Design, Installation, and Monitoring of Safe Crossing Points for Bats on a New Highway Scheme in Wales

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Abstract: The greater horseshoe bat (*Rhinolophus Ferrumequinum*) is strictly protected under European Union (EU) and United Kingdom (UK) legislation. This serves to ensure that the species (as well as its roosting sites and feeding habitat) receives strict protection and that appropriate monitoring of populations will be undertaken.

The Milton-Carew-Sageston area of West Wales (UK) has been shown to be utilized by much of the Welsh population of greater horseshoe bats. Potentially, therefore, anything which significantly affects this area could have an important impact upon the survival of this population.

A proposed road scheme, the A477 Sageston to Redberth Bypass, was to pass through a mosaic of pasture, hedgerows, marshy stream courses, and small woodlands, which constitutes near optimal foraging habitat and dispersal routes for bats. Greater horseshoe bats had been shown to cross the existing road in several locations, and there were known to be nine principal greater horseshoe bat roosts within 2.5 km of the study area.

In order to reduce the likelihood of the bats being killed on the new road, it was necessary to discourage the bats from foraging along the road verge, while simultaneously providing safe and attractive crossing points, at locations where the bats were already known to cross the route of the proposed road. This involved: (i) the maintenance of attractive linear features (lines of trees, hedgerows, etc.) perpendicular to the route to lure the bats away from the road; (ii) a relatively wide verge of poor quality habitat (e.g., amenity grassland, hard standing, etc.) directly adjacent to the carriageway (and for some distance along it) to discourage the bats from foraging along the road; (iii) safe crossing points at culverts underneath the road on the alignment of existing flight lines; and (iv) the omission or alteration of street lighting at crossing points to be retained so that these areas remain in relative darkness.

The exact location of the tunnels, the planting leading to them, and the engineering design of the tunnel approaches were developed by an integrated team of ecologists and engineers.

The measures were installed in 2002, and the road opened to traffic in 2003. The success of the mitigation measures have been monitored through bat activity surveys in 2003 and 2004, and the tunnels are proving to be extremely effective in allowing bats to cross the road safely. No records of bat/vehicle collisions have been recorded.

Information is also provided on other schemes in Wales which have involved the provision of safe crossing points and mitigation for horseshoe bats.

Introduction

This paper relates to a road improvement scheme in Wales, the A477 Sageston to Redberth Bypass, which is a single-carriageway road (two lanes of traffic, one in each direction), covering a distance of over 4 km (around 2.5 miles) bypassing two villages in West Wales, United Kingdom (UK). This road scheme severed the foraging habitat of greater horseshoe bats, and it was, therefore, necessary to design mitigation to avoid the mortality of bats crossing the route and to replace lost habitat. Other issues also influenced the scheme design and construction, such as road safety, traffic flows, community requirements, landscape sensitivity, and heritage.

The greater horseshoe bat (*Rhinolophus ferrumequinum*) is an endangered species and is subject to strict legal protection in the UK. Roads can have a significant negative impact on bats, individually and at population level, through the loss of roosting sites and foraging habitats, the fragmentation of foraging and commuting routes, and through the potential for road mortality. Greater horseshoe bats tend to fly low to the ground, which increases the risk of road casualties. They also avoid excessively-lit areas, increasing the risk of fragmentation of traditional foraging and commuting routes where road lighting is provided. Road schemes must, therefore, be carefully designed and constructed to ensure that foraging habitat and commuting routes for this species are not disrupted.

Legislation

All species of bats are protected in the UK under Section 9 of the Wildlife and Countryside Act (1981). The European Community "Habitats" Directive (enacted in the UK as the Conservation (Natural Habitats, &c) Regulations, 1994) gives further protection to the greater horseshoe bat. This ensures that the species, as well as its roosting sites and feeding habitat, receive strict protection and that appropriate monitoring of populations will be undertaken.

The Ecology of the Greater Horseshoe Bat

The greater horseshoe bat is one of the largest species of bat in the UK, typically 15-30 g, more commonly at the heavier end of this range, with a head and body length up to 71 mm. It has shown a significant decline in the last 100 years, particularly in western and northern Europe. Within the UK, it is now restricted to the south-west of England and south Wales. While the UK population of the species is believed to be increasing, the total number is likely to be of the order of 4-6,000 individuals.

The greater horseshoe bat feeds on insects within deciduous woodland, scrub, permanent pasture, and along water and hedgerows. Greater horseshoe bats have a high frequency call (of approximately 82 KHz), which is quickly attenuated. As a result, even relatively narrow gaps in hedgerows can have a significant impact on their behaviour. Road schemes that sever such commuting routes can, therefore, disrupt the activities of bats and prevent them reaching important foraging areas.

