ROADS AND WILDLIFE:
A STUDY OF THE EFFECTS OF ROADS ON MAMMALS IN ROADSIDE HABITATS

by

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ABSTRACT

There is increasing concern about the adverse effects of the road network on wildlife. The impacts of roads in the ecological landscape include habitat loss, habitat fragmentation and habitat degradation. These interrupt and modify natural processes, altering community structures and population dynamics. The large number of animal fatalities from road traffic accidents is also of concern. Only limited work has been carried out to investigate the intensity of these effects in the UK landscape.

This study investigates the effects of roads on both small and large mammals and reviews mitigation measures that have been installed to ameliorate some of these effects. Roads of all sizes present a significant barrier to animal movement and they affect it in specific ways. Movement of small mammals is inhibited by lack of cover and the hostile road surface, whilst fragmentation of the road-verge by highway-related structures, impedes dispersal and compromises the benefits of connectivity often ascribed to such areas. Large animals, which use roads to travel through their territory, are more likely to be struck by traffic and are therefore, more directly affected by traffic-intensity. There is room for further mitigation to reduce the worst of the road-related impacts.

DEDICATION

For you.

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1.1 Introduction

The environmental impact of roads is of increasing international interest and concern (Bennett 1991a, Forman and Alexander 1998, Forman and Deblinger 2000, Spellerberg 1998, Tromubulak and Frissell 1999). The impacts of roads include habitat loss, habitat fragmentation and habitat degradation that affect wildlife and its habitats both directly and indirectly (Table 1.1). Much of the debate on the effects of roads on wildlife has focussed on the barrier effect of roads for larger mammals. These animals have large ranges or undertake seasonal movements over large areas of mainly natural or semi-natural habitat (*e.g.* Gunther and Biel 1999, Paquet and Callaghan 1996, Andrews, 1990). Research has also been carried out on the impacts on small mammals (Adams and Geis 1983, Oxley *et al. 1974,* Korn 1991, Kozel and Fleharty 1979, Swihart and Slade, 1984, Mader 1984, van Langervelde and Jaarsma 1995). There has been less attention overall to animals in more modified landscapes with a long history of intensive land use and land management (but see Richardson *et al.* 1997). In the UK, there are around 370,000 km of roadways that pervade the length and breadth of the British Isles. Only in the northern-most parts of the UK, in central and northern Scotland, are there any large continuous areas of semi-natural habitat that remain intact; traffic is audible from virtually every location in England (see DETR 1998a). On the positive side, the road-verge can function as a 'green estate' of considerable length. The provision of linear vegetated verges may provide habitat for many species (Way 1977, Bellamy *et al.* 2000), a feature of particular importance in a landscape with diminishing areas

Table 1.1 A summary of the ecological impacts of roads upon local biota.

ECOLOGICAL IMPACT	EFFECT	SOURCE
POLLUTION:		
Foreign material used in construction.	May cause local pH change.	Detwyler 1971.
Dust.	Affecting photosynthesis, respiration, transpiration and facilitating pollutant impacts.	Farmer 1993.
De-icing salt.	Causes local salination and the spread of maritime species along verges.	Davidson 1971, Foster & Maun 1978, Jones 1981, Salim 1989, Scott 1985, Scott & Davidson 1982, Thompson & Rutter 1986, Thompson *et al*. 1986, Welch & Welch 1988.
Exhaust output including carbon monoxide, sulphur dioxide, nitrogen oxides, ozone, organic gases (e.g. ethylene) and heavy metals (e.g. lead).	Effects include stunted plant growth, increased heavy metal concentration in biota, and changes in ecological community composition.	Angold 1997b, Muskett & Jones 1980, Sarkar *et al*. 1986, Schonewald-Cox & Buechner 1992.
CHANGES IN LOCAL HYDROLOGY.:		
Increased runoff from impervious surfaces. Pollutants such as hydrocarbons and heavy metals in surface run-off from the road	Pollutants may enter the stream network and cause changes in the diversity and composition of aquatic macroinvertebrates.	Maltby *et al.* 1995.
Changes in streamflow.	Culverts can alter water tables in the vicinity, and roadside ditches connected to the stream network cause higher, earlier discharge and greater erosion and sedimentation.	Jones & Grant 1996.
DISTURBANCE EFFECTS:		
Gusts of wind from passing vehicles.	May inhibit plant growth and cause necrosis (yellowing) of leaves near roads.	Fluckiger *et al.* 1978.
Increased human access and noise.	disturbance cause reductions in bird population densities near roads in the Netherlands.	Reijnen *et al.* 1995.
PHYSICAL BARRIERS TO THE MOVEMENT OF ANIMAL SPECIES:		
Barrier effect.	Roads act as physical barriers to some species, and hinder the dispersal of others.	Andrews 1990, Baur & Baur 1990, Mader 1984, Mader *et a.l* 1990, Reh & Seits 1990.
Fauna mortality.	the amount of wildlife killed on roads is very much greater than was once thought.	Fehlberg 1994, Slater 1995
PROVISION OF ECOLOGICAL HABITAT AND CORRIDORS:		
Provision of linear habitat on the road verge.	The ecological and conservation value of road verges has been demonstrated.	Bellamy 2000, Way 1977.
Provision of ecological corridors along road verges.	There is considerable interest in the theory that road verges act as ecological corridors, but so far there is little hard evidence to demonstrate their need.	Coffman *et al.* 2001*,* Dawson 1994, Seabrook & Dettmann 1996, Spellerberg & Gaywood 1993, Tyser & Worley 1992,

of undisturbed or (semi-) natural habitat. In such landscapes, the continuous nature of the road-verge may also be important as a connecting route for wildlife between remnant habitat patches (Bennett 1991a, Bennett 1991b, Forman 1998, Forman and Alexander 2000).

This chapter explores the impact of the road and its verge in an intensified landscape and the influence it exerts on animals locally as a context for the research issues presented in this thesis. It considers only the major and immediate impacts of roads and does not therefore consider secondary or remote effects such as any stimulus provided for future development in the neighbourhood of roads.

1.2 Roads and verges from an ecological perspective

An obvious and pervasive effect of roads is the fragmentation of previously continuous habitat. The effects of habitat fragmentation are well documented and include a direct loss of habitat, an increased ratio of edge to habitat, a reduction in patch size and the isolation of remnant habitat (Andren 1994, Spellerberg 1998 see also Canters and Cuperus 1997, Debinski and Holt 2000, Evink *et al.* 1998, Evink *et al.* 1999, Forman 2000, Highways Agency 2000). Where roads are the fragmenting feature there are additional effects that include the impacts of pollutants, noise, mortality and the barrier effect of an inhospitable linear terrain of indeterminate length (Angold 1997a, Angold 1997b, Bennett 1991a and 1991b, Evink *et al.* 1996, Reijnen and Foppen 1997, Slater 1995, Spellerberg 1998).

1.2.1 Roads as barriers

When habitats and their associated populations are fragmented into smaller units and the normal interchange between individual species are severed, their long-term persistence may be threatened. Small and isolated populations are vulnerable to extinction in heterogeneous landscapes because of inbreeding depression or as a result of stochastic events (Fahrig and Merriam 1985, Harrison 1994, Opdam 1990, Wiens 1996). However, subsequent re-colonisation is a frequent and a widespread phenomenon (Brown and Kodrio-Brown 1997, Fahrig and Merriam 1994, Opdam 1990) and some insects and some mammals are thought to occur as metapopulations and survive because of regular dispersal to and re-colonisation of new and vacated patches (English Nature 1993, Hanski *et al.* 1995, Lankester *et al.* 1991). However, habitat fragmentation by roads is usually abrupt and often severe and there is frequently a simultaneous reduction in habitat quality and population size. If new constructions fragment an area in such a way as to leave habitat ‘islands' distant, disconnected and small, then the remaining populations may not be able to recover (Soulé 1987). Roads can impose major barriers to faunal movement, the intensity of the barrier being dependent on the intrinsic nature of the highway and verge (Bennett 1991a, Bright 1993, Penny Anderson Associates 1994, English Nature 1996, Mader 1984, Slater 1995, Vermeulen 1994). The effect of roads on specific mammals is well documented (Bennett 1991a, Clarke *et al.* 1998, Huijser 1999, Korn 1991, Putman 1997, Richardson *et al.* 1997, Rondinini and Doncaster 2002, Spellerberg 1998, Forman and Alexander 1998). Bennett (1991a) summarised three major factors which influence the permeability of roads: the width of the gap between suitable habitats (clearance), the relative mobility and behaviour of the animal, and the contrast between the 'barrier' (the road surface and sometimes the verge as well) and the adjacent habitat. The speed of the traffic, the size of the species and its dispersal behaviour are also cited as important factors when assessing the barrier effect of a road (van Langevelde and Jaarsma 1995). Wide roads with high traffic densities restrict animal movement most severely. The largest and busiest roads are generally penetrated only by dispersing individuals or when resources are scarce. Nevertheless, it is not just large or busy roads that impede movement; narrow gravel tracks can reduce the rate of crossing for ground-foraging arthropods (Mader *et al.* 1990) and molluscs avoid pathways that lack vegetation cover (Oggier 1997). All roads therefore can present some level of barrier and increase landscape resistance but the influencing factors will vary greatly between species (Debinski and Holt 2000).

Whilst roads may restrict the directional movement of small animals, they constrain movement rather than limit it absolutely. In studies where small mammals have been translocated to the opposite side of the road, they frequently return to their home side (Korn 1991, Kozel and Fleharty 1979). They appear to do so even when traffic density is high

(Richardson *et al.* 1997). These road crossings however, may merely indicate that home ranges are confined to one side of the road. Other studies clearly indicate that the natural inclination of small animals is to avoid crossing roads, and to adopt roads as boundaries to their normal home range. No naturally occurring road crossings by woodland rodents (*Apodemus flavicollis* and *Clethrionomys glareolus*) were detected over a five-year period by Mader (1984) and road crossings of stenotopic carabid beetles were equally rare. In another extensive trapping study of nearly 600 small mammals Oxley *et al.* (1974) found that only 14 out of a total of 651 recaptured individuals (0.02%) crossed roads, and roads which were wider than 30m were almost never crossed by small mammals despite inter-trap movements of over 200m.

Clearly, it is not uncommon for medium and large-sized animals to cross roads of all different widths (as evidenced by the high number of visible road casualties) but the indications are that, like small mammals, wide and busy roads check their movements. The frequency of road-crossings by medium-sized animals, *e.g.* brown hare (*Lepus europaeus*), grey squirrel (*Sciurus carolinensis*), and stoat (*Mustela erminea*), is greatly reduced with increasing road width (Oxley *et al.* 1974); hedgehogs (*Erinaceus europeus*) generally avoid roads (Huijser 1999, Rodinini and Doncaster 2002), and badgers (*Meles meles*) tend to avoid crossing wide roads with high traffic densities (Clarke *et al.* 1998). All species of deer regularly cross minor roads but primary highways often delimit home ranges and only seasonal dispersal appears to provoke any frequency of movement across larger, more heavily trafficked roads (Putman 1997).

A review of the literature shows that the severity and consequences of the barrier created by roads varies. In an already fragmented landscape, the barriers imposed by roads can seriously curtail interactions between con-specific populations, and the limited gene-flow, which results from this, can render small populations vulnerable (Opdam 1990).

1.2.2 Roads as agents of mortality

Accurate and precise mortality rates for many species are often difficult to obtain. Some countries maintain a national database for fauna casualties on roads but the records are usually for a limited number of larger species, and the reliability of these and other estimates produced from extrapolated data often produce wide-ranging results. For example, annual estimates of bird mortalities in the UK range from 30 million to 70 million (Penny Anderson Associates 1994). The difficulties of accurate recording are not easy to resolve. Many animals which are seriously injured will seek cover and die out of sight and, because of the speed at which corpses of small animals are scavenged and disappear from the road or are crushed and destroyed by passing vehicles, a single daily corpse census can seriously underestimate the death rate of small animals. On a road where 179 toad corpses were counted at dawn, all had been removed by scavengers by 08.30 hrs; a corpse remained for less than one hour during the daytime (Slater 1995).

