A METHOD TO ASSESS THE EXTENT OF ROAD AVOIDANCE BY WILDLIFE ON ROAD VERGES IN DECIDUOUS WOODLAND HABITAT, IN THE UK.

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Abstract

The intensity and growth of the road network in the UK during the last 20 years has reduced much of the British landscape to small fragments of often sub-optimal wildlife habitat. Whilst some autecological studies have been undertaken in Britain, there has been comparatively little research on the effects of roads on the assemblage of different mammal species commonly found on roadsides. This paper describes the pilot study using sandbeds to provide a holistic approach to elucidate the ecology of roads and wildlife. Sandbeds provide a method to assess the permeability of roads for an array of British mammals and can also be used to assess the effectiveness of measures designed to mitigate the effects of fragmentation arising from linear transport infrastructures. Study methods which use traps and which are routinely used for single species investigations are unsuitable when dealing with species which range in size from 48mm (shrews) to 1000mm (fallow deer). Footprints and tracks left in sand beds however, enable all mammals to be studied, whatever their size. The data collected provide a relatively easy and inexpensive means of assessing the extent to which various species are affected by different classes of roads and different traffic densities.

Introduction

Linear transport infrastructure such as roads and highways has a major impact on the environment. In the UK, there are around 370,000km of roadways (DETR, 1988), representing both considerable habitat loss under the footprint of the road and degradation of adjacent habitat by disturbance, noise and pollution. Habitat loss under the footprint of the road is a direct and obvious environmental impact and is an issue that is addressed by environmental impact assessments before new developments. However, the impact from habitat fragmentation caused by a dense road network in a highly populated country is arguably more far-reaching, potentially affecting migration of fauna, gene transfer between populations, population dynamics and ultimately reducing the fitness of individuals and populations. At the same time, road verges can represent a considerable ecological resource in the form of a >green estate= which can theoretically benefit wildlife by providing longitudinal habitat and >green corridors= facilitating the movement of genes and wildlife through an otherwise ecologically depauperate landscape.

The management of the road network=s >green estate= in the UK is divided between the Highways Agency (for motorways and all-purpose trunk roads) and the various local highways authorities (for all other roads). The Highways Agency in England is an executive agency, part of the Department of Environment, Transport and the Regions. It has responsibility for the Trunk Road Network that extends across England connecting the major conurbations with ports, airports and manufacturing and distribution centres. The network comprises of only 4% of the roads by length, but carries 34% of all traffic including more than half of all heavy goods vehicle movements. The network is strategically important within the national economy and caters for very high traffic flows.

The Highways Act 1980 is the primary legislation that provides the Highways Agency (HA) with powers on behalf of the Secretary of State for Transport for the operation and improvement of the Trunk Road Network. European legislation (EC Directive 85/337 as amended by EC 97/11) requires that all major road projects are subject to environmental impact assessment (EIA) and that an Environmental Statement is published that sets out the impact that the proposed highway scheme may have in a number of categories. Environmental Impact Assessment was established by statute for all major road projects in the UK in July 1988. It is now a well-established procedure for new roads, and must take account of factors which may prove damaging to wildlife and the natural surroundings. Proposals for new developments must be critically examined and measures must be recommended to avoid or ameliorate any adverse impacts anticipated.

There are a number of protected species of fauna in the UK which are particularly at risk from highways and the traffic that they carry, notably the badger (*Meles meles*), the otter (*Lutra lutra*) and all our native species of bat. Deer, of which there are six species present in the UK (including introduced species), are at risk from collision with traffic and may be a road safety issue, but are not protected in law.

The badger and its sett are entirely protected by the Badger Acts 1973 and 1992. The HA has gathered 20 years of experience in providing mitigation for badgers where their setts or territory are affected by highways. The relocation of setts has been carried out successfully and tunnels have been provided to reconnect foraging routes severed by highway construction. Fencing is a necessary part of the tunnel provision to direct the badger to the tunnel (or any other crossing facility such as a farm underpass). The population of badgers in the UK is estimated at 300,000 and deaths due to collision with road traffic are estimated at 50,000 animals every year. In general this does not pose a threat to the total UK badger population but it is a serious animal welfare problem since many animals are badly injured and are seen on the roadside and many more die away from the road as a result of their injuries. Much of the existing road network has no facilities for badgers to cross the line of the road in safety and the retro-fitting of tunnels and associated fencing would be prohibitively expensive other than in particular black spots where accidents occur at a high level of frequency and threaten the viability of a local badger population. The HA has installed over 150 badger tunnels on the Trunk Road network since 1978 and has surveyed their effectiveness in one region of the UK where badgers are most numerous. The measures installed during the first ten years of provision have in some cases proved ineffective. The common errors are with the location of tunnels and the robustness of fencing. Learning from these mistakes the HA has published a comprehensive guidance note on mitigating for the effects of highways on badgers in Volume Ten of the Design Manual for Roads and Bridges (DMRB, 1992).