The Value of the Corridor to Greater Horseshoe Bats

The line of the proposed bypass runs through a mosaic of pasture, hedgerows, marshy stream courses, and small woodlands around the villages of Milton and Sageston, which constitutes near optimal foraging and dispersal habitat for bats. Greater horseshoe bats had previously been shown to cross the existing road in several locations at the western end of the scheme (see fig. 1) (Stebbings 1996), and a number of known greater horseshoe and lesser horseshoe (*Rhinolophus hipposideros*) bat roosts were within 4 km of the study area.

The area around the scheme has been shown to be utilized by much of the West Wales population of greater horseshoe bats, and is located between the two most important roosts in the region. A major bat roost at Stackpole (approximately 10 km to the southwest of the scheme) is known to contain approximately 300 greater horseshoe bats, while that at Slebech (12 km (7.5 miles) to the north of the scheme) supports about 150 individuals. Radio-tracking studies have shown that bats routinely disperse between these roosts (often via Carew Castle situated 600 m from the bypass), crossing several major roads in the process. The dispersal of bats around the area varies throughout the year, as bats move to different roosts in order to take advantage of seasonal changes in food availability and to reach hibernation sites. It was, therefore, identified as a risk that bats would cross the route of the new bypass at several different locations over the course of the year.

Carew Castle, which lies to the north of the village of Milton, was designated as a Special Site of Scientific Interest (SSSI), a national designation, in 1995. It is included in Pembrokeshire Bat sites and Bosherton Lakes Special Area of Conservation (SAC), a Europe-wide designation indicating the international value of this roost to this endangered species. The Castle itself is included within the designated sites because of its importance as a transitory roost, especially in the spring and autumn, by greater and lesser horseshoe bats.

Identifying Bat Crossing Points

The points at which bats were most likely to encounter, and cross, the new road were identified, in order to inform mitigation requirements. This was achieved both by assessing the existing bat survey and radio-tracking data, and on the basis of a walk-over survey. The potential significance of the impact of the scheme on greater horseshoe bats was not fully recognized during early scheme development, but during detailed design work by the authors at the start of construction. A total of 12 potential crossing points were identified, as shown in figure 1.

Bats could encounter the route of the new road in a variety of locations, but these points represented the most likely features that horseshoe bats would use. They comprised single discrete features (for example, a lane bounded by hedgerows which was relatively isolated from other potentially valuable features for foraging or commuting bats), or clusters of potential crossing points (for example, a group of hedges intersecting the route). Monitoring these potential crossing points involved pairs of surveyors stationed at appropriate locations. Some remained largely stationery at suitable vantage points; others patrolled short transects in order to "cover" adjacent features. At each location, bats were recorded and identified by using a combination of heterodyne and time- expansion bat detectors. In particular, time-expansion detectors were used to record the sounds of the different species heard, and these recordings were downloaded onto a computer and their sonograms analyzed to confirm field identifications. At all locations, the surveyors focused on detecting horseshoe bats, but as many other bats as possible were recorded incidentally.

Wherever possible, the numbers of bats, the species involved, the directions and height of flight, and their activity (i.e., apparently foraging or commuting) were recorded. In some instances, the bats involved could be seen; on other occasions the surveyors had to rely on echolocation calls alone.

All crossing points were monitored on at least two occasions during the summer at the start of construction in 2001. These visits were undertaken in good weather conditions, when temperatures remained over 10?C, with no rain and very light winds. Monitoring began 30 minutes before dusk and continued until at least three hours after. Each dawn, following the monitoring surveys, and incidentally at other times, the verges of the existing A477, focusing on the most likely crossing points were searched with care for any bat road casualties. The existing road was also examined for bat vehicle strike casualties, particularly at the locations of likely crossing points.

A total of six monitoring visits, each covering two nights, were carried out in 2001 in order to examine in more detail the activity of greater horseshoe bats. In addition, attempts were made to investigate the movements of horseshoe bats to and from the known roost in Carew Castle, to the north of the route.