Statistics for the number of road-kills in England and the UK are given in various reviews on wildlife and roads (Bennett 1991a, Penny Anderson Associates 1993, English Nature 1996, Slater 1995). It is believed that roughly one million wild animals are killed on roads in the UK each year. Estimates suggest that 29-40% of all amphibians; 5000 barn owls (*Tyto alba*), equal to between 30 and 60% of UK population (see Penny Anderson 1994); 50,000 badger (*Meles meles*), equal to approximately 49% of UK population (Clarke *et al.* 1998); 50,000-100,000 hedgehog (*Erinaceus europeus*), representing approximately 5% of the UK population (Morris 1994) and 58% of the UK population of foxes (*Vulpes vulpes*) (Harris and

White 1994) die on roads each year. In the New Forest, Hampshire, more than 60 deer are reported killed each year and, at a countryside park in Staffordshire, 180 are killed annually (English Nature 1996). Unlike mainland Europe there are no British mammals which migrate large distances as part of a seasonal pattern of activity. These figures therefore, relate to individuals killed on roads that intersect their normal home territory, or are killed crossing roads when dispersing from their natal territory or when roaming during the breeding season.

In contrast to the highly intensified landscape of Britain, continental land masses retain large tracts of continuous high forest and undeveloped areas, which support a greater diversity, and abundance of animals. Consequently, more research effort is focussed on the larger mammal species. Many of these larger species have extensive home ranges and also follow seasonal migratory routes which necessitate crossing many major highways, increasing their exposure and vulnerability to road traffic. In Slovenia, where a stable population of 320-400 grizzly bears (*Ursus arctos)* occupy a range of 5000 km^2 there were 10 reported road deaths in a two year period (Kobler and Adamic 1999). In Yellowstone National Park, (an area of 8,992 km^2), there were eight black bears (*Ursus americanus*) and two grizzly bears killed on the roads in a 10-year period (Gunther and Biel 1999). In a Minnesota study, 11% of all known wolf (*Canis lupus*) mortalities were caused by vehicle collisions (Paquet and Callaghan 1996) and, also in the US, there were an estimated 538,000 deer killed on the road in 1991/2. In Sweden 55,000 deer were killed on the road in 1996 and 12,000 were killed by vehicles in Germany in the same year (Putman 1997). In countries where the built environment predominates, medium-sized animals, such as hedgehogs, polecats (*Mustela putorius*), rabbit (*Oryctolagus coniculus*) and fox, represent a high proportion of the road-killed victims. Holsbeek *et al* (1999) estimated that four million such animals are killed on Belgian roads each year. Thus on an international scale, roads and traffic are a major cause of death to both large and medium-sized animals mammals; no similar estimates exist for small mammal species. International interest in these incidents is increased by the animal welfare issue when large animals are struck by cars. The frequency of accidents means that the safety of motorists also becomes a major consideration.

1.2.3 Factors which increase the risk of faunal road fatalities

Animals with high densities in adjacent roadside verges, or which have large home ranges, or which disperse widely are the most frequent traffic victims (Adams and Geis 1983, van Langevelde and Jaarsma 1995). Medium and large-sized mammals are particularly at risk, especially when the emergence of young coincides with high traffic volumes (Oxley *et al.* 1974). Various species show seasonal peaks in accident rates often with a higher percentage of males being killed (Davie *et al.* 1987, Mead 1997, Reeve and Huijser 1999, Rotar and Adamic 1995, van Langevelde and Jaarsma 1995). This suggests that breeding or dispersal behaviour may be partly responsible, but increases in summer-time accidents may also be associated with higher summer traffic-levels (Moshe and Mayer 1998). Other species at risk of traffic accidents are those which are attracted to or spend a disproportionate amount of time on a road, such as snakes, which are attracted to the heat absorbing surface of the road (see Spellerberg 1998) and large herbivores which are attracted by the minerals available in rock salt deposited on roads to prevent freezing (see Slater 1995). In the UK birds that use roadside verges as a food resource, those that walk rather than fly across the road (such as the moorhen, *Gallinula chloropus),* and corvids that scavenge on other road-kills, are particularly susceptible (Mead 1997).

Various factors contribute to the large number of road-related animal deaths but the predominant causes are believed to be traffic density and road width (Clarke *et al.* 1998, Oxley *et al.* 1974, van Langevelde and Jaarsma 1995). These two factors directly affect the success, or otherwise, of an animal reaching the opposite side of the road with an increase in either reducing the probability of the animal crossing safely. However very high traffic volumes can, reduce some threats to wildlife. By suppressing activity near roads and limiting the crossover rate, fewer animals are killed because of collisions with vehicles (Verboom 1995). A study of badgers undertaken by Clarke *et al.* (1998) illustrates this effect. It revealed that an increase in badger mortality was proportional to increases in traffic density but only up to a certain traffic threshold above which badgers resisted crossing the road, and consequently the proportional mortality rate fell.

Most accidents involving faunal casualties occur at night, coinciding with an increase in activity for many species and a reduced field of vision for motorists. On English roads, the total animal death toll appears to be greater than that in other European countries (Penny Anderson Associates 1993). This may be because English roads are not as straight as those elsewhere, or because many English roads are hedge-lined, or it may be a combination of these and other factors. Generally, the number of deaths is related to and influenced by the local landscape although even the day of the week can be related to the numbers killed. Davie *et al.* (1987) found that red fox deaths were highest on a Friday or Saturday night when the volume of traffic is also generally higher.

1.2.4 Ecological Impact of Road Fatalities

If road mortalities are high, they can impact at the population level. The decline of occupied badger setts by some 30% in the Netherlands during a 20-year period from 1960 to 1980 is attributed to traffic mortality (van der Zee *et al.* 1992). Currently, in the UK, the badger population seems able to withstand the loss from road casualties, but Clarke *et al.* (1998)

asserted that if UK traffic volumes continue to rise in line with the (then) Department of Transport predictions, mortality rates, in combination with the high level of habitat fragmentation in the UK, may lead to future population declines. In a sample population of hedgehogs in the Netherlands, 2% were killed by traffic (Huijser and Bergers 1995). A later study by the same authors also indicated a considerable reduction in population densities in areas close to the road (up to 30% fewer), although these differences may not necessarily be a result of traffic intensity (Huijser and Bergers 2000). Frog and toad populations can be decimated by even fairly low volumes of traffic (Reh and Seitz 1990), and Fahrig *et al.* (1995) suggested that toad populations could be in a state of global decline as a result of the increase in traffic world-wide. Anecdotal evidence from questionnaires distributed to voluntary toad patrol groups in the UK identified traffic increase as the factor considered most important in a perceived decline in toad populations (Foster 1996).

Hard information is still lacking about the effect of roads and traffic at the population level (Bennett 1991a) but the consensus is that road-kill is insignificant at the population level (Forman and Alexander 1998, Reijnen and Foppen 1997). From the available evidence, the population effect appears generally to be at a local level where there are small populations, or for endangered species (Bright 1993). Munguira and Thomas (1992) found no apparent effect on the populations of butterflies and Putman (1997) reported that the high accident rate of deer and other ungulates is not sufficient to threaten population status. Nevertheless, the mortality rate, combined with the barrier effect of roads, may become of increasing significance in a patchy and fragmented landscape where local populations are increasingly reliant upon metapopulation functions and the occasional dispersal of individuals from separated populations.

1.2.5 Road-verges as habitat

In ecological terms, roadside verges can be classified as edge-habitat having extreme length but very little depth. Edge habitat can provide for both the species typical of adjacent habitat types and the specialised species of overlapping habitats (Way 1977). In the UK, road-verges are frequently separated from the adjacent landscape by hedges and ditches and they are often managed differently from the surrounding landscape. Consequently, they may feature remnant habitat patches and/or different communities than those of adjacent areas. The loss of natural and semi-natural habitat has been so severe in the UK this century that roadside verges, which offer an extensive and relatively undisturbed habitat, are becoming increasingly important (Penny Anderson Associates 1993). In the last comprehensive roadside survey in the UK, Way (1977) recorded, 20 of the 50 species of mammal, 40 of the 200 species of bird, 25 of the 60 species of butterfly, 8 of the 25 species of bumblebee, all 6 reptile species and 5 out of 6 species of British amphibians. More recently, Cresswell Associates (2000) reported 40% of priority habitats and 53% of priority species, identified in the UK Biodiversity Action Plan, as known or likely to occur on the of the UK highways. The soft estate (*i.e.* the road-verges) of the trunk road network represents about 30,000 hectares (Highways Agency 2002a). Road-verges therefore have considerable potential as an ecological resource and are likely to become increasingly important as refuges for wildlife in intensified landscapes. Several roadside areas have already been designated for their distinctive contribution to nature conservation, six as SSSI's, two as Specially Protected Areas (a pan European designation to protect habitats of important species) and one as a National Nature Reserve.

The fauna of road-verges in the U.K. is diverse but the habitat is not suitable for all native species. Invertebrates are generally plentiful on roadside verges. In agricultural landscapes, verges provided a periodic refuge for retreating individuals escaping from agricultural treatments in neighbouring fields (Mader 1984). On verges adjacent to heathland, Eversham and Telfer (1994) observed several rare species of beetle that were more numerous on the verge than on a nearby nature reserve. In other situations however, where the road-verge is markedly different from the adjacent habitat (as in the case of adjacent woodland), 'interior' species may avoid penetrating the verges altogether (Mader 1984) and, for some carabid beetles, the roadside can act as a sink habitat (Pulliam 1988) with populations maintained only by continuous immigration (Vermuelen 1994). Road-verges and the central reservations can support a wide variety of butterflies including rare species. On road-verges in Hampshire and Dorset, 27 species of butterfly were recorded, representing 47% of butterflies species found in the UK. The range of suitable breeding habitat, the width of the verge and the abundance of nectar were factors which positively influenced the diversity and abundance of species, whilst the volume of passing traffic is apparently no deterrent to breeding moth and butterfly species (Munguira and Thomas 1992). Birds may be attracted to road-verges for foraging, or occasionally for breeding, especially when the surrounding landscape is unsuitable for these purposes. Eighteen different species of birds were recorded as using various sections of the roadside verge in one Danish study (Laursen 1981). Skylarks (*Alauda arvensis*) were the most abundant species and were found to forage more frequently on the road-verge than in adjacent fields. They were also found to favour the roadside as a nesting site when adjacent fields provided inadequate cover early in the nesting season. Where open fields were the predominant landscape cover, passerines such as the greenfinch (*Carduelis chloris*) and starling (*Sturnus vulgaris*) were observed to travel long distances to feed on road-verges. However, on busy roads the noise levels had a negative effect on bird densities and it is possible that birds only breed on the sub-optimal road-verge habitat because of over-capacity or lack of more suitable habitat rather than because it is a preferred nest site. Further research is needed at the population level to determine the role of the verges in the dynamics of these species. The undisturbed roadside areas also provides habitat for large numbers of small mammals, especially for edge and generalist species (Forman 1995) with a corresponding increase in the number of predator species (Dawson 1994).

1.2.6 Road-verges as movement facilitators

Paradoxically, whilst roads may be the source of much habitat fragmentation they may also be a mechanism by which to restore connectivity in an intensive landscape. Due to their linear nature, roads and their verges frequently cross environmental and topographical contours (unlike 'natural' corridors) and can link a range of different habitats, thus facilitating biotic movement through an otherwise unsuitable landscape. They have been widely promoted as a means of retaining and/or enhancing connectivity, and linking habitat patches (Beier and Noss 1998, Harris and Scheck 1991, Loney and Hobbs 1991, Merriam 1991, Saunders and Hobbs 1991). It is argued that corridors can assist both colonisation and re-colonisation and thus prevent local extinctions from accumulating into more widespread and irreversible extinctions.

Getz *et al.* (1978) were able to show that voles (*Microtus pennysylvanicus*) extended their range by some 90 km through utilisation of the verge of an interstate highway and the roads connected to it, implying a corridor function for some species in certain conditions. Nicholls and Margules (1991) concluded that if corridors provide habitat that can maintain populations, then it is possible that they will also provide a dispersal corridor; a function which would additionally permit re-colonisation following patch extinctions. In fragmented habitats, linking routeways enhance the movements of small mammals (Coffman *et al.* 2001) although they appear to differentially affect the movement of males and females (Davis-Born and

Wolff 2000). Nevertheless, corridors are not just a means of dispersal, but rather, an important landscape feature that should be considered in their own right (Perault and Lomolino (2000). Roadside verges also provide important habitat as well as connecting routes (Bellamy *et al.* 2000, Downes *et al.* 1997, Eversham and Telfer 1994, Vermeulen 1994) and, as such, may be an important population source. Bolger *et al.* (2001) concluded that there is often little difference in the community and population structure of corridor habitats, remnant habitats and connected habitats.