The otter is a mammal that is both elusive and rare in the UK, and is very much threatened by the impact of highways. Road casualties now account for 60% of otter deaths. As a result of strategic conservation efforts and a successful release programme, the otter is returning to UK rivers and watercourses. Many of these are now crossed and re-crossed by highways, and the high volumes of traffic on trunk roads put the otter at high risk when crossing. The otter is protected under European law, being listed in Annexes IIa and IVa of the EC Directive (92/43) >The Conservation of Natural Habitats and of Wild Flora and Fauna= (commonly referred to as the Habitats Directive). The UK Biodiversity Steering Group Report has identified the otter as a priority species for conservation and protection and the HA is committed to assisting in the detail objectives of the Species Action Plan for the Otter. The principal threat to the otter is the loss of riparian habitat where the highway crosses the watercourse, usually through the use of cylindrical culverts which in times of high water flow present a formidable obstacle to the movement of the otter, otters may then seek to cross the highway. A dry ledge through the culverted section of river will usually suffice to provide a safe passage for the otter. Broad span bridge structures or viaducts are the preferred option for the crossing of major watercourses and rivers since they allow the riparian features to be carried through under the highway which also benefits other species such as the water vole (*Arvicola terrestris*) (which has had an unprecedented fall in population numbers in recent years). Otters may also use tunnels where that is the only option for safe crossing below the highway. These should be located within 50 metres of the riverbank and above possible flood levels. The otter is guided to the tunnel by fencing, and where practicable a water channel running from the watercourse to the tunnel entrance enhances use. The installation of otter mitigation measures on highways that affect otter territory throughout the UK will be a major task for the HA in England, and for the other UK highways departments in Wales, Scotland and Northern Ireland. There are potentially more than 700 crossings to be surveyed in England alone in the next two years. The HA has published guidance on nature conservation advice in relation to otters as part of the DMRB Vol. 10 in the Advice Note HA 81/99.

Bats enjoy protection in European law under the provisions of the Habitats Directive (q v), and there are 14 species of bats present in the UK. Highway construction can destroy bat roost sites as well as feeding habitat, and may sever traditional flight routes. It is possible to provide crossing points for bats in highway construction and this is now being done in England either through the adaptation of existing structures, usually culverts or tunnels, or the provision of new ones. Bats favour watercourses if a culvert can be provided, which should be more than one metre in diameter. Planting of native shrubs can be provided to lead the bats to the crossing. Structures such as bridges can host bat roosts and are therefore potentially important habitat for these animals. Any major alterations such as the maintenance of existing structures or their demolition, are operations that may directly threaten bats. Bat boxes and artificial bat roosts can be fitted to structures where it is practical to do so and monitored for use/occupation. The DMRB provides guidance on the management of highways in relation to bats in the Advice Note HA 80/99

Deer are now very widespread in the UK with an estimated population of 1.5 million of all species. It is considered likely on the basis of extrapolated data that as many as 40,000 road traffic accidents occur on highways in the UK involving deer. Usually these result in the death or serious injury to the animal and this is both an animal welfare problem and a serious road safety consideration. It is likely that in certain parts of the UK road traffic deaths account for between 10% and 50% of the annual cull of deer. There is active deer management in many parts of the UK on the larger land holdings such as those owned by the Ministry of Defence and the Forestry Commission. The 30,000 hectare highway estate associated with the Trunk Road Network in England is often used as a movement corridor and shelter by deer, especially as over 13,000 hectares are planted with predominantly native species of trees and shrubs. Within interchanges, areas as extensive as 30 hectares provide good habitat for deer and can act as a refuge from more intensively managed land where culling may take place. However, the absence of deer management and the heavy traffic volumes on trunk roads presents a very real danger to road user safety where deer may cross the carriageway. Fencing and the provision of adapted crossing points such as farm underpasses or bridges with suitable grass surfaces and linear shrub planting are the most likely elements to be used by deer.

The impact assessment, guidance and mitigation measures for medium to large size mammals such as otter (*Lutra lutra*) or badger (*Meles meles*) in the UK are becoming fairly well understood, although there is still concern that growth in traffic density may cross a threshold of barrier effect beyond which population effects become severe (Clarke et al, 1998). Thus in the UK there are an increasing number of dedicated fauna passages designed or adapted for individual species but few generalist wildlife passages. It is a common strategy in conservation ecology to target conservation efforts to a >flagship species=, a large showy species which has popular appeal, and to assume that if the right flagship species together with its habitat is protected, then the ecosystem with all its component species will probably be protected. There is little evidence that the >flagship= approach to fauna passages will work to mitigate the wider impacts of roads on wildlife. Research is therefore needed using a more holistic approach to elucidate the impacts of roads as barriers for a range of species, and to monitor existing fauna passages with an aim to understanding their use by different species (including those for which they were designed). It is important to note that if the effectiveness of fauna passages is to be determined, more information is required than the certainty of use by given species. It is necessary to know also the extent to which the road otherwise acts as a barrier to movement (or a mortality sink). It is also of interest, particularly in fragmented landscapes, to determine the extent to which the road verge itself may act as a movement corridor through the landscape. There are a range of methods available (Tables 1-3) for monitoring the use of fauna passages and road verges with the following objectives:

? To investigate the extent to which road verges can function as a wildlife corridor.
? To investigate the extent to which roads act as barriers to movement.
? To evaluate the effectiveness of eco-passages.