Greater horseshoe bats were recorded on five of the six visits, in relatively low numbers, and were found to encounter the route in only one section where those hedgerows in close proximity were severed by the bypass. In total, greater horseshoes were observed crossing the proposed route on two occasions, with most records relating to commuting bats which were deterred from continuing across the line of the route by the site clearance work which had already started in advance of construction. It was considered that this represented a significant corridor used by bats which was likely to have been used more heavily prior to the start of work. Other bat species recorded were soprano pipistrelles (*Pipistrellus pipistrellus* and *Pipistrellus pygmaeus*), noctule bat (*Nyctalus noctula*), Natterer's bat (*Myotis nattereri*), and other myotid bats unidentified to species. Although lesser horseshoe bats are known to roost in the area, none was recorded during these initial surveys. Bats crossed under the route at the Milton Culvert, a culverted watercourse at the western end of the route.

Figure 1. The location of potential bat crossing points.

Mitigation Design: Bat Tunnels

Following the baseline surveys, mitigation measures were proposed to provide safe crossing points at the two locations bats had been observed to cross. Although the number of bats crossing at this point was low, it was more economical to install them as part of the main works than to retro-fit later. Since the road was on an embankment at the crossing points, two culverts were set into the embankment, one at each crossing point. A large corrugated steel section elliptical tunnel of 2.2 m diameter was installed at one crossing, and a similar but smaller (1.8 m diameter) tunnel, at the second location (see figure 2). The tunnels were located to be on the alignment of the identified flight path, including one which was not perpendicular to the road. These were installed at a cost of approximately £100,000 ($180,000 USD).

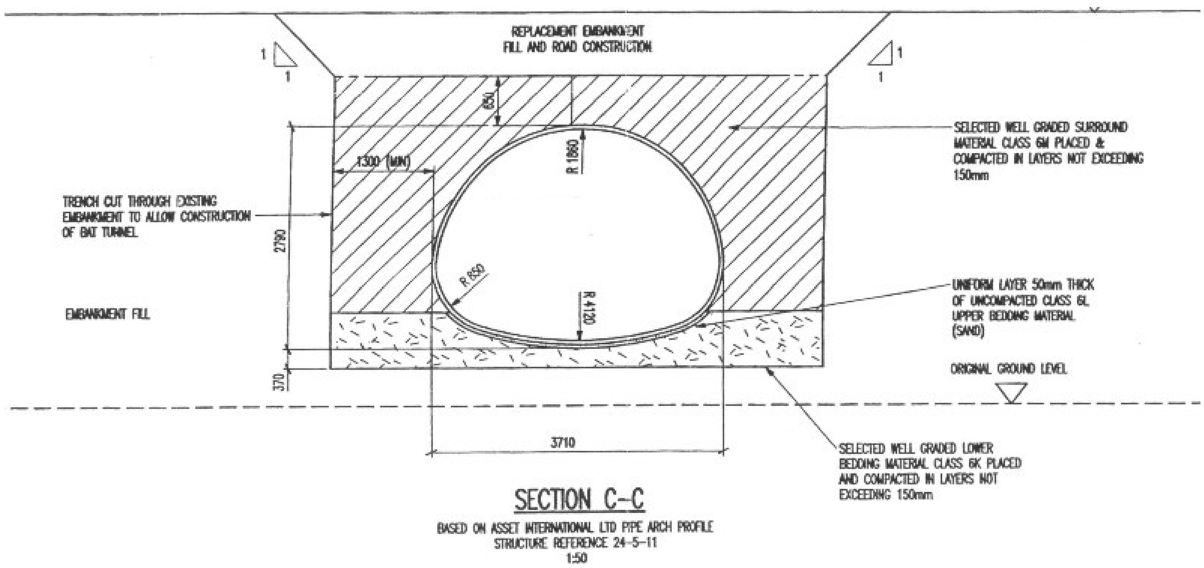

Figure 2. Bat culvert in section.

The culverts were positioned on the lines of severed hedgerows so that they followed the bats desired flight lines as far as possible. Small embayments were made in the embankment earthworks creating a "funnel" shape to maximize the chance of bats encountering the tunnel. Planting was provided around the vertical sides of the funnels, extending towards the severed hedgerows, to increase the funnel effect (see figure 3). The intention of the planting was to guide bats from the severed hedgerow to the culvert mouth, and, thus, planting was not extended up over the top of the culvert as this might encourage bats to fly over the road.

Figure 3. Planting at the bat culvert. These photographs show the planting at an early stage. In the photograph to the left, the culvert is located in the recess.

Container-grown plants were used to replace/restore linear features removed during the works, to guide bats to the culvert mouths.