The 'corridor' theory, and research investigating its effects however, is not without controversy. Noss and Beier (2001), for instance, asserted that the results of studies of movements by small mammals through corridors are inappropriate for predicting the responses of those animals most affected by habitat fragmentation (larger-bodied animals with large home ranges) and they conclude that studies of small mammal movement along corridors is unhelpful in resolving conservation issues at the broader scale. Others point out the risk attached to corridors if they fail to provide a throughway to favourable habitat that is within reach of the animal; they then operate as sink habitat and, at the same time, deplete the source population (Pulliam 1988, Saunders and Hobbs 1991, Vermeulen 1994). Furthermore, there is a risk of invasive species or disease moving along corridors to areas that would not otherwise be affected (Hess, 1994). Some critics go further and question the basic premise on which the value of corridors has been promoted. They assert that corridors are limited in their application, that there is no evidence to show that species cannot do without them and there is a lack of empirical data in support of the corridor theory (Bonner 1995, Dawson 1994, Rich 1994, Simberloff *et al.* 1992).

1.3 Management Considerations

1.3.1 Buffer zones

Buffer zones can be used to prevent degradation of core habitat and to reduce the undesirable effects of edge (Angold 1997a). They can be established beside roads by increasing the width of the road-verge and softening the transition from adjacent habitats by planting or by natural regeneration. Broadening the road-verge will provide a margin between the road and any adjacent core habitat and, at the same time, may assist linear movement along the verge, providing habitat or refugia. Road-verges often have high levels of species diversity (Bellamy *et al.* 2000, Way 1997, Haines-Young *et al.* 2000) but this may be at the expense of other, arguably more desirable features. Wider road-verges increase the available habitat and thus encourage greater species abundance, as well as providing a buffer zone between core habitat and road-associated pollutants. However, an increase in the area of road-verge, which results in a greater loss of the original habitat and its associated flora and fauna, is clearly undesirable. Additionally, if broad road-verges are responsible for an increase in faunal abundance there may be a consequential increase in mortality rates from roadside accidents.

1.3.2 Improving the safety and permeability of roads

Allowing a severed habitat to extend to the verge on each side of the road will reduce the clearance between favourable habitats and facilitate crossings, whether or not mitigation measures such as bridges, tunnels or culverts, designed or adapted for wildlife use are employed. The conflict arising from this approach is that an increase in crossover and a reduction in sight lines along the perimeter of the road can increase the number of road-killed animals. If the barrier-effect of roads is to be reduced, both an increase in the safety and an increase in the permeability of roads need to be considered. Reduction in traffic volume and speed, in conjunction with a reduction in the width of the road, can contribute to 'defragmentation' of habitat and increase ecological safety. From an ecological viewpoint, a concentration of traffic on a limited number of roads is considered preferable to diffusing traffic across the network (van Langevelde and Jaarsma 1995). Greater permeability of the road has been achieved in many European countries in recent years through the provision of 'eco-passages' (a generic term for artificially constructed underground or over-ground passageways designed to facilitate faunal movement across roads). In the Netherlands more than 350 fauna passageways have been introduced into the national trunk road system in the last 10 years (Bekker *et al.* 2001) and in the UK, a 40 mile stretch of the newest motorway, the M40, features 14 badger tunnels (Hepinstall and Blood 1993). Further linking structures are planned in a range of European countries that are collaborating on an initiative launched by the European Commission to combat the fragmenting effects of transport infrastructures (Highways Agency 2000).

The monitoring of eco-passages has shown that they are used by many different animals (Bekker *et al.* 1995) although their overall effectiveness in terms of reducing mortality and promoting interaction between sub and meta-populations is still being studied. The extent to which location affects their use by different species, and the behaviour of animals when confronted by passageways (which will determine whether or not they accept and use them) requires further investigation (Bekker *et al.* 2001, Nieuwenhuizen and van Apeldoorn 1995). It is generally agreed that to be effective wildlife passages should be designed with particular species in mind and meet specified criteria; tunnel dimensions, for example, can greatly affect usage (Clevenger and Waltho 2000, Janssen *et al.* 1995). However, even with good design not all animals will use the smaller passages, especially when the underground passages have to traverse long distances as, for instance, under motorways. The alternatives are to construct viaducts, to tunnel the road, or to construct 'green' bridges. Green bridges or eco-ducts have been used in many European countries, but the cost of installation either during initial construction or as a retrofit measure, can be prohibitive. There are few UK examples; the bridge across the M25 connecting Epping Forest on the outskirts of London is an exception.

There is now widespread use of roadside fencing to prevent animals from wandering onto the roads and, when properly erected and maintained fences are successful in reducing animal mortality (Rotar and Adamic 1995). The greatest reductions in road casualties are realised when fences are used to funnel animals towards a tunnel or eco-passage entrance and prevent crossings elsewhere. The drawback of fencing is that whilst preventing mortalities, it can virtually eliminate movement between habitats on either side of the road. An extensive network of eco-passages is required if habitat connectivity is to be maintained. In Austria the fenced road network is almost total and effectively divides the country into 14 habitat fragments; 543 eco-passages are presently installed to improve the permeability of the fenced road network (Volk and Glitzner 1998).

1.3.3 Environmental Impact Assessment and Mitigation

Despite a promise of a reduction in road building when the Labour Party took government in 1997, the 10 year transport plan (Department of Transport, Environment and the Regions 1998) provided for an increase in the highway infrastructure to the tune of £180 billion, and a return to previous policies designed to accommodate increasing mobility with inevitable environmental consequences (Docherty 2001).

Environmental impact assessment (EIA), established by statute in the UK in July 1988 for all major road projects is now a well established procedure and takes account of factors which may prove damaging to wildlife and the natural surroundings. The EIA process is required to critically examine proposals for new developments and to recommend measures to avoid or ameliorate any adverse impacts arising from the proposed scheme but the effectiveness of the procedure is considered to be less than satisfactory (Byron *et al.* 1999). Direct habitat loss is quantifiable and easily considered by the assessment process, but issues such as fragmentation, the barrier effect, wildlife mortality and the provision of wildlife corridors are more controversial, and the EIA procedure not only (allegedly) fails to be comprehensive in its account of impacts, but the response to fragmentation is perceived as being determined often by cost rather than appropriateness (Kirby 1997). The lack of routine testing of the predictions made in Environmental Assessments and the absence of long-term monitoring and after-care procedures for areas affected by, or established as a result of construction, is also considered to be disappointing (Cibien and Magnac 1998, Janssen *et al.* 1995, Marshall *et al.* 1995, Therivel and Thompson 1996).

1.4 Summary

New roads will inevitably lead to habitat loss and fragmentation. The ecological impacts will depend on the nature and extent of the existing road network, and the degree to which natural and semi-natural habitats are already fragmented and isolated by intervening land use. Even when roads do not directly destroy habitat, the noise and disturbance associated with them may impact significantly on those species that require an undisturbed and/or interior habitat.

It is vitally important in fragmented habitats that the movement of individuals through the landscape is accommodated, we cannot be assured of their long-term persistence if we do otherwise (Opdam 1990). The evidence suggests that in a highly modified landscape, some species respond by becoming increasingly sedentary, so that isolation by habitat fragmentation is intensified by genetic and behavioural modifications of the species. Conversely, if faunal movement continues, despite ever increasing traffic densities and without further provision for safe passage, traffic fatalities will be an inevitable consequence that may depress populations of certain species. Roads, and the unprecedented increase in traffic levels in recent years, are a relatively new evolutionary pressure and the effects of this new selective pressure have yet to be fully understood.

1.5 Research Questions

Our current understanding of the processes that operate within heterogeneous and fragmented landscapes is still incomplete. In the context of roads, we need to gain a fuller understanding of both the primary and the secondary impacts of roads on the surrounding wildlife. Research so far, has largely considered the effect of roads at a species level (see Table 1.2) and relatively little work has been undertaken to study the impacts of roads at the population and the community level. Furthermore, the majority of research into the impacts of roads on wildlife has been undertaken in countries of mainland Europe and the US. In the UK, there is a greater density of roads and a greater density of traffic than in most other countries in the world. The faunal communities are also not the same as those found elsewhere; generally they are less diverse and particularly, they lack the large mammals found in countries of continental mass. None of the UK domestic terrestrial species has such large home territories, roam so widely or migrate such long distances as the larger animals in these other countries.

Table 1.2 The current extent of research on the impacts of fragmentation resulting from roads

Topic	Current Research Level	Research Gaps	Approach/Method
Barriers	individual / species	population / community level	multi-species & probably sub-community approach; long term population studies
Corridors	individual / species	population / community level	multi-species & probably sub-community approach, long term population studies
Mortality	individual / species /community	population	long-term population studies
Habitat	population / community	population / community level	survey, long-term monitoring
Eco-Passages	individual / species	population / community level	multi-species approach, long term population study

The existing research is valuable in that it provides direction and focus for more detailed studies, but it is erroneous to think that conclusions reached for different species in different locations will apply equally to all situations. The empirical research described in the following chapters, tests the relevance of the work undertaken elsewhere and assesses whether the general principles applied in other countries, are equally valid in the UK.

The scope of the research is broad so that effects on the full range of animals commonly found in these habitats can be assessed. The effects of fragmentation on species and communities were examined and, as part of this research, a pilot study was undertaken to see if connectivity could be effectively established for small mammals on road verges that had been interrupted by highway-related structures. Finally, badger tunnels installed to retain connectivity in separated habitats, were monitored.

The research structure is outlined in Table 1.3. There are five empirical chapters that investigate various wildlife responses to the highways infrastructure. Each of these chapters is self-contained but it links to the next through the theme of road impacts on wildlife. All the chapters follow a similar structure. The introduction provides the background and context of the area to be investigated and specifies the study purpose. The research methods are outlined in the second section, which includes a description of the site, full details of the methods and techniques employed, and the data analysis undertaken. Results of the study are given in the third section and these are discussed in the penultimate section of each chapter. Brief conclusions are provided in the final section. The specific themes of the chapters are as follows:

Chapter 1 is a review of the literature and reproduces and updates the published journal article by Underhill and Angold (2000), see Journal Article at the end of the Appendices.

Table 1.3 Summary of chapter contents.

Chapter no.	Subject matter	small mammals	larger mammals	Subject detail
Chapter 1	*Context*	X	X	background to the study into the impacts of roads on wildlife in the UK
Chapter 2	*Method study*	X		pilot study of two techniques for monitoring wildlife activity
	The barrier effect	X		factors inhibiting movement across roads
Chapter 3	*The barrier effect*		X	investigation into the intensity of the barrier effect
	Disturbance		X	effects of roads and traffic on spatial organisation and movement
Chapter 4	*The barrier effect*		X	roads or habitat
	Fragmentation		X	effects on community structure
Chapter 5	*Road verges*		X	the value as habitat and movement corridors
	Fragmentation and 'defragmentation'		X	effects on fragmentation & experimental treatments to reconnect road verges
Chapter 6	*Mitigation*	X		effectiveness and limitations
	Habitat fragmentation	X		mortality risks
Chapter 7	*Conclusions*	X	X	summary and recommendations

Chapter 2 draws from the author's contribution in the article produced in Conference Proceedings (Underhill *et al.* 1999). It provides a study of the movements of larger animals in relation to the road. Although there is considerable evidence showing the detrimental effects of traffic on the movement of such animals (Forman and Deblinger (2000), for instance, suggested a road-effect zone that extends an average of 600m into adjacent habitat), there has been little work in the UK on the responses of animals to roads and traffic. Two different methods were piloted to monitor the cause, effect and intensity of the barrier effect arising from roads.

Small mammal responses to roads and traffic are examined in Chapter 3. Their movements were recorded during four sessions, over the course of a 12-month period, providing data that enabled some conclusions to be reached about those species most severely affected by roads.

The data also provides initial indications about the factors most likely to inhibit small mammal movement across roads.

The spatial distribution and dynamics of woodland small mammals were further studied in Chapter 4. This longer-term study was carried out to detect, more specifically, the respective roles of habitat and roads in the spatial arrangement of small mammals in road-adjacent areas. The data was also used to assess the effects of fragmentation on small mammal communities.

Chapter 5 outlines a further small mammals trapping study. Unlike the previous two studies, which monitored small mammal movement in woodland habitats, this work was carried out on the grass verge of two dual carriageways. The investigation was designed to assess whether the disruption to movement, caused by breaks in road-verge habitat, was equivalent to habitats severed by roads. The results of experimental treatments intended to reconnect fragmented habitats are also described in this chapter.

The final empirical chapter, chapter 6, covers a monitoring study that evaluated existing measures of mitigation (specifically badger tunnels), installed to offset the effects of habitat fragmentation arising from the construction of a motorway. The results of a recording exercise on road-killed animals are also reported here. The road-kill data provides a wider understanding of the number and species of animals that are most at risk on roads in the UK.

The final chapter, chapter 7, summarises the results of this series of studies.