The methods range from direct trapping of the target species, to more general methods such as video recording of all fauna activity and techniques for recording the footprints of animals using the area. Each method has its own advantages and disadvantages as indicated in the tables, but in general the methods have one or more of the following disadvantages: expensive, labour- intensive, highly skilled personnel required or not comprehensive in terms of data obtained.

The effect of roads on the entirety of small mammal populations is much less well understood than the effect upon medium or large mammals. There is research to show that road verges can be a valuable habitat for small mammals in the UK (Bellamy et al, in press), and mark-recapture style work to show that some roads may discourage small mammals from crossing (Richardson et al, 1997). However most of these methods target a single species or narrow range of species, or study presence or absence of species on the verge and our understanding of the behaviour of the wider mammalian community around roads is minimal. We need to know not only which species are present but also their relative activity levels on the road verge, in the adjacent habitat, and in actually crossing the road. This will then give an indication of the relative importance of the verge as habitat, of any inhibition of mammalian activity in close proximity to the road, of the extent to which the road verge may act as a linear movement corridor, and of the extent to which mammals may venture on or across the road verge.

An intensive trial of sandbeds alongside roads has been established in central England to investigate the suitability of the method to assess activity levels of a range of fauna at varying distances from roads.

Study Area

Woodland sites were selected for the initial study because they constitute a relatively stable and less intensively managed habitat than other semi-natural habitats, they provide discrete, easily delineated boundaries and a habitat that contrasts with the road verge. This may, as a consequence, increase the potential number of species to be found there. A total of eight sites were selected (see Table 4) each located in or near the county of Warwickshire in central England on roads which cut through mature deciduous or mixed woodland. Four different road categories were represented in the study: motorways with high traffic flows (125,000 vehicles per day), roads with traffic volumes in excess of 8000 vehicles per day, those with up to 3000 vehicles per day, and minor roads which carried up to 1500 vehicles per day. Each of the four road categories was replicated once giving the total of eight sites.

With the exception of one mixed woodland site in which the interior, but not the margins, was dominated by conifer, the woodlands were comprised of native, deciduous trees, with ash (*Fraxinus excelsior)* and English oak (*Quercus robur*) as the dominant canopy species and a typical understory of hazel (*Corylus avellana*), field maple (*Acer campestre*) and holly (*Ilex aquifolia*). Dogwood (*Cornus sanguinea*), bramble (*Rubus fruticosus*) elder (*Sambucus nigra*) and honey suckle (*Lonicera periclymenum*) were present in the shrub layer and the field layers included dog's mercury (*Mercurialis perennis*), wood anemone (*Anemone nemorosa*) and bluebell (*Hyacinthoides non-scripta*) along with wood-sage (*Teucrium scorodonium*) and lesser celandine (*Ranunculus ficaria*). At the road-verge margin most of the woods had hedgerow remnants which included hawthorn (*Crataegus monogyna*), blackthorn (*Prunus spinosa*), and privet (*Ligustrum vulgare*). On the road verges there were a mixture of grasses, shrubby species and forbes, for example, cock's foot (*Dactylis glomerata*), Yorkshire fog (*Holcus lanatus*), wood small-reed (*Calamagrostis epigeisos*), red fescue (*Festuca rubra*) ground elder (*Aegopodium podagaria*), nettle (*Urtica dioica*) field rose (*Rosa arvense*) hogweed (*Heracleum sphondylium*), common dog's violet, (*Viola riviniana*) lesser burdock (*Articum minus*), lords and ladies (*Arum maculatum*) and cleavers (*Galium aparine*). In spring and summer some of the vegetation was dense, but only the 'sight line' (the 1 metre linear strip immediately adjacent to the road) on the two busiest categories of road was cut.

Method

Trials have been undertaken using sandbeds to assess their suitability as a technique for detecting wildlife activity on the roadside and in adjacent habitats. Sandbeds were laid between February and March 1999 at the approximate midpoint of the woodland section of eight selected roads. In preparation, linear strips of coarse vegetation were cut back and the ground raked to provide a relatively even surface. To retard the re-growth of vegetation a weed suppressant membrane was installed prior to laying the sand. Three different materials were tested: a specialist thin black membrane available from horticultural agents, metre-wide bitumastic roofing felt (a weather proofing roofing product available from builder merchants) and reclaimed carpet cut to appropriate widths. Finally, silver sand, which is fine enough to register all sizes of footprint and which is less likely to form a surface crust when drying out after rain, was laid directly onto the membrane in 0.5m or 1.0m wide linear strips. The sand was laid to a depth of approximately 1-3cm, although depth was influenced by the wetness of the sand. The surface of the sand was smoothed with a soft bristle broom. A 10m x 1m sandbed requires approximately 200kg (5 x 40kg bags) of sand.