The plants used were:

1. *Crataegus monogyna* (120-150 cm)
2. *Salix caprea* (80-100 cm)
3. *Salix cinerea* (80-100 cm)
4. *Sambucus nigra* (80 cm)
5. *Ilex aquifolium* (40-60 cm)
6. *Rosa canina* (60-80 cm)
7. *Prunus spinosa* (60 cm)

Monitoring

Bats crossing the road

Further bat activity surveys were undertaken between April and September 2002 and between May and October 2003 (Cresswell Associates 2003, 2004) in order to monitor bats crossing the scheme. The results of these surveys broadly supported the conclusions of the 2001 survey work, that relatively small numbers of greater horseshoe bats encounter the route and that they do so in a small number of key locations. However, greater horseshoes traversed the scheme (either over the road or through culverts) at almost all crossing points where they were recorded.

The frequency at which both horseshoe bat species encountered the scheme at the crossing points adjacent to the bat culverts was low in 2002 and 2003. The 2002 surveys showed reduced levels of activity for this species at these two crossing points, compared to 2001. This could have been a temporary effect due to the additional impact represented by the presence of both the old A477 and the scheme under construction, or a consequence of land-use changes in the wider landscape. However, greater horseshoe activity at these crossing points remained low in 2003 and, although beyond the scope of these surveys, no major changes in land-use patterns have been observed in the vicinity of these crossing points.

Since all the hedgerows and other potential linear features crossing the route had been removed prior to the 2001 surveys, "historical" bat activity could already have been altered substantially, reducing the likelihood that the bats would cross the scheme in 2001.

As far as future mortality associated with bats crossing the new road is concerned, the monitoring in 2002 and 2003 confirmed that greater horseshoe bats appear to be crossing the route relatively infrequently and in small numbers, which suggests that the frequency of road mortality may be expected to be low. However, the bats do appear to encounter the route at hedge-top height and due to the surrounding landform, this would make them vulnerable to traffic using the road. It is conceivable that, as the vegetation close to the new road re-grows and the new plantings mature, the bats may be encouraged back across the route in additional locations. In addition, it is possible that horseshoe bats encountering the new road would be encouraged to forage along its new verges and developing hedgerows, thus subjecting them to enhanced risk from road traffic.

In addition to the installation of culverts, it was also considered appropriate to review planting proposals on each side of the scheme in the area around a crossing point to ensure that bats were deterred from using "unsafe" crossing points. Typical measures included:

1. The maintenance of attractive linear features (lines of trees, hedgerows, etc.) perpendicular to the route to lure bats away from the road.
2. A relatively wide verge of poor quality habitat (e.g., amenity grassland, hard standing, etc.) directly adjacent to the carriageway (and for some distance along it) to discourage the bats from foraging along the road.
3. The omission or amendment of street lighting at "retained" crossing points so that these areas remain in relative darkness, without compromising road safety.

In areas where such landscape planting forms a critical role in "funneling" bats towards a particular structure, their effectiveness will be expected to increase as the plantings mature.

Bat culverts

Bat activity within the two bat culverts was recorded in 2002 and 2003 using automatic monitoring equipment. The equipment consisted of a Pettersson D240X bat detector capturing and downloading ultrasonic calls onto a Sony Professional Walkman tape recorder. As with recordings obtained by surveyors in the field, recordings were downloaded onto a computer and their spectrograms analyzed to and in the identification of species.

Greater horseshoe bats were recorded using the bat culverts in 2002 and 2003. In both years, greater horseshoe bats were recorded using each culvert on only one occasion. One of the bat culverts was also used by a lesser horseshoe bat. These low figures may in part be due to the fact that the frequency at which the species encountered this part of the scheme was greatly reduced, compared to 2001. Furthermore, given the directionality of the bats' echolocation calls, and the technical limitations of the automatic monitoring equipment, it is possible that only bats flying in one direction were recorded, and that these results are, therefore, an underestimate of the use of the culverts by greater horseshoes.

The two bat culverts were well used by myotid and pipistrelle bats, both for commuting and occasionally foraging bats. The culverts were used extensively by these species once the scheme was opened to traffic. Due to the low levels of horseshoe bat activity encountered at these crossing points and the lack of true baseline data, it was not possible to fully assess the success of the bat culverts. However, the suitability of the culverts for greater and lesser horseshoes (as well as other bat species) has been confirmed, and their effectiveness is likely to increase significantly as the planting at the culvert mouths matures. In 2004 a single survey visit recorded greater horseshoe bat passes in one of the culverts, and it appears that their use is increasing.