CHAPTER 2. AN INVESTIGATION INTO THE EFFECTS OF ROADS AND TRAFFIC ON WILDLIFE WHICH UTILISE ROAD-ADJACENT HABITATS

2.1 Introduction

Roads of all sizes appear to act as a filter to the natural movement of animals (Bennett1991, Forman and Alexander 2000, Spellerberg 1998, Verboom 1995). Large-bodied animals with large home ranges or species that disperse widely will encounter roads most often and are therefore most affected (Paquet and Callaghan 1996, Andrews 1990). The impacts are most significant for rare or threatened species, or species with low population densities. In Britain, as well as elsewhere, the barrier effect of roads has been largely inferred from road-kill data for such species as badgers (Clarke *et al.*1998, Jefferies 1975), otter (Philcox *et al.* 1999) and polecats (Birks and Kitchener 1999). Road-kill data provide information about animals that attempt to cross roads and the presence and distribution of individual species, but it provides no direct information about why some animals are more prone to collision than others, the degree to which different animals avoid roads, what factors contribute most to the barrier effect, or how limiting the effects are to the dispersal of various animals. In terms of the polecat, for example, most information regarding the re-establishment of the species to areas where it had gone extinct has been largely derived from road-kill data, yet relatively little is known about how its distribution is influenced by the density of the main road network (Birks and Kitchener 1999).

The biota of the UK road-verge was last assessed by Way (1977) but changes in traffic volumes and highway management during the last 20 years are likely to have affected the roadside communities of terrestrial fauna. The Countryside Survey (Barr *et al.* 1990) recorded only habitat and landscape features, and other recent synecological studies of terrestrial vertebrates (Bellamy *et al.* 2000, Garland 2002 unpublished) have concentrated exclusively on small mammals. Harris *et al.* (1995) stated that our knowledge of the distribution of large-bodied vertebrates in the UK is poor and there is a general lack of information pertaining to the status of British mammals. There have been few recent studies, although the Mammal Society UK is currently engaged, through its membership, in a nationwide survey of mammal distribution. The perceived trend in population status of UK mammals is that even some of our better-known and ubiquitous animals do not necessarily have a secure future (Harris *et al.* 1995). Appendix A provides a summary of the status of some of the more common animals whose status may be vulnerable. Many of the 44 breeding terrestrial mammal species in Britain are known to face population threats of one kind or another (Harris *et al*. 1995) and roads may substantially contribute to these threats. Possible road-related impacts include population fragmentation or isolation (7 species vulnerable), habitat changes (31 species vulnerable), fatalities from pesticide ingestion and from pollution (25 species vulnerable) and road-deaths.

2.1.1 Study purpose

Our understanding of the activities of the wider mammalian community around roads is minimal, even more so in the UK than in the rest of Europe. We need to know not only the structure of the terrestrial communities which utilize areas close to roads but also the relative activity levels of different species on the road-verge and in adjacent habitats and the frequency with which they attempt to cross the road. Research of this kind will also help us to understand of the functional importance of these areas and can assist in determining the extent to which road-verges may act as a linear corridor as well as the extent to which roads and traffic inhibit activity in adjacent areas.

One reason for the paucity of data for larger animals is the difficulty in obtaining such information. The movements of small mammals can be detected through trapping programmes, but for the range of widely dispersed, larger species, there are relatively few methods available. The research outlined in this chapter describes the results of two different methods that were piloted to assess their usefulness as methods of wildlife auditing. The first method used sandbeds laid alongside roads that captured the footprints of passing animals. The second used infrared closed- circuit television (CCTV) that recorded night-time animal activity.

The specific aims of this part of the research are to:

- Detect the range of species typically found alongside UK roads and adjacent habitat (from which some value of roadside verges may be inferred).
- Investigate the intensity of the barrier effect and the extent to which animal activity may be limited by roads and traffic.
- Critically assess the efficacy of the two methods piloted in achieving the above; neither sandbeds nor CCTV is commonly employed as a technique for assessing animal activity in open areas and it is important therefore to evaluate the effectiveness of the method in gathering such data.

Two hypotheses were tested:

- Roads and traffic inhibit the natural movement of animals and there will be a direct and negative relationship between traffic volume and animal activity in roadside habitats.

- Animals are sensitive to traffic and avoid areas close to roads. It is proposed that there will be a direct relationship between animal activity and distance from the road but the effect will be species-specific.

2.2 Sandbeds as a method of environmental audit

As animals move about their territory, they leave many distinctive signs and the unique tracks and footprints left in mud or on soft ground have long been used as an indicator of an animal's passage. Tracks left in soft ground or snow have been recorded in studies to investigate the activity patterns of different ungulate species by Mayle *et al*. (2000), Mandujano and Gallina, (1995) and Jedrzejewska *et al*. (1997). None of these methods is appropriate for synecological investigations in a temperate climate however. Sandbeds have been used extensively to monitor the activity of animals within confined areas such as underpasses and tunnels (Clevenger and Waltho 2000, Bekker *et al*. 1995, Veenbaas and Branjes 1998 and others), but they have been used less frequently as an auditing method in open areas (but see Bider 1968, Crooks 2002 and Engeman *et al*. 1999). Their use was piloted here as a means of identifying movements of the assemblage of animals that may be found in roadside habitats.

2.2.1 Methods

2.2.1.1 Study sites

Woodland sites were selected for this study because they constitute a relatively stable and less intensively managed habitat. They provide discrete, easily delineated boundaries and a habitat that contrasts with the road-verge. A cluster of eight sites was selected (Figure 2.1) all of which were on roads that cut through mature deciduous or mixed woodland. Four different road categories were represented in the study: motorways with high traffic flows with approximately 125,000 vehicles per day, A class roads, with an average traffic volume in excess of 10,000 vehicles per day, B classified roads, with up to 3000 vehicles per day and minor roads that carry up to 1500 vehicles per day. Warwickshire County Council supplied

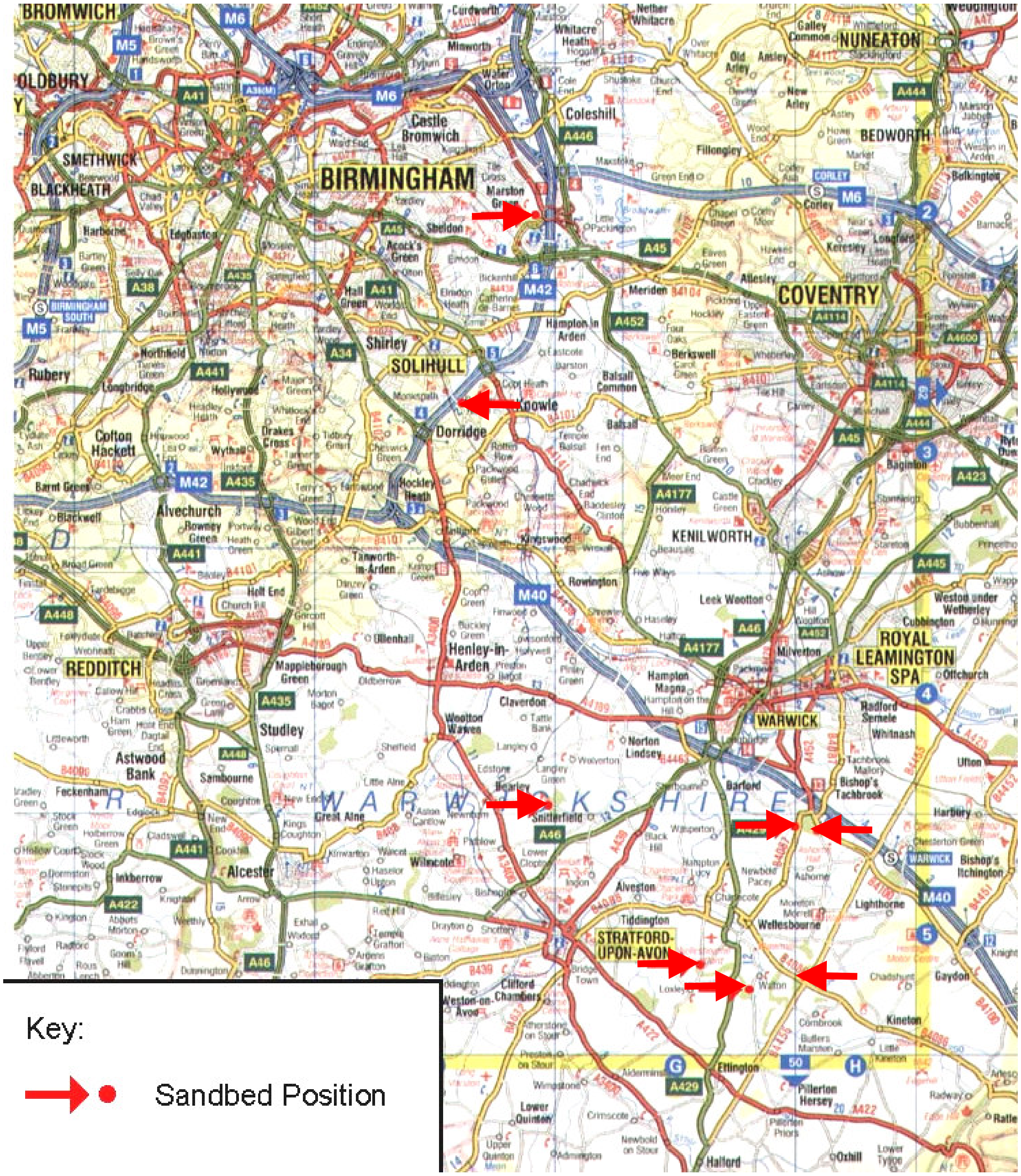


Figure 2.1. Ordnance Survey map showing the approximate location of the eight sandbed sites.

traffic-count data. Each of the four road categories was duplicated giving eight sites in total. The attributes of each of the woodland sites, which ranged in size from 1.5 hectares to 39 hectares, are shown in Appendix B. With the exception of one mixed woodland site in which the interior, but not the margins, was dominated by conifer, the sites were deciduous woodland, with ash (*Fraxinus excelsior)* and English oak (*Quercus robur*) as the dominant canopy species and a typical understorey of hazel (*Corylus avellana*), field maple (*Acer campestre*) and holly (*Ilex aquifolia*). Dogwood (*Cornus sanguinea*), bramble (*Rubus fruticosus*), elder (*Sambucus nigra*) and honeysuckle (*Lonicera periclymenum*) were present in the shrub layer, while the field layers included dog's mercury (*Mercurialis perennis*), wood anemone (*Anemone nemorosa*) and bluebell (*Hyacinthoides non-scripta*), wood-sage (*Teucrium scorodonium*) and lesser celandine (*Ranunculus ficaria*). At the road-verge margin, most of the woods had hedgerow remnants that included hawthorn (*Crataegus monogyna*), blackthorn (*Prunus spinosa*), and privet (*Ligustrum vulgare*). On the road-verges there was a mixture of grasses, shrubby species and forbes, for example, cock's foot (*Dactylis glomerata*), Yorkshire fog (*Holcus lanatus*), wood small-reed (*Calamagrostis epigejos*), red fescue (*Festuca rubra*), ground elder (*Aegopodium podagaria*), common 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 1-2 metre linear strip immediately adjacent to the road) on the two busiest categories of road was cut.

2.2.1.2 Sandbed construction

Sandbeds were laid between February and March 1999 at each of the eight sites. The sandbeds were positioned on the road-verge at the approximate centre-point of each woodland section to provide the maximum expanse of equivalent habitat either side of the sandbed. 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 through the sand, a weed suppressant membrane was installed prior to laying the sand. Three different materials were tested: a horticultural thin black membrane, a one metre-wide bitumastic roofing felt, and reclaimed carpet cut to appropriate widths. Initially, both 0.5m and 1.0m wide linear strips were installed, but all the widths were increased to 1.0m after a trial period. Silver sand, which is fine enough to register all sizes of footprint and which is unlikely to form a surface crust when drying out after rain, was laid directly onto the membrane. The sand was laid to a depth of 1-3cm (depth was influenced by the wetness of the sand) and swept smooth with a soft bristle brush. A 10m x 1m sandbed required approximately 200kg (5 x 40kg bags) of sand.

The sandbeds were laid out in the form of a 'T' so that the top of the 'T' ran parallel and adjacent to the road edge (Figure 2.2). The 'vertical' section of the 'T' ran from the centre of the roadside strip, perpendicular to the road, through the verge and into the adjacent woodland. This provided three separate monitoring sections: roadside, verge and woodland. The roadside strips were approximately 10m in length; the width of the verges ranged from 0.7m to 7.3m and the section within the woodland was approximately 7.5m in length.