The sand beds were laid out in the form of a 'T' so that the top of the 'T' lay alongside and as near to the road as possible (Figure 1). The 'vertical' section of the 'T' was then run as a transect from the centre of the roadside strip, perpendicular to the road, through the verge and into the adjacent woodland. The roadside strips were roughly 10m in length and the section within the woodland approximately 7.5 metres. The width of the verge ranged from 0.7m - 7.3m.

An intensive 14 day period of monitoring every three months was initially planned but, because of the frequency of rainfall in Britain's temperate climate and because the sites degraded so much between recording periods, the duration and frequency of recording was changed after the first seasons monitoring to 5 days of observations every month. Before each recording period sites were prepared by removing any overgrowing vegetation or debris from the sand beds, raking the sand to aerate and de-compact it, topping up the sand as necessary and brushing it smooth for inspection early the following morning when prints would still be fresh. After each daily inspection the sandbeds were again brushed to remove recorded prints.

Daily inspections of the sites were made to record overnight activity. Each pass by an animal across the sand bed was recorded against the relevant sand bed section *i.e.* roadside, verge or woodland. A maximum of 5 passes for any one section was recorded for multiple passes by one species. Where an individual animal moved perpendicular to the road and crossed more than one section it was recorded only once, and the record was assigned to the section nearest to the road. To enable direct comparison between sections and sites the raw data was standardised by dividing the raw totals by the length of the sandbed and multiplying by 10.

Results

The initial survey period provided a total of twenty-seven recording days for the complete suite of eight sites. The four month duration over which these observations were made highlighted factors which are important to the success of the technique.

Principally, the method is heavily weather dependent. Heavy rain will wash out prints. When wet, the sand compacts and prints of small mammals such as mice do not register. A sustained period of dry weather removes all moisture and adhesion from the sand, which then fails to hold the form of a print B altough even in the absence of clear prints, trail morphology was often sufficient to enable species identification. Moist, cool weather with overnight temperatures between 0 - 101C, provides optimal conditions which leave the sand sufficiently moist to hold well-defined prints of both large and small mammals (Figure 2). A heavy dew is ideal. Fresh prints invariably provided greater definition and early morning inspections of the sandbeds were therefore routine. This timing also enabled evening or morning prints to be distinguished because of the greater definition of prints after dew-point.

Of the various weed suppressant materials tested, all were efficient in suppressing weeds but there were other drawbacks. The specialist material was expensive and was easily dislodged when scraped by forging animals or by enthusiastic raking of the sand. Carpet was time consuming to collect and cut but was robust and cheap and, by virtue of its permeability, it also gave the most consistent results. The roofing felt was impermeable and the overlying sand consequently took longer to dry out after wet weather but it was finally preferred because it was supplied to the correct length and width and easy to lay.

Positioning of the sandbeds was also important. On roads where traffic was heavy and fast the air turbulence quickly shifted the sand in dry weather eradicating prints and necessitating frequent replacement of sand. At one such site, repositioning the roadside sandbed one metre distant from the road on the uphill rather than the downhill side and where there was an approaching bend was successful in overcoming the problem of sand drift. Initially some of the sandbeds were grossly disturbed by vehicles when motorists used them as stopping places, but two or three short upright stakes 12" x 1" x1" placed at intervals along the roadside strip was a successful in deterrent.

All but the rarely recorded species (eg hedgehog, shrew, roe deer) were recorded on both the 0.5m and the 1.0m wide sand strips. The width of the sandbed did not obviously influence the propensity of different species to cross. Deer often avoided crossing the sandbed altogether but there was no indication that they avoided the wide sand beds more often than the narrow sand beds. The increased number of prints per individual recorded on the wider surface area however, greatly facilitated species identification. The doubling of material costs was the principle disadvantage of the wider strips.

All the species recorded as crossing the sandbeds seem to have habituated to them fairly quickly. Badger routinely investigated new sandbeds from the first night they were laid and rabbit activity was as high on the first night as on subsequent nights. It was unusual to find fox and rodent prints during the first few days of sandbed establishment, but thereafter its presence did not seem to inhibit their passage. Deer appeared to habituate least well and, although prints were not infrequently found on the sandbeds these were few in comparison to the numbers found in soft ground nearby.

During appropriate weather conditions, footprints of all sizes of mammals could be accurately identified but prints of small mammals whilst sometimes remarkably well defined were frequently difficult to identify accurately and individual species could not be identified. A standardised total of 1812 sets of mammal footprints, equal to 1047 actual sets of prints, and 13 different mammal species were recorded for the eight sites over a period of 27 count days. These were classified by site and by section of site (roadside, verge and woodland). For the sites the results range from 95 to 380 sets of prints, the range for the totals for the different sections of the sites, *i.e.* roadside, verge and woodland, the range was from 258 to 827 (Figure 3). There was no significant difference between the eight sites but there was a significantly greater number of prints on the verge than on the roadside and the woodland (Anova $P<0.005$), suggesting that the road verge may be extensively used either as habitat, for foraging or as a wildlife corridor. The fact that activity is greater on the verge than on the roadside suggests that animals may be attracted by the verge, but show avoidance of crossing onto the hard surface of the road itself.