Milton culvert
Monitoring was also carried out within a stream culvert in Milton village elsewhere on the scheme, which was lengthened to accommodate the increased width of the new bypass. Bats had regularly used the culvert prior to the construction works. In 2002, greater horseshoe bats were recorded using the stream culvert at Milton on all but one visit, confirming the importance of the stream corridor as a commuting route for this species. Typically, two to four greater horseshoe passes were recorded per survey night throughout the year, though again this may only represent bats flying in one direction. Myotid and pipistrelle bats were also recorded using the Milton stream culvert throughout the survey season.

Bat casualties
Following opening of the new scheme to traffic on 29 August 2002, searches were also made along the verges of the new road for bat casualties at likely crossing points. No bat road casualties were recorded on any of the eight visits, either during baseline surveys or once the road had opened.

Although no evidence of bat casualties was found, this should not be interpreted as confirmation that no road casualties occur along the new road, or potentially on the existing road. When hit by a vehicle, the corpse may travel some distance, even remaining attached to the vehicle, before dropping to the ground. Bat bodies are small, particularly when the wings are closed, and in dense or tangled vegetation (such as a hedgerow) they would be inconspicuous. It would be expected that, particularly immediately after opening of the scheme when vegetation along verges was sparse, corpses would be easier to detect; however, they may also be more attractive to nocturnal and diurnal predators (e.g., cats, foxes, birds of prey) in these areas.

The effect of lighting on bat movements
Following installation of lighting at the Milton road junction, close to the culvert used by greater horseshoe bats (shown in figure 4), it was noted during surveys in 2003 that light levels at the mouth of the southern end of the culvert were increased, compared to 2001 and 2002, but not at a regular level across the entrance – one area slightly darker than another. A lighting column on the south side of the A477, located above and to the west of the culvert, spills light behind the lighting column and away from the road. A lighting column to the north of the A477 (east of the culvert) also sheds lights across the road and across the culvert mouth.


Figure 4. The Milton culvert

Levels of greater horseshoe bat activity at the Milton culvert remained high throughout the 2002 survey season. In 2003, however, and subsequent to the road opening in late 2002, the levels of greater horseshoe bat activity at Milton culvert were significantly reduced. The reduced levels of activity were particularly apparent in summer 2003, as no greater horseshoe bats were recorded on three survey visits in June and July. The culvert is most in use during spring, and, therefore, the patterns of use are seasonal as well as related just to light levels. It is considered highly likely that this reduction in activity is a result of the increased light levels at the culvert mouth on the southern side of the scheme (primarily due to the lighting column on the west side of the culvert south of the road), as horseshoe bats are known to avoid well-lit areas. The bats that were observed using the culvert in 2003 appeared to modify their behavior in response to the lighting by hesitating before flying faster and lower between unlit area.

It is not known whether survey results for greater horseshoe bats at Milton culvert in previous years represented regular use by small numbers of bats, infrequent (possibly seasonal) use by larger numbers of bats, or both. It may be that the seasonal importance of Carew Castle nearby, in spring and autumn (as described in previous reports), means that bats using the culvert at these times of year are more likely to do so in order to move between roosting sites, rather than commuting between their roost and foraging areas (as would perhaps be more likely to be the case for bats using the culvert in summer). Consequently, it is difficult to assess any impacts that the reduced use of this culvert in 2003 may have on greater horseshoe bats. Clearly, if lighting at this mouth of this culvert were affecting the bats' movements between seasonal roosting sites, or regular movements between roosts and key foraging areas at critical times of the year, it could have a potentially significant impact, through habitat fragmentation, on the Pembrokeshire greater horseshoe bat population. Conversely, if the lighting were only affecting the foraging behavior of a small number of individual bats, the impact of the lighting in the long-term would be less significant.

The following remedial measures were, therefore, considered to mitigate the impact of the lighting on the bats' use of this crossing point.

1. Realigning the lighting
2. Installing a baffle on the lighting column to minimise the light spill away from the road itself

This would reduce light levels at the edge of mature vegetation close to the scheme, but because of the proximity of the lighting column to the culvert, would probably not be effective in reducing light levels at the culvert mouth itself without also reducing light levels on the road carriageway above.

Consequently, it was also recommended that:

The area between the headwall of the culvert and the ends of the wingwalls be screened more effectively.

The latter could be achieved by the planting of, for example, willows on each side of the watercourse tied together at the tips to create a "natural" arch extending out from the culvert mouth, or by provision of a screen. Potential screening methods include using standard "garden" type fencing panels or using standard street furniture materials, such as a blank road-sign panel fixed on posts and aligned parallel to the existing fencing running down the wingwall.

At the time of this writing, these measures have been accepted but not yet implemented by the relevant highway authority. Further monitoring will take place in 2006.