Quarterly recording sessions lasting for 10 days were initially planned to start in March and continue for a twelve-month period, but this regime was replaced by monthly recording sessions, of three consecutive days because of difficulties in maintaining the sandbeds between sessions. The shorter sessions reduced the number of recording failures due to rain obliterating prints; they also facilitated sandbed maintenance (see Table 2.1). Good print impressions require damp sand but no rain. Frequent overnight rain and long spells of dry hot weather meant that monitoring days could not always be consecutive, and in October 1999, only one day of monitoring was achieved.

Prints were identified and recorded from the roadside, verge and woodland sections of sandbed in the early morning whilst the sand was still damp. It was often difficult to discriminate accurately between the sets of tracks for any one species when there were more than five sets of prints. Thus, a maximum number of five sets of prints *per* section, *per* day, were recorded for multiple incursions by any one species. As the purpose of the exercise was to record activity in relation to the road, when an individual passed over more than one section of sandbed, when entering the wood from the road, for instance, only the incursion nearest the road was recorded. The number of sandbed incursions was used as an indication of species activity. It is important to note that the repeated passage of a few animals or single movements by several animals provide the same result, and so the term 'activity' does not necessarily relate to the number of individuals crossing the sandbed. Sandbeds were cleaned, replenished, raked and brushed smooth after each inspection in preparation for the following day's monitoring.

Figure 2.2 The layout of a typical sandbed indicating the proportions of each of the three sections. The roadside section and the woodland interior section of the sandbed were of a constant length, road-verges varied in width and consequently the length of the sandbeds placed there also varied.

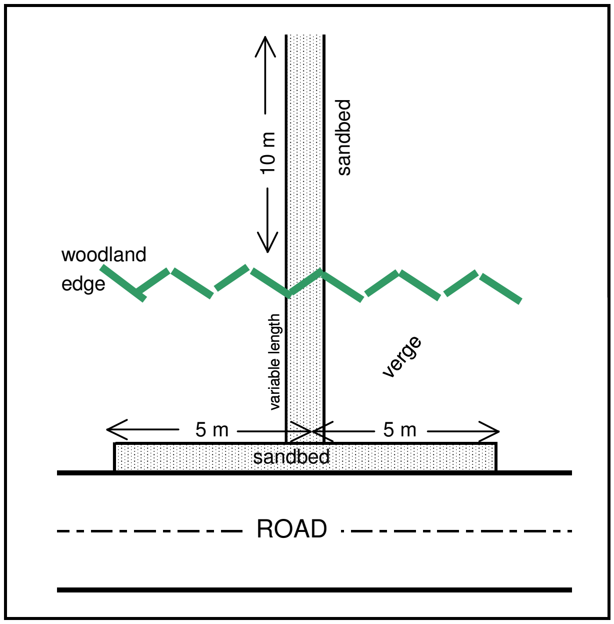


Table 2.1 The sandbed monitoring dates undertaken during the 9 month period, from March 10th to November 24th, 1999. Highlighted dates indicate days on which rain obliterated tracks and when it was therefore necessary to repeat the sandbed preparation and monitoring.

Month	Dates												Total days' monitor'g	no. of days tracks rained out
March	10	11	**12**	13	14	15	16	17	18	19	20	21	11	1
April	20	**21**	29	30	-	-	-	-	-	-	-	-	3	1
May	1	2	3	4	-	-	-	-	-	-	-	-	4	0
June	17	18	19	**20**	24	25	26	-	-	-	-	-	6	1
July	12	13	14	15	16	-	-	-	-	-	-	-	5	0
August	22	23	24	**25**	29	30	-	-	-	-	-	-	5	1
September	6	7	8	**9**	-	-	-	-	-	-	-	-	3	1
October	19	**20**	-	-	-	-	-	-	-	-	-	-	1	1
November	20	21	**22**	24	-	-	-	-	-	-	-	-	3	1
Total days' monitoring	9	7	6	5	4	3	2	1	1	1	1	1	41	7

2.2.1.3 Data Analysis

The number of sandbed incursions is assumed equal to one pass of the sandbed by one animal (but see above), and this has been used as an index of activity. Animal prints and tracks were generally identified to species level but it was difficult to distinguish between the prints of mice, voles and shrews and these were therefore grouped in a single category of small mammals. An 'other' category was included for any animals which could not be reliably identified.

Data were standardized to the number of incursions per one linear metre of sandbed and all analysis used these standardized data so that direct comparisons could be made between sites.

Chi-squared test for homogeneity was used to test normality of distribution of species at the different sites. To fit the requirements of the test, counts for different species were aggregated where expected frequencies were less than five. To test whether detected differences were due to traffic volume, Spearman's rank correlation test was performed on the site counts for individual species. Activity counts for the replicate sites were amalgamated to provide four data sets which related to four different traffic densities with average daily traffic volumes of approximately 1500 vehicles, 3000 vehicles, 11,000 vehicles and 125,000 vehicles.

If animals are disturbed by traffic, it can also be assumed that they will avoid areas in proximity to the road and therefore there should be greater activity at greater distance from the road. Within-site differences were tested by Chi-squared test using the activity totals recorded for each of the commonly occurring species on the three different sandbed sections. Species counts were again amalgamated as necessary, to match the Chi-squared test criterion, which requires expected frequencies greater than five. As a further test of the effect of traffic on species movement, species counts for each sandbed section were regressed against a calculated distance from the road using Pearson's linear regression. The distance for each sandbed section was calculated as follows; the sandbed section nearest the road (the roadside section) was taken as one metre distant from the road, for the verge section, the distance from the road to the midpoint of the verge sandbed section was the calculated distance used, and for the woodland section, the distance from the road to the midpoint of the woodland sandbed section was used.

2.2.2 Sandbed Results

A total of 1,862 separate incursions onto the sandbeds was recorded over the nine-month monitoring period. Activity ranged from 156 incursions at Wellesbourne to 369 incursions at Motorway North (Table 2.2). Eight species were identified from the sandbeds: roe deer, fallow deer (*Dama dama*), muntjac (*Muntiacus reevesi*), badger *Meles meles*), fox, rabbit, hedgehog and squirrel. Activity levels for rabbits (883) and small mammals, *i.e.* mice, vole and shrews (548) were disproportionately greater than for other species, accounting for 47.3% and 29.3% respectively of the overall activity count. Of the remaining species, foxes were the most frequently recorded species (165) accounting for 9% of total activity, followed by squirrels (134), muntjac deer (58), and badgers (36). Other species were not common. Activity counts for the different species varied between sites. The two motorway sites had the highest number of recorded incursions, but rabbits and small mammals accounted for 90% of the recorded activity. If the counts for these two high frequency species are removed from the data set, there is an inverse relationship between activity and traffic volume (Figure 2.3). The standardized data for each of the commonly occurring species were analysed to determine the influence of traffic on inter-site differences (Table 2.3). All the commonly occurring species were negatively associated with traffic volume although correlation was only significant for muntjac.

The different sandbed sections *i.e.* roadside, verge and woodland, have been used as a measure of activity levels relative to the road; the roadside section being closest, the verge section being at an intermediate distance and the woodland section being the section which is most remote from the road. There was a highly significant difference in the recorded activity across the three sandbed sections using the standardised data ($\chi^2 = 185.73$, df = 12, p = 0.001) with most activity being in the woodland and verge and a marked reduction of activity on the roadside. The spread of the activity across the sandbeds is shown at Table 2.4 and Figure 2.4. The Pearson product-moment correlation indicates a significant positive association between distance from the road and (standardised) animal activity counts (r = 0.437, d.f. = 24, p =0.033, two-tailed test) but the points are widely scattered.

Table 2.2 The actual number of sandbed incursions for each of the eight Warwickshire sites during the 43 monitoring days spaced over a 9 months period from March 1999 to November tt1999.

Site Daily traffic volume	Snittfld 1480	Oakley 1500	Loxley 3000	Bowshott 3300	Wigglnd 8500	Welslbne 13600	Mtwy N 125000	Mtwy S 125000	Grand Total	Mean	s.d.
Roe	0	0	1	0	0	0	0	0	1	0.1	0.4
Fallow	1	3	3	1	0	4	0	0	12	1.5	1.6
Muntjac	14	18	7	4	12	2	0	1	58	7.5	6.7
Fox	35	19	27	15	32	11	14	12	165	20.6	9.4
Badger	19	2	4	4	0	5	0	2	36	4.5	6.1
Hedgehog	0	1	1	0	0	0	1	0	3	0.4	0.5
Squirrel	14	33	6	9	40	4	6	22	134	16.8	13.6
Others	2	2	2	2	3	4	6	1	22	2.8	1.6
Sm mamm	49	11	49	129	58	70	52	130	548	69.0	41.2
Rabbit	110	103	144	1	88	56	290	91	883	110.4	83.9
Grand total	244	192	244	165	233	156	369	259	1862	232.8	67.2

a) includes counts for rabbits and small mammals

b) excludes counts for rabbits and small mammals

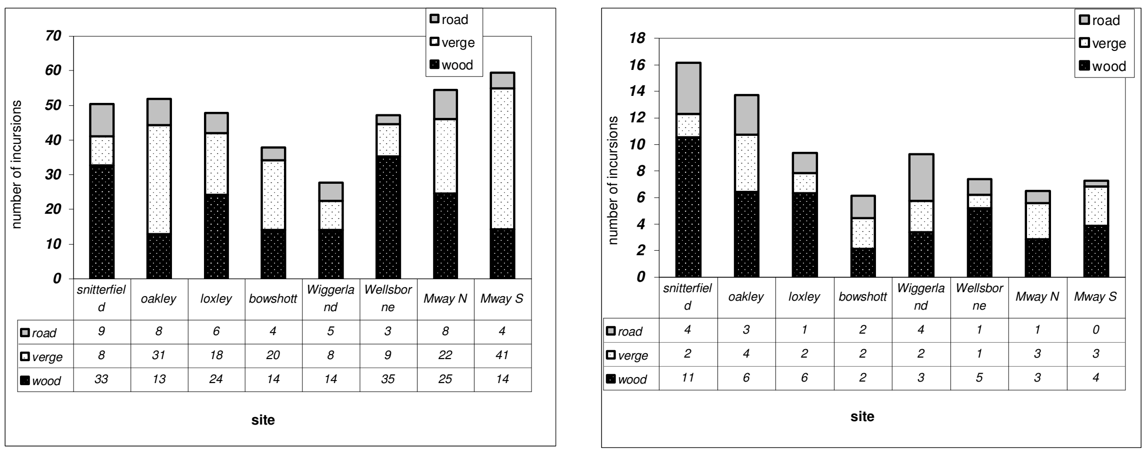


Figure 2.3 Standardised activity indices (*per* linear metre) for animals on each of the three sandbed sections at each of the eight sites. The sites are shown in order of traffic volume, with those sites with lowest traffic density appearing on the left of each chart. (Note that the charts are drawn to different scales.)

Table 2.3. The recorded frequencies (standardized to per 1 metre length) correlated against traffic volume using Spearman's rank correlation (two-tailed test).

	r_2	p	d.f.	significance
fox	- 0.706	0.051	8	NS
squirrel	- 0.479	0.223	8	NS
small mam	- 0.263	0.528	8	NS
rabbit	- 0.071	0.865	8	NS
muntjac	- 0.857	0.014	8	*

Table 2.4 The actual number of sandbed incursions for each of the three different sandbed sections for the 43 recording days from March 1999 to November 1999

	roadside	verge	woodland	sum	mean	s.d.
Roe	0	0	1	1	0.3	0.6
Fallow	3	0	9	12	4.0	4.6
Muntjac	19	6	33	58	19.3	13.5
Fox	96	23	46	165	55.0	37.3
Badger	25	2	9	36	12.0	11.8
Hedgehog	2	0	1	3	1.0	1.0
Squirrel	32	18	84	134	44.7	34.8
Sm mamm	85	189	274	548	182.7	94.7
Rabbit	260	250	373	883	294.3	68.3
Others	7	5	10	22	7.3	2.5
sum	529	493	840	1862	620.7	190.8
mean	58	54.2	92.2	204.4		
s.d	83.5	95.3	136.1	307.0		

Figure 2.4 The activity counts for the total number of animals found at different distances from the road. Counts are positively and significantly correlated with distance (two-tailed test).

2.2.3 Evaluation of sandbeds as a wildlife auditing technique.

Sandbeds, as an instrument for monitoring animal activity, are heavily weather-dependent and require monitoring periods that coincide with periods of suitable weather. Heavy rain will wash out prints and data will be lost. Additionally, wet sand becomes compacted and prints of small mammals do not register. It is only possible to use the sandbeds again when the sand has dried out sufficiently to be brushed smooth and is capable of recording all prints; this requires up to eight days of continuous dry weather during cool periods. During the nine-month study period, there was rain on an average of 15 days each month. The average number of consecutive dry days each month was just five. In addition to the days during the study period when wet weather made it unsuitable for recording, data was washed out by rain on seven separate occasions. The opposite effect of a sustained period of dry weather also presents problems. When all moisture is removed from the sand it fails to hold the form of a print. Spraying the sandbed as part of the site preparation was insufficient for satisfactory print registration in these conditions. Data were discarded on three days during the study period because of hot, dry weather. Optimal conditions are provided by a period of dry, cool weather with overnight temperatures between 0ºC and 10ºC and heavy dew is ideal. Fresh prints invariably provided greater definition and for this reason early morning inspections were found to be most suitable.