An ordination using DECORANA (two-way indicator species analysis; Hill 1988), showed that there were differences in fauna activity between the types of road (Figure 4). The motorway sites clustered near the origin, with scores associated with records of shrews, rats, roe deer, fallow deer, hedgehogs and rabbits. Local roads were spread out more along axis 2, indicating species such as voles, mustelids and shrews, whereas the smallest roads were spread out along axis 3, indicating high activity levels of muntjac deer, squirrels, roe deer and voles. It is evident that sites associated with different sizes of road, and associated differences in intensity of use, have different mammalian fauna. The sandbed methodology enables a consideration of the activity of the entire mammalian fauna of a site, and is thus uniquely able to elucidate the impact of roads of different types upon the activity of a range of small to medium sized mammals.

Discussion

The conflicts where fauna is at risk of death from collision with traffic have to be balanced against the value of highway land as a refuge from intensive farming, industrial land use and other built development that are the pattern in England at the end of this century. The road building programme in the UK has been greatly reduced in both rate and scale from that envisaged in the early 1990=s. Nevertheless, new roads will continue to fragment landscape and habitats, and there is much that can be done to improve existing infrastructure and ameliorate some of the worst effects of fragmentation if these are understood and standard procedures for monitoring and mitigation are established. Study methods which use traps and which are routinely used for single species investigations are unsuitable when dealing with species which range in size from 48mm (shrews) to 1000mm (fallow deer). Footprints and tracks left in sand beds however, enable all mammals to be studied, whatever their size. The data collected provide a relatively easy and inexpensive means of assessing the extent to which various species are affected by different classes of roads and different traffic densities.

Conclusions

Sandbeds are a useful non-selective census technique (Table 5). Sandbeds and footprint data have been used in the past to verify the use of faunal passages by target species. However, to assess the effectiveness of faunal passageways at a population level it is necessary to extend the use of sandbeds to know:

1. whether such tunnels provide the sole means by which a species crosses a road, and
2. whether animals present on the road verge fail to cross despite the means to do so safely.

Sandbeds are fairly labour-intensive, especially when used in the open rather than in a fauna passage itself. Initial results suggest that the following factors are important for the success of the technique:

1. The sand bed must be sufficiently wide (in excess of 1m) to prevent the larger mammals from jumping over it.
2. It may take some time for animals to become habituated to the new substrate.
3. The underlying substrate must be sufficiently rough to prevent slippage of wet sand and sufficiently robust to prevent the growth of vegetation through it (old carpet is ideal).
4. Weather conditions are critical - the sand must be lightly moist to hold small prints.
5. Sandbeds work only in dry weather and must be visited frequently (optimum daily in UK climate).

Provided these factors are taken into account, it has been shown that sandbeds may be used to compare different sites, and to assess the relative activity of the mammalian fauna on different parts of the site. This enables the elucidation of activity patterns in habitats, verges, and animals moving onto the tarmac (and therefore potentially crossing the carriageway) as well as in fauna passages themselves, thus giving potential information concerning the impact of roads on mammalian fauna at a community as well as a population level.

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Table 1. Methods to investigate the extent to which road verges can function as a wildlife corridor

Approach	Method	Advantages	Disadvantages
Identify the nature of movement along road verges and the species which utilise the corridor	Capture-mark-release (Mammals/arthropods/gastropod)	Indicates the rate, extent and direction of movement Allows details of individual mammals to be recorded e.g. weight, gender. Population densities can be determined from results	Large number of traps required. Labour intensive/frequent visits. Licensing required for many species. How representative is one phylum of another, e.g arthropods of mammalian fauna?
	Direct observation	Able to identify direction of movement	Most mammals are predominantly nocturnal. Night imaging equipment required. Accurate id requires moderately high skill level
Identify species which utilise the road verge as habitat	Sand pads	Relatively inexpensive Only moderate id skills required	Daily inspections required Exposed sand pads may be obliterated by inclement weather In high activity area early tracks may be obliterated by subsequent ones Imprints, particularly of small fauna, may not be sufficiently well defined for accurate identification.
	Observation of field signs	Inexpensive A useful complimentary method	Many animals are cryptic and even with highly skilled surveyor much may be missed
Identify landscape features which may influence use of road verges	Record (and map) physical features of habitat (including edaphic features?).	Quick and easy Can be done in tandem with other investigations	Theoretical approach with no evidence on how the landscape is perceived by fauna
	Conduct controlled experiments using different features e.g old timber, different substrates etc	Provides easily obtained comparative data	Only able to investigate a limited range of relatively mobile features.
Establish the extent to which road verges are utilised within different ecotypes i.e. agricultural mono-crop, deciduous woodland.	Select sites to reflect different habitats	Provides easily obtained comparative data	Difficult to ensure constancy of all other variables
	Fixed transect lines of sand pads	A relatively simple and inexpensive method to show the level of activity across a given area It will also show any transition from the road verge through adjacent habitat and gives a useful indication of disturbance	As noted above The different habitats may be occupied by different species so the influence exerted by habitat type may not be directly comparable (although this does not negate the results)
	Trap line	In addition to above this method also allows accurate identification of species and their details and shows if road verge usage is species specifice.	As noted above.