Overall, the Sageston-Redberth Bypass gives us an example of how bats can be safely directed under roads using culverts with associated planting and by manipulating lighting and landscape planting. To some extent, the success of the mitigation at Sageston relates to the fact that the scheme is on an embankment at the points bats cross it. There are different issues to resolve where roads are at grade or in cutting. A range of other such situations are described below.

Other Schemes

A487 Llanwnda

The A487 from Llanwnda to south of Llanllyfni Improvement in North Wales is close to a site of European value for lesser horseshoe bats and severs a number of regularly-used commuting routes. Like the A477, it is a single carriageway scheme. There have been records of bat casualties of the common pipistrelle, soprano pipistrelle, brown long-eared (*Plecotus austriacus*), and lesser horseshoe bat (Billington 2001, 2002, 2003). A number of innovative mitigation techniques are being used for Lesser Horseshoe Bats on this scheme with mixed success. Some have proved to be more successful than others, including semi-permanent bollard based lighting to deter bats from crossing the road and divert them to an underbridge; and fencing to guide bats to that location. However, much of the fencing that had been installed to prevent bats from crossing the road, 2 m and 4 m high, with single and double cranks at the top of the fence, has not worked as well as expected. This may relate to the manoeuvrability of lesser horseshoe bats. When they encounter a fence, they fly up over it and immediately twist to return to their original flight path height.

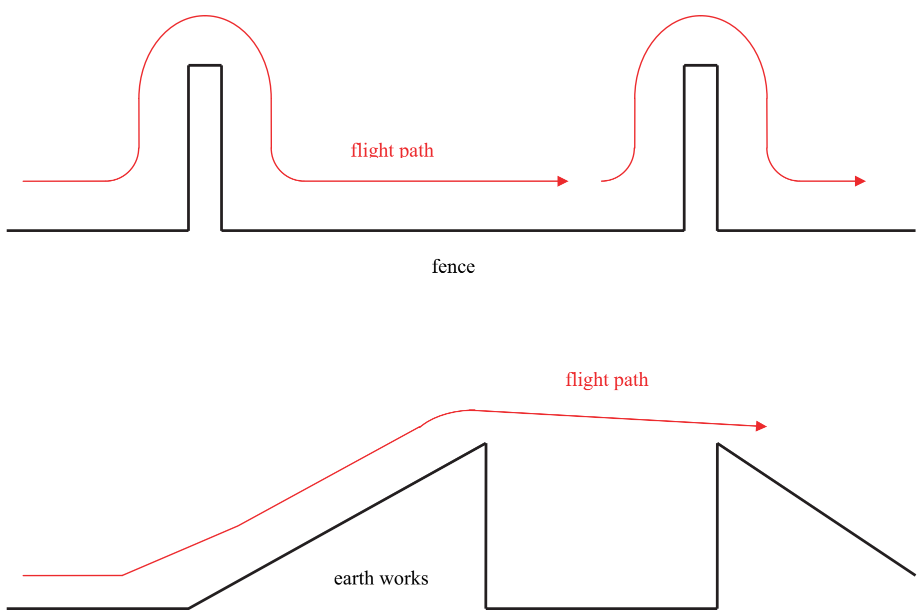

Figure 5. Flight paths of lesser horseshoe bats over obstructions.

In contrast, gently-sloping earthworks (false cuttings) seem to have greater success in extending the bats' higher flight path.

If the potential impact on bats had been better recognized at an earlier stage, more effective means of "lifting" bats up and over the road might have been possible.

Sirhowy Enterprise Way

Mitigation was required for the proposed Sirhowy Enterprise Way in south Wales, as bats were known to use woodland on either side of the new road. Daubenton's (*Myotis daubentonii*), whiskered (*Myotis mystacinus*), and brown long-eared bats were known to forage in the area, and, therefore, it was necessary to design appropriate mitigation for these species. Flight paths crossing existing roads, either at tree canopy level or through bridges, and foraging habitat on and near the proposed route were identified. Based on the findings of these surveys, four high-level crossings comprising netting (approximately 2.5 m wide) tensioned between tree canopies were proposed (see figure 6). This, combined with a reduction in lighting at important locations, provided a commuting route across the road, linking important foraging habitat. To date, only one of these structures has been installed, and its success is yet to be monitored.

Figure 6. Bat crossing at Sirhowy.

Mitigation in addition to crossing points is often required to complement or enhance the crossing structures installed by enhancing one side of the road or another.