Of the various weed suppressant materials tested, all were efficient in suppressing weeds but there were drawbacks. The specialist material was expensive and was easily dislodged when scraped by foraging animals or by enthusiastic raking of the sand. The roofing felt was impermeable and the overlying sand consequently took longer to dry out after wet weather, but it could be purchased in the correct lengths and widths, and it was easy to lay. Carpet was time-consuming to collect (discarded carpet was collected from a large carpet retailer) and needed to be cut to length, but it was robust, cheap and permeable.

Prints of all but the rarely recorded species (e.g. hedgehog, shrew, roe deer) were found both on the 0.5m and the 1.0m wide strips and the width of the sandbed did not appear to inhibit crossing. There were never many deer prints in the sandbeds but there is no indication that deer avoided the wide sandbeds more often than the narrow ones. The wider strips however, provided a wider surface area on which more prints were recorded. This greatly facilitated species identification. The doubling of material costs was the principlal disadvantage of the wider strips.

Positioning of the sandbeds was also important. On roads where traffic was heavy and fast, the air turbulence shifted the sand and eradicated prints in dry weather. This necessitated frequent replacement of sand. At one site, repositioning the roadside sandbed from a downhill location to an uphill location, where traffic moved more slowly, was successful in overcoming the problem of sand drift arising from speeding vehicles.

Initially some of the sandbeds were grossly disturbed by vehicles when motorists used them to pull off the road but two or three short upright stakes (12" x 1" x1") placed at intervals along the roadside strip was successful in deterring subsequent intrusions.

All the species recorded as crossing the sandbeds seem to have habituated to them quickly. Badgers routinely crossed 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 they appeared regularly. Deer appeared to habituate least well, and the number of prints left on the sand bed was generally fewer than found in soft ground nearby.

During appropriate weather conditions, footprints of all sizes of mammals can be identified with practice, but prints of small mammals, whilst often remarkably well defined, were frequently difficult to identify with certainty. With the exceptions of the smaller mustelids, *i.e.* stoat, mink and weasel, the anticipated range of species was all detected using the sandbeds.

An inability to determine whether multiple incursions were the result of one or several individuals was an obvious drawback of the system and multiple incursions increased the likelihood that prints registered early in the session would be obscured by subsequent ones.

2.2.4 Recommendations for the use of sandbeds

The early sandbed monitoring trials demonstrated that lengthy intervals between monitoring inspections were not suitable because of the rapid deterioration of the exposed sites. More frequent, monthly, monitoring sessions were sufficient to control vegetation growth and avoid severe deterioration of the site but fairly intensive sandbed preparation was still required at the start of each monitoring session. Monitoring on consecutive days when site inspection could be coupled with site preparation was the most efficient regime but this was prone to interruption by wet weather. Monitoring just during the summer months may reduce the problem of repeated site preparation and, as an alternative to regular weeding and cutting back of vegetation, herbicides could be employed.

Site inspections over a three-day period provided sufficient data for a reliable analysis of the more common species but not for those that were rarely recorded. The low counts obtained for some species prevented statistical investigation. Longer or more frequent monitoring periods, particularly in the late summer months when species abundance is usually greatest, would assist in obtaining larger data sets that lend themselves more readily to statistical analysis. The sandbeds in this study were designed to obtain a general census of animal activity and were positioned centrally along the woodland section, but if there are species of particular interest, the sandbeds would be better positioned where other field signs indicate that these animals are active. Alternatively, the method should be reserved for monitoring commonly occurring species and alternative methods sought for other species.

2.3 Closed circuit television (CCTV) as a method of environmental audit

The CCTV study was set up to record the level of nocturnal animal activity in the vicinity of roads with different traffic volumes. It was used to corroborate data provided by the sandbed monitoring study and provide additional and complimentary information about the barrier effect imposed by traffic and roads on animal movement.

2.3.1 Methods

A remote video surveillance system was used at four of the eight Warwickshire roadside sites that had previously been used for sandbed monitoring: Loxley, Oakley, Wellesbourne and Wiggerland (see Appendix B for site descriptions). These sites were selected because of their proximity to each other. Motorways were not included because the widths of the carriageways exceeded the field of view on the equipment being used.

The equipment required for each system included four rechargeable 12-volt gel batteries, an infrared lighting system, two cameras with infrared filters, a picture-in-picture control unit (used to produce one close and one more distant image on one video recording) and a VHS time-lapse video recorder (VCR) with time-logger. Equipment that was not required on the roadside was housed in camouflaged, padlocked boxes in the adjacent woodland. Cameras and infrared lights were positioned on posts or trees, opposite sandbed sites. The infrared lights provided adequate forward illumination to reach to the far-side verge of the widest road (approximately 20 metres) and about 20 metres along the length of the road. Camera angles were set for optimum coverage of the area lit by infrared lights. The near-camera view included the sandbed monitoring strip, the road and verge adjacent to it, and a section of the nearside verge. The far-camera view was of the distant roadway and verge that were visible without infrared lights after daybreak (Figure 2.5). Batteries and videotapes were changed daily. The system was programmed to start at 21.00hrs and continue until 07:00hrs using VHS 3 hour videotapes in 12-hour time-lapse mode.

Due to of a series of equipment failures, the planned simultaneous recording of roads with high traffic and low traffic volumes, which would have provided information that was directly comparable, was not possible. For the same reason, not all sites were recorded for the same number of nights (see Appendix C for recording dates at each study site).

The videos were examined off-site and a record was kept of species and the behaviour of individuals as they approached the road. Occurrences of multiple incursions onto the sandbeds by single individuals were also recorded to assess the accuracy and reliability of sandbed monitoring.

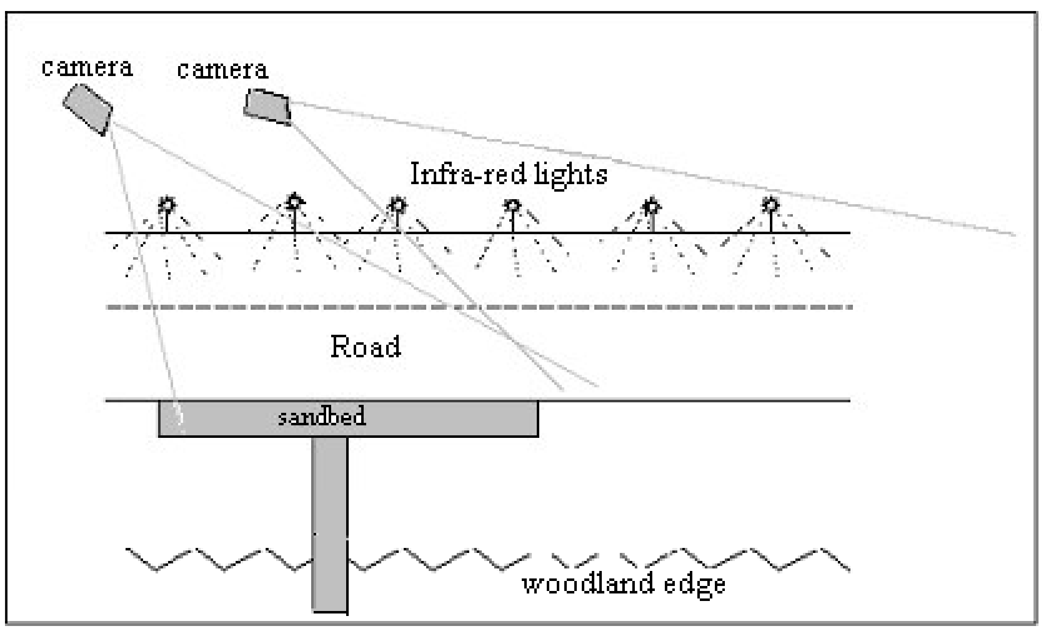


Figure 2.5 Diagram of the typical set-up of the CCTV recording system used at the roadside to monitor nocturnal wildlife activity.

2.3.2 Data Analysis

The number of recording nights was different for each site and to provide results that were directly comparable between sites the data were standardized. Standardization was achieved by multiplying the average daily species count at each site by the average number of recording nights (18). These standardized figures were used for inter-site analysis.

Differences in animal activity between sites with different traffic volumes (traffic data were provided by Warwickshire County Council) was examined using non-parametric Mann-Whitey U test, with data from the low-volume roads of Loxley and Oakley amalgamated and compared with the amalgamated data from the high-volume roads of Wellesbourne and Wiggerland. An association between species' abundance and traffic volume was investigated using Spearman's Rank correlation coefficient. The behaviour exhibited by individuals when close to roads was examined as a qualitative measure of road avoidance and used to complement the quantifiable data. To test the efficacy of the two different monitoring systems, the average daily counts for the sandbed and the CCTV study were compared using Mann-Whitney U test.

2.3.3 CCTV Results

All recording was done during the period 18th March 2000 to 23rd June 2000. This produced 20 nights of coverage at Oakley, 19 nights for Loxley, 19 nights for Wiggerland and 15 nights coverage at Wellesbourne, giving a total of 75 nights' coverage for the four sites. Ten different species were captured on camera during this period. Rabbits and foxes were the most frequently recorded animals, squirrel and muntjac were often recorded, hedgehogs and badgers were only occasionally recorded and the remaining species were recorded rarely (Table 2.5).

Table 2.5 The number of animals and the number of sites at which different species were recorded by CCTV.

Species	freq.	%	nights recorded	daily ave	sites
rabbit	108	39.42	54	1.44	4
fox	98	35.40	44	1.29	4
squirrel	23	8.39	14	0.31	3
muntjac	21	8.39	16	0.31	3
hedgehog	8	2.92	5	0.11	2
badger	6	2.19	6	0.08	2
fallow	5	1.82	2	0.07	1
roe	2	0.73	2	0.03	1
frog	1	0.36	1	0.01	1
polecat	1	0.36	1	0.01	1
total	274	100	145		
mean	28.1		14.5		
sd	42.0		19.1		

Table 2.6 The (standardised) number of different species recorded by CCTV at the different field sites.

Species	Loxley	Oakley	Wells	Wigg	sum	mean	s.e.
rabbit	2.12	0.78	1.95	1.26	6.11	1.53	0.31
fox	0.66	1.83	1.70	1.16	5.35	1.34	0.27
muntjac	0.05	0.96	0.00	0.05	1.06	0.26	0.23
squirrel	0.00	0.46	0.00	0.66	1.11	0.28	0.17
hedgehog	0.30	0.09	0.00	0.00	0.39	0.10	0.07
badger	0.20	0.00	0.16	0.00	0.36	0.09	0.53
fallow	0.00	0.00	0.41	0.00	0.41	0.10	0.10
roe	0.00	0.00	0.08	0.05	0.13	0.03	0.20
other	0.05	0.05	0.00	0.00	0.10	0.02	0.14
total	3.39	4.15	4.30	3.18	15.02	3.76	
mean	0.35	0.43	0.45	0.30			
s.e.	0.22	0.20	0.25	0.15			

Species were not distributed evenly across the sites (Table 2.6). Of the more common species, muntjac deer were found almost exclusively at Oakley, squirrels were frequently present at two sites but absent from the others and there were relatively few recordings of foxes at Loxley, whereas hedgehogs and rabbits seemed to favour this site. The total number of animals recorded at sites with different traffic densities was compared, but differences were not significant (Mann-Whitney U test, $n = 20$, $p = 0.967$, two-tailed test).

The hour at which individuals were recorded on camera was compared with average traffic flow for the corresponding time (Figure 2.6). This revealed a highly significant negative correlation between the accumulated species activity and traffic volume ($r_{s} = -0.937$, $n = 14$, $p = <0.01$, two-tailed test).