Table 2. Methods to investigate the extent to which roads act as barriers to species' movement

Sub-objectives:	Method	Advantages	Disadvantages
Determine species which avoid crossing or moving onto roads	Barrier sand pads (situated along road perimeter)	Inexpensive Only moderate id skills required Coverage can be extensive	Exposed sand pads pads will be obliterated in inclement weather. Labour intensive, daily inspections required. In high activity areas early tracks may be obliterated by subsequent ones. Imprints, particularly of small fauna, may not be sufficiently well defined for accurate identification
	Trap line grids	Able to record rate and direction of movement & allows accurate id of species	Expense of traps Many species require a license for handling
	Direct observation, (noting also time, road /traffic spec, weather etc).	Able to identify direction of movement Provides useful supplementary information which may indicate features affecting crossings	Most mammals are predominantly nocturnal. Night imaging equipment required. Accuracy of recording dependent on the skill of the observer. Labour intensive
	Road kill counts	Direct evidence of crossing Accurate identification possible in most cases Provides information on conflict points and features which may influence this. Useful complementary methods	The proportion and species of crossing animals may be skewed

Table 3. Methods to evaluate the effectiveness of eco-passages.

Approach	Method	Advantages	Disadvantages
To determine the frequency of use of eco-passage and the fauna which uses them	Sand pads (either in centre of large passageways or at either end of smaller passageways)	Inexpensive In covered conduit, medium will not be spoiled by poor weather	The medium itself may inhibit movement. Daily inspections required In high activity area early tracks may be obliterated by subsequent ones. Imprints, particularly of small fauna, may not be sufficiently well defined for accurate identification. It may not be possible to detect whether there are many individuals using the passage infrequently or one individual using it a lot.
	Ink pads or marble dust for small mammals	In covered conduit, medium will not be spoiled by poor weather	As above.
	Triggered photography	All species detected and accurately identified Site visit frequency low and therefore duration of study can be extended. High levels of activity do not compromise results Equipment outlay not excessive (dependent on number of sites). No change in the physical layout, as in sand pads, which could inhibit movement	Security of equipment cannot be guaranteed Camera noise may intimidate. Any equipment faults would remain undetected between visits
	Triggered timed video recording	In addition to the advantages of still photography the behaviour of animals entering the passages can be studied.	As with still photography Video equipment relatively expensive.
	Noise activated tape recording	Useful adjunct and back-up to other methods to assist in identification. Equipment relatively inexpensive	As with still photography
To determine if animals avoid using passages	Sand pads around the entrance of the tunnel	As already noted for sand pads in Table 1	As already noted for sand pads @1b
To determine whether animals need eco-passages to cross roads	Barrier sand pads adjacent and following the road sides in areas where eco-passages present or dry pitfall traps for arthropods (pitfalls and drift netting for amphibians)	As already noted for sand pads in Table 1.	As already noted for sand pads in Table 1.
	Sand pads across overpass and underpass verges if present in the vicinity of eco-passages or dry pitfall traps for arthropods (pitfalls and drift netting for amphibians)	As previously noted for sand pads in Table 1. Pitfall traps are easy to manage and allow for accurate identification	As previously noted for sand pads in Table 1. Pitfall traps require frequent and regular inspections.
	Road kill counts in vicinity of eco-passages	As previously noted for road kills in Table 1.	As previously noted for road kills in Table 1.

Table 1 Information on study sites: road statistics, verge and habitat detail.

	Bowshott	Loxley	Motorway N	Motorway S	Oakley	Snitterfield	Wellesbourne	Wiggerland
U.K. map reference	SP 303532	SP 262 535	SP 198 857	SP 192 806	SP 311 593	SP 313 593	SP 276 536	SP 313 593
Area of un-fragmented woodland in which the site is located	15ha	4ha	5ha	1.5ha	48ha	6ha	39ha	7ha
Total area of woodland connected to the site but fragmented by roads	65ha	63ha	12.5ha	3ha	56ha	39ha	63ha	56ha
Verge width	1.3m	3.3m	7.3m	3.3m	0.7m	4.0m	3.0m	6.0m
Woodland dominants	Fraxinus excelsior Ilex aquifolium Mecurialis perennis	Fraxinus excelsior Acer campestre Hedera helix Mecurialis perennis	Quercus robur Betula pendula Rubus fruticosus Teucrium scorodonia	Fraxinus excelsior Cornus sanguinea Ranunculus ficaria	Fraxinus excelsior Acer campestre Rubus fruticosus Anemone nemorosa	Fraxinus excelsior Viburnum opulus Ilex aquifolium Hedera helix	Fraxinus excelsior Corylus avellana & Acer campestre Mecurialis perennis	Fraxinus excelsior Corylus avellana Hyacinthoides non-scripta
Verge dominants	Bromus sterilis	Glechoma hederacea Helix hedera Heracleum sphondylium	Festuca rubra Teucrium scorodonia Rubus fruticosus	Holcus lanatus Festuca rubra Heracleum sphondylium	Urtica dioica Rubus fruticosus Rannunculus repens Arum maculatum	Rubus fruticosus Anthryscus sylvestris Chamerion angustifolium Valerian	Dactylis glomerata Heracleum sphondylium Festuca rubra Geum urbanum	Heracleum sphondylium Athryscus sylvestris Urtica dioica Rannunculus repens Rumex obtusifolius
Ave daily traffic flow	3300	3000	125,000	125,000	1500	1480	13600	8500