A470 Lledr Valley

During surveys to inform mitigation for the improvement of the A470 in Lledr Valley to single carriageway standard, lesser horseshoe bats were recorded foraging on either side of the road, and a bat roost was recorded adjacent to the scheme. Mitigation measures were proposed to provide alternative roosting sites for bats, involving construction of a hibernation chamber and roosting sites within the dry stone retaining walls for the scheme. The hibernation chamber (shown in figure 7) comprised a buried structure with access through a letter-box-sized entrance hole (shown in figure 8). A low level concrete pipe provided access from the outer to the inner chamber, ensuring an unventilated, stable microclimate within the inner chamber. This also ensured that there was no natural light within the inner chamber and provided optimal conditions for hibernating and roosting bats. Rough, untreated wooden boards and battens were fixed to the chamber wall and ceiling in order to provide crevices and roosting sites for bats. The hibernation site is currently being monitored to assess its success.

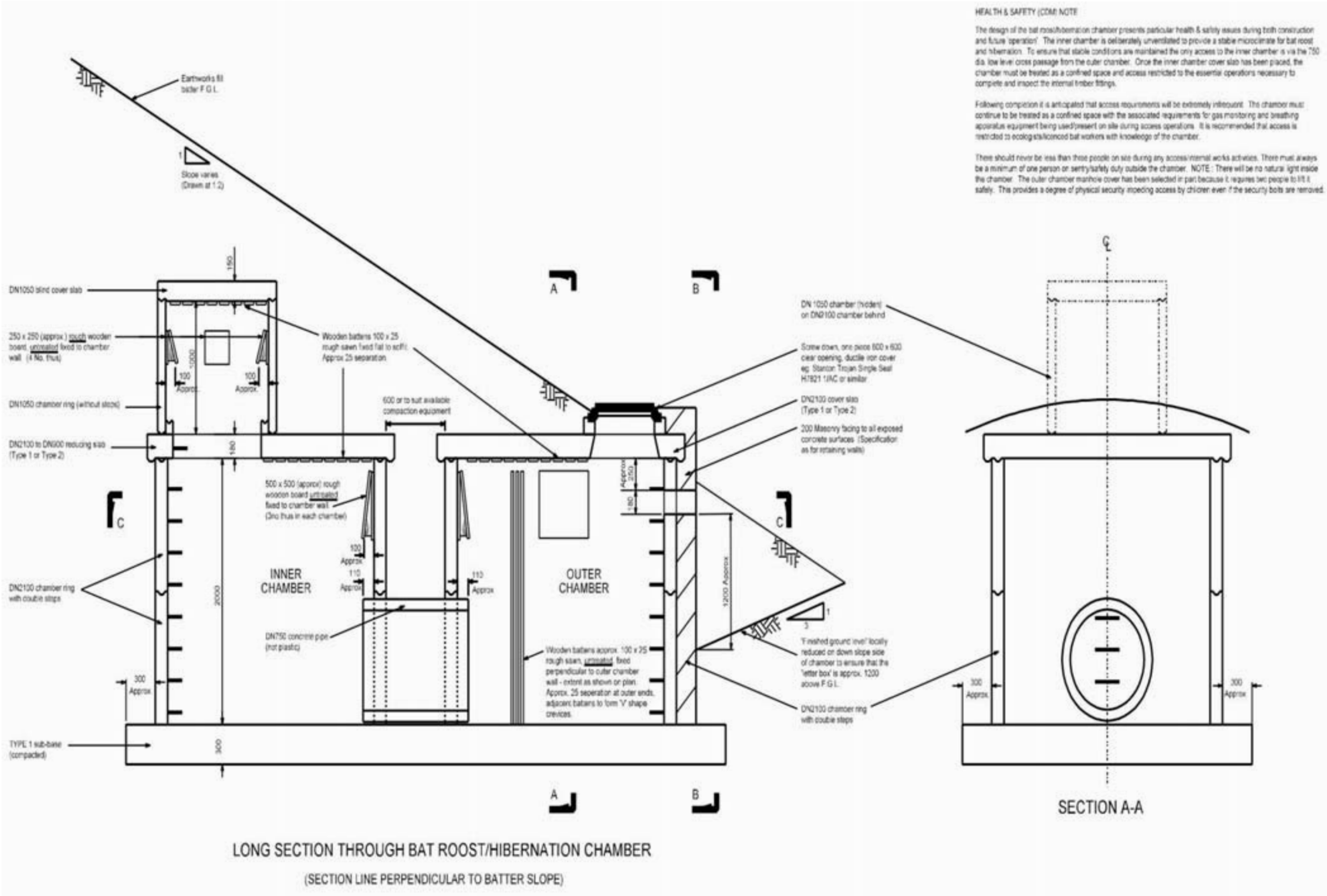

Figure 7. Plan of the bat hibernation chamber at Lledr.