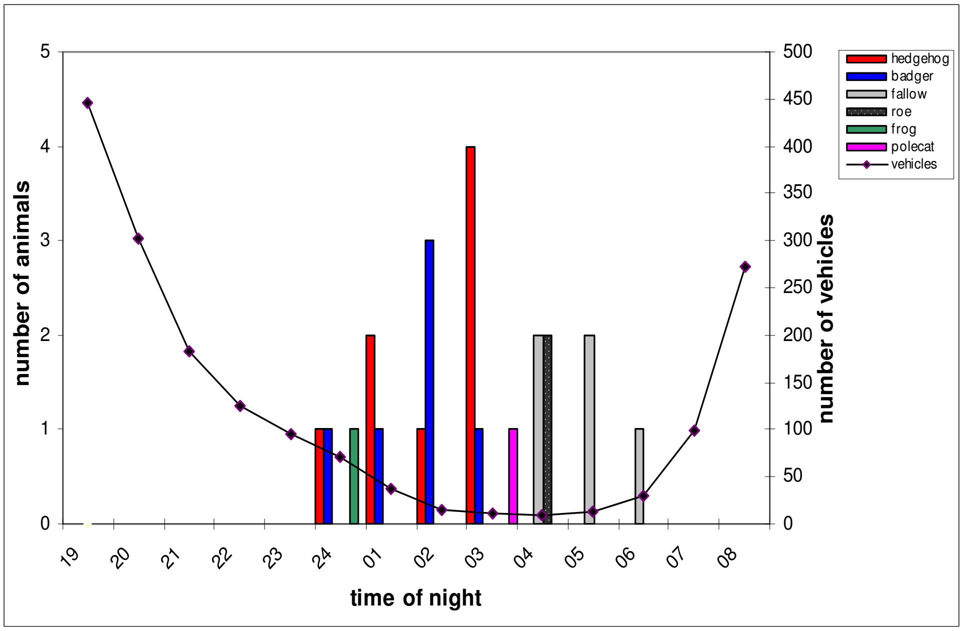
2.3.3.1 Road usage and behaviours of different species

Utilisation of the road and its verges varied considerably between species and can be clearly seen on the video footage. A summary of activity and behaviour of each of the different species recorded on CCTV is given below.

Rabbits

Rabbits were recorded on 108 occasions. All rabbits grazed the road-verges. Although only a few were observed crossing the road, several moved down the road on the tarmac, presumably to different grazing areas. There were three instances when rabbits were grazing at the road edge when cars approached. On one occasion the rabbit sat up in an ‘alert’ position, on the second occasion the animal moved away from the road and into the wood and, on the third occasion, the animal offered no response. Activity times were predominantly crepuscular but rabbits also appeared during the hours of darkness.

Low frequency species



High frequency species

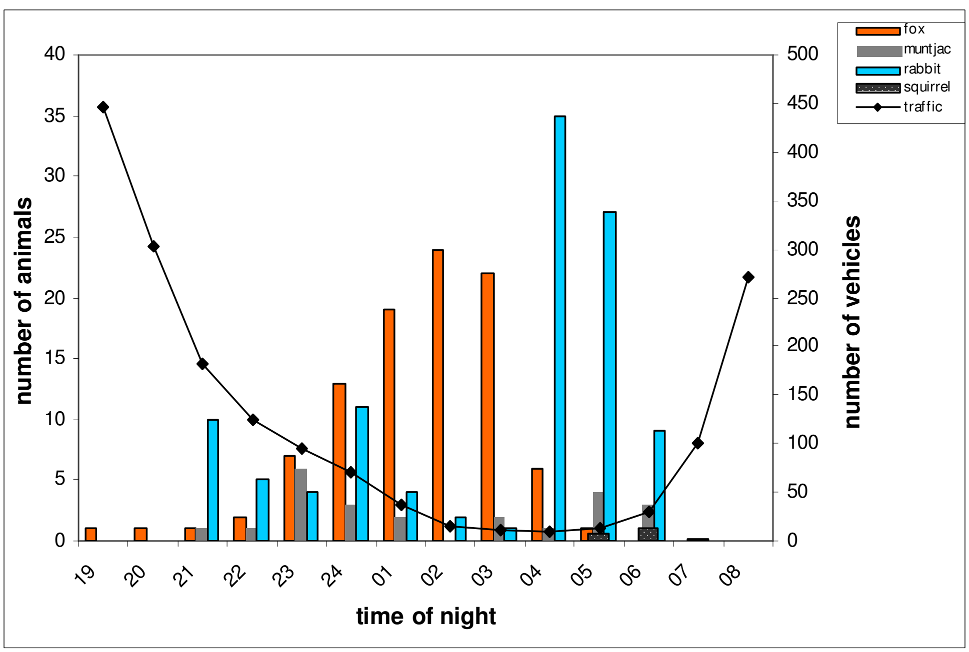


Figure 2.6 Species' activity at different times of night (19:00hrs – 08:00hrs) set against average traffic volumes for the same times. The uppermost graph shows the activity of the infrequent, or rarely occurring animals, the lower chart shows the commonly occurring animal. N.B. For clarity, animal frequency on the two charts has been plotted on different scales.

Foxes

Ninety-eight foxes were recorded on 97 occasions (a vixen and cub were recorded together on one occasion). Of these, 74 moved along the road, sometimes in the centre, sometimes nearer the verge. There were three occasions only when foxes crossed from one side of the road to the other, although there were 11 instances, all at one site, when they either entered the wood from the road or left the wood to join the road. Animals on the road usually moved at a trot. In about a quarter of the recordings they were filmed inspecting the road-verge. At one site, there was a musking point in the camera's field of view and 11 times foxes stopped either to mark or to inspect the spot. They also inspected the infra-red lights at the site where they were nearest to ground level. There were two occasions when a fox was on camera as a car approached and on both occasions, the fox withdrew into the wood. A fox was also recorded retreating into a wood when a badger approached along the road. It returned to the roadside when the badger had passed. Activity was spread across the recording period but foxes were most active between 24:00hrs and 04:00hrs.

Squirrels

Squirrels were recorded on 23 occasions predominantly on the road-verge. On all but one occasion, they were foraging for food or actually eating. On 11 occasions at one site however, a squirrel (possibly the same individual) spent considerable periods on the tarmac at the road edge. It appeared to be eating, but it was too far from the camera for this to be verified. When cars approached (3 occasions), this squirrel moved back several metres onto the verge but quickly returned once the vehicle had passed. There was only one occasion when a squirrel was observed actually crossing the road. Activity was confined largely to the morning hours after dawn.

Muntjac deer

Twenty-one muntjac deer were recorded on 19 occasions (a mother and fawn appeared together twice). Four were recorded only in the woodland. Ten were recorded grazing and moving along the road-verge. There were no instances of muntjac travelling down the tarmac portion of the road. There were nine instances of them crossing from one side of the road to the other. There were two instances where cars approached as the animals were grazing on the road verge. On the first occasion the individual retreated into the wood, on the second occasion the animal remained on the verge motionless whilst the car passed, and then resumed grazing. Activity was spread fairly evenly across the whole of the recording period.

Hedgehogs

Hedgehogs were recorded on eight occasions. They moved down the centre of the tarmac on every occasion. On four of the occasions, they appeared to be foraging; on the other occasions, they seemed to be using the road as a movement corridor. Activity was recorded only between 24:00hrs and 03:00hrs.

Badgers

Badgers were recorded on 6 occasions. On all the recorded occasions, the animals moved along the tarmac close to the verge. Only on one occasion, was an individual recorded crossing the road, but even then, it continued down the tarmac on the opposite side rather than moving into the woodland. They were often observed foraging along the road-verge. Activity was recorded only between 24:00hrs and 03:00hrs.

Fallow deer

Five fallow deer were recorded in two recording sessions. All crossed the road. None spent any time on the road-verge except just prior to crossing when they hesitated at the roadside edge. Although they appeared as a pair and a group of three, none of them crossed the road together; one always reached the other side before the next followed. At the approach of traffic, the speed at which they crossed increased in relation to the proximity of the vehicle. Activity was confined to the morning hours between 04:00hrs and 06:00hrs.

Roe deer

Roe deer were recorded on two occasions. One animal crossed directly from one side of the road to the other. On the second occasion, the individual meandered very slowly from one side of the road to the other. The two recordings were both made between 04:00hrs and 05:00hrs.

Polecats

A polecat was recorded on one occasion only, when it moved at a rapid pace along the tarmac at the road edge, close to the verge. The individual was observed at 04:00hrs

Frogs

One frog was recorded. It moved slowly along and across the road. The individual was recorded at 24:00hrs.

2.3.4 Evaluation of video recording as a wildlife auditing technique

Wildlife surveillance using video recorders is a method that has had only limited use despite its apparent suitability for monitoring cryptic species, yet it provides a method by which an area can be observed for long periods without manipulation of the habitat and is not weather dependent. In addition, because the data is visual, it provides a reliable, unambiguous record, obviating the need for verification by other means.

The advantages and drawbacks of video monitoring of wildlife are fully discussed by Stewart *et al*. (1997). The particular benefit of this study was that it provided for the first time, direct, verifiable evidence of traffic and road-related behaviour on a whole assemblage of UK animals that reside in relatively small fragmented habitats separated by roads. This is information that cannot be inferred from other indirect methods of monitoring. It is distinct from autecological studies that have been undertaken previously insofar as it enables direct inter-species comparison of movement and behaviour. For this study, it was also particularly valuable in corroborating the findings from sandbed monitoring.

The drawbacks of the technique, apart from the initial cost, relate to the system itself rather than the method of monitoring. The principal difficulty was that it frequently failed in the field. Some of these problems were resolved on-site (latterly by modifying the way the system operated) but others required expert attention, and repairs to the system were costly and entailed suspending the study during the repair period. Theft of equipment in such prominent positions was a concern, but only one inexpensive item was stolen during the several months during which the equipment was used. The other difficulty of the CCTV system in this study was that traffic flow meant that the movement detector could not be utilized. Not only did this considerably increase the time needed to view the recording (video recordings can be searched automatically for movement when the movement detector has been used), but, more importantly, it meant that the automated device that switched the recording to real time mode could not be utilized; this compromised the quality of recording.

2.3.5 Recommendations for the use of CCTV

The attempt to use CCTV to monitor simultaneously, two roads with different traffic levels, was frustrated by equipment failure and this resulted in differences in the recording period for the sites. Technical training may have circumvented some of these problems but, for trouble-free operation, it is essential to use equipment that can handle the rigours of fieldwork.

The data derived from CCTV were not wholly suitable for statistical analysis because of the small numbers of many species recorded. However, this is a problem not of the method but one associated with dispersal of animals across a wide area. CCTV provided footage of behavioural aspects of many species that could not be derived by any other means and in this respect, it is a valuable and uniquely suitable instrument for the recording of cryptic species.

2.4 Discussion

2.4.1 Comparison of methods

A comparison between the CCTV and the sandbed results for the communities of the eight different species common to both studies (Table 2.7) found no significant difference between the two methods (Mann-Whitney U test: N=32, W=930, p=0.141, two-tailed test). This implies that both methods are equally good recording techniques. However, the video recordings revealed many occasions when single animals remained in one area for extended periods producing a multitude of tracks; multiple prints on the sandbeds, inevitably distorted the sandbed counts. This was especially true for grazing rabbits (and probably for squirrel and small mammals). On this basis, it is difficult to see how the number of incursions onto a sandbed can be reliably used to estimate absolute abundance, however, they can be used as an index of relative abundance, as done in the US for scent station surveys (Conner *et al.* 1983, Crooks, 2002, Linhart and Knowlton 1975, Sargeant *et al.* 1998). A further shortcoming of sandbeds is that much activity along roadways goes unrecorded when the preferred route of individuals bypassed the sandbed. CCTV recordings show foxes frequently travelling along the tarmac portion of the road, and the same is occasionally true of hedgehogs, badgers and polecats. Additionally, whilst the majority of species recorded in the study were common to both studies, some were not. Small mammals were recorded as one of the highest frequency counts on the sandbeds, yet they did not feature at all on the CCTV recordings and some species recorded on camera (albeit only once for each species; a polecat and frog) were never identified on the sandbeds. However, video recordings did, verify that when an animal crossed a sandbed its presence always registered.