Figure 1. Research site with sandbed being laid, showing weed-suppressant membrane and sandbed along the narrow verge, and disappearing into the habitat perpendicular to the verge.

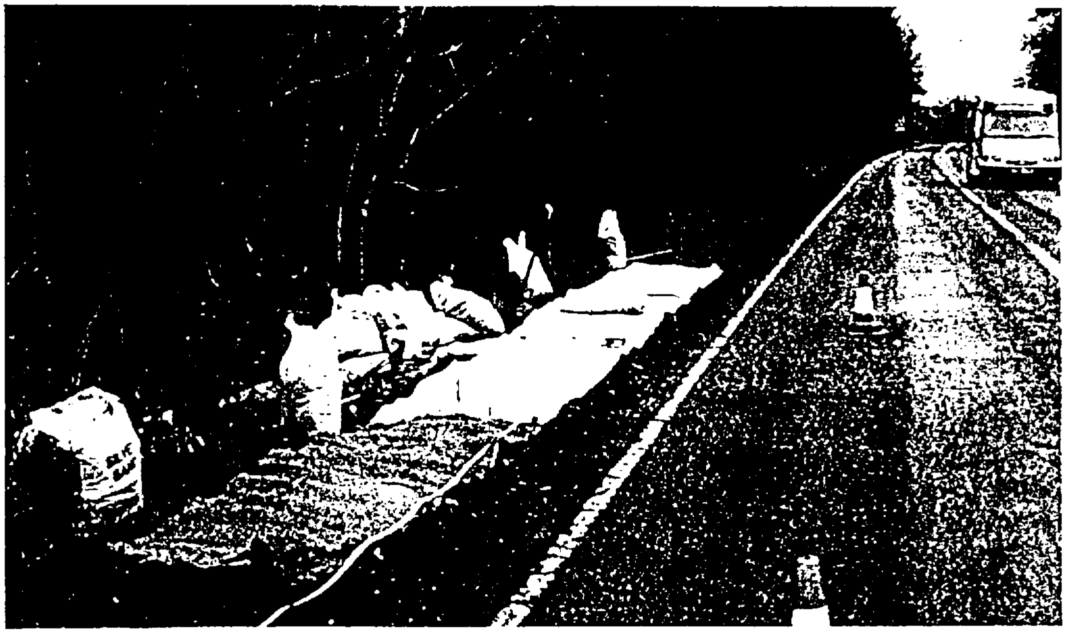

Figure 2. Sand of the correct consistency and moisture level will hold well-defined prints of both large and small mammals, but sandbeds laid in the open need to be recorded daily in the British climate.

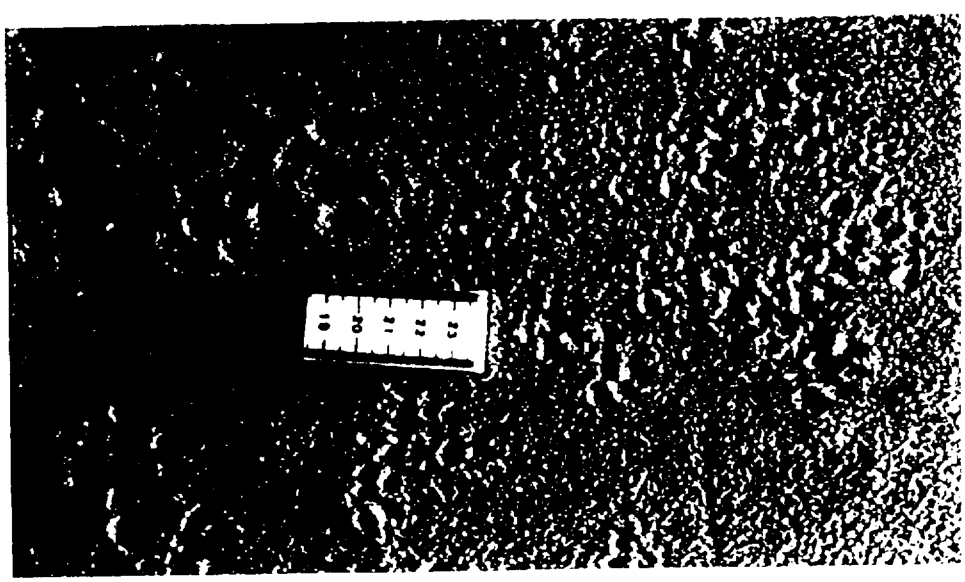

Figure 3. Total number of prints at each site.