Figure 8. External view of the bat hibernation chamber at Lledr, showing the letter-box-sized entrance to the underground chambers.

A second mitigation measure involved providing bat roosting sites within the dry stone retaining walls for the road. This comprised letter-box-sized entrances (shown in figure 8) leading to small chambers within the road embankment. This not only provided suitable roosting sites for bats, but also provided a refuge for other species, including reptiles.

Figure 9. Entrance to the bat chamber within the retaining walls at Lledr.

Conclusions

The route of the Sageston to Redberth Bypass passes through optimal foraging habitat and commuting routes for the greater horseshoe bat, a species strictly protected by EU and UK legislation.

In order to reduce bat casualties on the new road, it was necessary to prevent bats from foraging on the road verge and provide safe crossing points. This was achieved through a combination of planting, designed to encourage bats away from the road; crossing points at culverts underneath the road; and a change in street lighting at crossing points to be lit, so that these areas were more likely to be used by bats, without compromising road safety. Baseline surveys were carried out in order to identify bat crossing points to inform mitigation requirements.

The road was opened to traffic in 2003, following installation of the mitigation measures in 2002. Following construction, further monitoring was carried out to evaluate the success of the mitigation. These surveys confirmed that greater horseshoe bats were using the retained and additional culverts, as were other species of bats. These measures have reduced the frequency with which bats cross over the scheme, thus reducing the risk of casualties. These surveys highlighted the need for additional mitigation measures at the Milton culvert, which was being used by bats less frequently after the road improvement, apparently due to the change in light levels in this area. Measures have been proposed to re-align the lighting, minimize light spill away from the road, and screen the area being used by bats. Further monitoring is scheduled for 2006 to evaluate the success of these additional measures.

The effectiveness of this mitigation has depended upon:

- Timely identification of the potential impacts allowing mitigation measures to be put in place during construction and avoiding costly retro-fit.
- Locating safe crossing points for bats in the positions most likely to be effective based on comprehensive baseline survey information.
- Modifying the earthworks and planting close to crossing structures to ensure that bats are led towards them.
- Monitoring effectiveness post-construction so that any necessary modifications can be made.

The other experience in Wales described in this paper supports these conclusions, but it is true to say that more needs to be learned about the way individual species of bats cross and use roads, and the effectiveness of mitigation. Work to continue to improve the knowledge of bats and roads interactions continues to take place.

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Biographical Sketches: Stephanie Wray holds a B.S. degree in zoology and a Ph.D. in mammalian ecology. Her research interest in bats dates back 15 years, and she has undertaken projects in the UK and overseas. She recently completed a major research project on the use of habitats by lesser horseshoe bats at the landscape scale. Stephanie is a director of the environmental consultancy, Cresswell Associates, and specializes in ecological impact assessment.

Paola Reason holds a B.S. degree in zoology and an M.S. in conservation. Her interest in bats began 15 years ago, and she has undertaken a large number of projects in the UK and overseas – one of which has resulted in the funding of an NGO actively working in the Comoro Islands to promote fruit bat conservation. Paola is assistant director at Cresswell Associates and specializes in protected species work primarily relating to bats and the development of best practices.

David Wells holds a B.S. degree in biology and has been involved in bat conservation and research for 15 years. While at university he undertook a research project into the roosting ecology of pipistrelles, the findings of which were reported at the UK national bat conference. David is a senior ecologist at the environmental consultancy, Cresswell Associates, specializing in protected species surveys and mitigation design. Much of his work involves coordinating, and leading, the large survey teams required for monitoring bat activity on road schemes and other developments. This has recently included coordinating fieldwork for a research project into habitat use by lesser horseshoe bats.

Warren Cresswell holds a B.S. degree in zoology and a Ph.D. in mammalian ecology. His experience of carrying out specialist ecological surveys and developing and implementing innovative mitigation measures dates back over 15 years. Warren is a director of the environmental consultancy, Cresswell Associates, and specializes in ecological impact assessment, in particular, for protected species.

Hannah Walker holds a B.A. degree in biological sciences. She is an assistant ecologist at the environmental consultancy, Cresswell Associates, and has carried out a number of ecological surveys to inform mitigation for developments affecting bats. This has involved bat activity and emergence surveys as well as analysis of the results of these surveys.

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