 0300 h and 0500 for those returning to the roost at the end of the night. The likelihood of these bats being hit by a vehicle - when it takes no more than two seconds for a bat to cross the road, and traffic rates at dusk and dawn are in the region of 2.7 and 0.57 vehicles/min, respectively – was extremely low. Notwithstanding this, the provision of safe crossings for greater horseshoe bats in this location is considered appropriate, especially given the rarity and low reproductive rate of the species.

We therefore conclude that the underpasses and culverts incorporated into the design to allow bats to safely cross the new road fulfilled their function effectively over the first five years of the scheme's existence. Critically, the proportion of bats using the mitigation relative to that flying over the road was high, and the majority of encounters with the road took place when traffic volumes were very low.

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