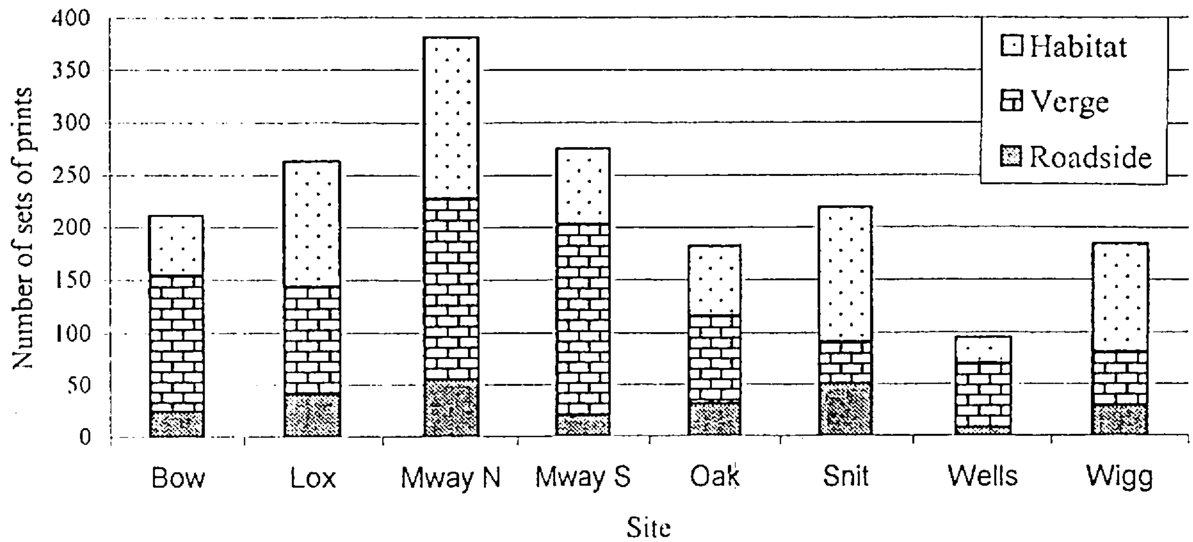

Figure 4. Ordination of monthly average numbers of footprints per species for each section of each site.

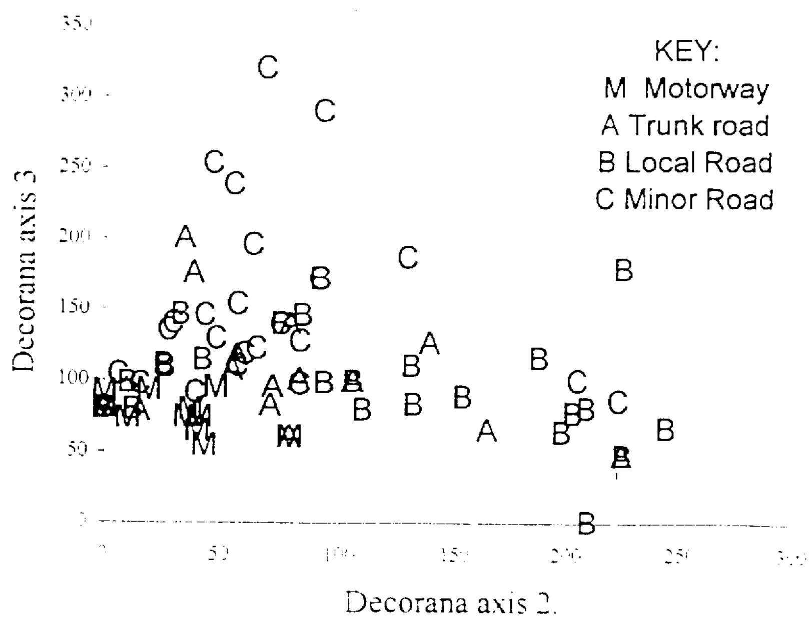

Table 5. The benefits and limitations of sandbeds for recording animal activity near roads.

Benefits and Uses	Limitations
Able to detect the full assemblage of animals in a given area including the most cryptic species	Small mammal prints may not always register and/or may be difficult to distinguish
It is a non-intrusive method which avoids any potential trauma to individuals	Animals may favour or avoid sandbeds
There is no interference with the natural movement of individuals (unlike trapping)	Experience is required to accurately identify different prints
It can provide a quick measure of species richness, distribution and diversity and has potential to provide information about population fluctuations.	One set of prints is arbitrarily recorded as one individual, but in practice multiple sets of prints may be the result of one or more animals
When linked to extraneous factors, such as weather, disturbance etc it can provide information about animal behaviour	Where there are high levels of activity, prints made early in the monitoring period may be obliterated by subsequent ones
Standardisation enables comparisons between sites	The method is strongly weather dependent