Table 2.7 Daily average of species recorded by sandbeds and by CCTV

Sandbeds

Species	Loxley	Oakley	Wells	Wigg	sum	mean	s.e.
rabbit	1.86	1.51	0.58	1.00	4.95	1.24	0.28
fox	0.30	0.30	0.23	0.70	1.53	0.38	0.11
muntjac	0.07	0.16	0.05	0.09	0.37	0.10	0.02
squirrel	0.00	0.28	0.02	0.56	0.86	0.22	0.13
hedgehog	0.02	0.00	0.00	0.00	0.02	0.01	0.01
badger	0.02	0.05	0.05	0.00	0.12	0.03	0.01
fallow	0.00	0.02	0.02	0.00	0.05	0.01	0.01
roe	0.00	0.00	0.00	0.00	0.00	0.00	0.00
sum	2.74	2.49	1.49	2.74	9.47	1.04	0.30
mean	0.27	3.47	0.15	0.28	1.04		
s.e.	0.18	0.15	0.07	0.12	0.48		

CCTV

Species	Loxley	Oakley	Wells	Wigg	sum	mean	s.e.
rabbit	2.12	0.78	1.95	1.26	6.11	1.53	0.31
fox	0.66	1.83	1.70	1.16	5.35	1.34	0.27
muntjac	0.05	0.96	0.00	0.05	1.06	0.26	0.23
squirrel	0.00	0.46	0.00	0.66	1.11	0.28	0.17
hedgehog	0.30	0.09	0.00	0.00	0.39	0.10	0.07
badger	0.20	0.00	0.16	0.00	0.36	0.09	0.53
fallow	0.00	0.00	0.41	0.00	0.41	0.10	0.10
roe	0.00	0.00	0.08	0.05	0.13	0.03	0.20
sum	3.39	4.15	4.30	3.18	15.02	1.77	0.28
mean	0.35	0.43	0.46	0.30	1.77		
s.e.	0.22	0.20	0.25	0.15	0.78		

The two methods of investigation are very different in terms of the required input. They also differ in output (Table 2.8). The lack of any significant difference between the daily averages recorded by the two methods indicates that sandbeds can be a useful monitoring tool in some circumstances but they are a crude instrument of measurement. Reliable counts of individuals, the time of individual activity and the recording of individual behaviours are all details that the passive sandbed medium is unable to deliver. Nevertheless, sandbeds can reveal some information, on small mammal activity for instance, that cannot be acquired by CCTV, and from places where CCTV would be difficult to operate. They also do not require the same degree of technological sophistication or capital outlay as CCTV. These considerations may make them a useful and attractive alternative for data gatherings. Nevertheless, CTTV recording provides a quality of detail much superior to that obtained from sandbed monitoring and in general terms would be the preferred instrument of monitoring when cost, location and the focal taxa do not preclude it.

2.4.2 The range of roadside species and the value of roadside verges

Ten different species, excluding small mammals, were identified in road-adjacent habitats. Grazing animals such as rabbits and muntjac were found using the verge as a feeding resource but, whilst the road-verge is utilized by some species, the road itself is utilized by more. Even squirrels, when foraging on the road-verge were observed spending large amounts of time actually on the road. The explanation for this behaviour of squirrels is not clear; there was no fallen mast along the road but it is possible that they were consuming accumulated invertebrate remains swept to the kerbside edge by passing vehicles. Hedgehogs foraged on the tarmac as well as apparently using the road as a movement corridor. Hedgehogs are known to favour linear habitat, especially woodland edge and hedgerow habitat

Table 2.8 The advantages and disadvantages of two different systems used to identify animal activity in the vicinity of selected roads.

Sandbeds	CCTV
Costs of installation and maintenance insubstantial	Substantial expense to purchase equipment
The system is not subject to technical breakdown	It is a technical system which is subject to breakdown
Cost of maintenance and repair is insubstantial and can be undertaken immediately	Cost of equipment repair can be substantial and time-consuming and severely interrupt survey work
A non-technical system which requires no technical skill to install, maintain and operate	A technical system which requires some technical skill to install, maintain and operate
Accurate identification of the records (i.e. tracks) requires experience	Identification of records is straightforward and only requires visual recognition
Several sites can be recorded simultaneously	Simultaneously site recording is restricted by the cost of equipment
System can be installed in any accessible area	Equipment needs uninterrupted view to operate successfully
The system is weather dependent and periods of bad weather can severely interrupt survey work	The system can be operated under any conditions although poor weather may impair the quality of the visual record
Multiple incursions by one animal cannot be distinguished from incursions by several individuals	Individuals can be distinguished
The data record is temporary	The system provides a record that can be stored indefinitely. This enables verification of the record and viewing by others at a later date
Area coverage is limited and activity may be missed if an animal selects a route which does not cross the sandbed	There is a wide field of view
The passage of an animal is the only aspect of animal behaviour that can be detected	Activity and behaviour can both be monitored
Records have to be scrutinised on site	Records can be studied remotely

(Huijser *et al* 2000), but it is the road-verge, not the road, that is generally promoted as the means of connectivity through the landscape matrix (Andrews 1990, Doncaster *et al.* 2001, Downes *et al.* 1997, Getz *et al.* 1978, Nicholls and Margules 1991). Indeed, it is suggested that whilst hedgehogs may be attracted to road-verges they may actively avoid the road surface (Huijser 1999); this contrasts with the findings of this study and, although the dataset for hedgehog was small, it serves to emphasise the value of different monitoring methods.

It has been suggested that although large predator species may move along roads that have little vehicular traffic, (Forman 1995, Bennett 1991), road surfaces, roadsides and adjacent areas are little used as conduits for animal movement (Forman and Alexander 1998). Smaller animals in the UK however, do not necessarily follow this pattern; hedgehog, badgers, polecats and particularly foxes, all seem equally well disposed to using the tarmac portion of the road as a means of moving through the landscape. Neither lack of cover nor the unnatural texture of the road surface appears to act as a deterrent. It is not surprising that for animals with relatively large territories, the road network is utilised as a passageway at times when traffic density is low. The easy, uninterrupted transport highway facilitates movement between different parts of an animal's territory just as it does for the human species. It is reasonable to assume that dispersing individuals may utilise roads in the same manner. However, it is not suggested that the use of roads by animals is the same irrespective of the volume of traffic. The roads that were monitored in the CCTV study carried volumes of traffic up to 14,000 cars each day, but on all these roads, there were periods when there was little or no traffic. On roads where traffic volume is greater or there are no periods without traffic it is likely that road-use is curtailed, as proposed by Clarke *et al.* (1998). It is unlikely that animals found on roads with high traffic densities use them as a routeways. The traffic threshold that prompts changes in behaviour and suppresses road-related movement has yet to be determined.

Although some animals were found to use the roads themselves to move about their territory, no evidence was found of animals using the road-verge as a means of passage (the high activity count for foxes on the verge section of the sandbeds was almost exclusively the result of movement from the road into the wood, it was not the result of lateral movement along the verge). This is an important finding, which contradicts much of the assumptions about road-verge usage.

Animals using the roads, albeit when traffic volume is negligible, expose themselves to considerable risk. Mortality rates for fox , badger and hedgehog are considerable (Clarke *et al.* 1998, Davie *et al.* 1987, Morris 1994, Harris and White 1998) and most of the records for polecat distribution have been derived from road-kill data (Birks and Kitchener 1994). Different behaviours and activities of some animals when near roads predispose them to a greater risk of mortality (Bennett 1991). Thus, foraging along roadways, using the road as a corridor, or crossing roads that intersect habitats and territories, all increase risk. The evidence collected here indicates that many animals spend considerable amounts of time on the tarmac portion of the road. This inevitably increases their chance of being struck by a vehicle and it suggests that the high mortality rates of certain species is often not just a result of incidental road crossings which, by chance, coincides with passing of vehicles.

The activity of most species was confined to the early morning hours or just after dawn when traffic volume is at its lowest. Consequently, there were few occasions to observe the specific behaviours of individuals when confronted by approaching traffic. When data derived from the sandbed studies at the different sites was examined (each had different traffic densities), there was a negative correlation between traffic volume and the activity of the more common animals, but these associations were generally not significant. This relatively weak association with between traffic volume and species abundance is a reminder of the many other variables that effect animal distribution at the site level. However, when counts of animals for the specific times of day are correlated against traffic density (using CCTV data) there is a strong and significant negative correlation between traffic and the number of animals. This suggests that traffic suppresses animal activity, but care must be taken in the interpretation of these results. It is possible that the relationship reflects not a causal link but merely a natural peaking of animal activity coinciding with a reduction in normal traffic flow.

Distance from the road is significantly associated with increased activity levels in the sandbed study. This suggests an avoidance of roads, but evidence from CCTV footage shows considerable activity on the road. Differences between these two sets of results are explained in two ways. Firstly, CCTV was only able to record road and road-verge activity, not activity in adjacent woodland habitat, so it was not possible to gauge or verify differences between the two habitats with CCTV. Secondly, activity on the road recorded by CCTV, although frequent, also tended to be species specific, and when the sandbed data is examined, the species recorded by CCTV moving along the road were found in high numbers on the road sections of the sandbeds. Undoubtedly, there are sensitive species that will generally avoid unnecessary contact with the road and whose presence in roadside areas is probably an artefact of transitional movements through fragmented habitat. Nevertheless, none of the animals observed as part of this study appeared to find roadways with clearances up to 14.5 metres an impenetrable barrier during times when traffic density was low. Even roe deer were recorded for fairly lengthy periods on the road when traffic was absent. These observations add weight to the argument that on roads comparable to the A class roads studied here (≤ 14.5 metres with traffic volumes ≤ 15,000 vehicles daily), traffic has a greater inhibiting effect on larger mammals than a lack of cover or between-habitat clearance.

2.5 Conclusions

Traffic appears to affect the movement of animals more so than other factors. There is no apparent barrier-effect associated with the road structure itself, neither the absence of cover nor the hard-edged woodland/road appears to be a deterrent to animals moving onto the actual road surface. Nevertheless, tracks were more frequent within the woodland habitat suggesting that animal activity does increase at distance from the road but the effect is species-specific.

The results of this study provide new information about the movement of UK fauna in relation to roads. Previously, this information had been assumed or inferred from indirect studies, or was derived from studies elsewhere on animals different to those found in the UK. This investigation reveals the considerable amount of activity on roads and road-verges adjacent to woodland. It indicates which species may be most affected by the barrier-effect imposed by roads and which of the commonly occurring species use roads as a functional resource. The study also helps to separate the effects of road clearance and traffic in suppressing animal movement.

CHAPTER 3. THE EFFECTS OF ROADS ON THE ACTIVITIES OF SMALL MAMMAL WOODLAND COMMUNITIES: A CAPTURE-MARK-RECAPTURE STUDY.

3.1 Introduction

To assess adequately the effects of fragmentation by anthropogenic linear infrastructures, analysis of species movement patterns is essential (Diffendorfer *et al.*1995). Chapter 2 investigated the barrier effects of roads (a principal component of habitat fragmentation) on the assemblage of larger UK animals that might be found in road-adjacent habitats, but movement of these animals is difficult to monitor comprehensively because of their cryptic nature, their wide-ranging and often nocturnal movements and their relative lack of abundance. Consequently, the incidence of recorded road crossings for many species is small and numerically insufficient for rigorous statistical analysis. In contrast, because of their abundance and their readiness to enter baited traps, the activity, distribution and behaviour of small mammals can be monitored more easily.

This chapter reports on the results of a capture-mark-recapture programme of small mammals ($\leq$ 50 grams) carried out at a cluster of four of the woodland sites in Warwickshire that had been previously used for sandbed and CCTV monitoring. Each site is intersected by a road categorised by either low or heavy traffic volume. This enabled a two-by-two replicated study of the movement and spatial distribution of different small mammal species in relation to the road. A seasonal series of short-term (three to five days) capture-mark-recapture sessions was conducted over a twelve month period. The spacing of the trapping periods across the year enabled temporal variations in demography and individual movements to be monitored.

3.1.1 Study Purpose

This study investigates the spatial and temporal movements of small mammals in woodland habitat and the extent to which different sized roads may affect and filter movement. The following hypotheses are investigated:

- Individuals that move the greatest distance are most likely to encounter roads and will therefore cross them more frequently.
- The width of the road moderates the barrier-effect of roads. Movements across roads should therefore be greater on narrower roads
- The disturbance created by roads causes small animals to avoid road-adjacent areas. Captures will therefore be greater at trap rows furthest from the road.

3.2 Methods

Capture-mark-recapture is commonly employed in the study of small mammals (Murray and Fuller 2000) and although it is a resource-intensive method, it enables the individual details of the captured animals to be systematically recorded (Southwood and Henderson 2000, Krebs 1999). A major drawback associated with the technique, and of particular importance to this study, is that the incarceration of individuals and the attraction of small mammals to baited traps tend to regulate movement (Wolton 1985). Particular consideration was given to this aspect in the design of the trapping protocol.

3.2.1 Study sites

Four woodland study areas in Warwickshire (Loxley, Oakley, Wellesbourne and Wiggerland) were selected for this part of the study. These had been used for the CCTV and sandbed monitoring studies described in chapter 2. Each of the four sites was subdivided into A and B sites to distinguish between the different sides of the road. Site details are given at Appendix B and the location of the sites are shown at Chapter 2, Figure 2.1.

3.2.2 Trapping design

A square grid of 6 x 6 trap points with 10 metres between each point was marked out. The range and distance moved by individuals depends on a number of factors including, species, sex, habitat and relative abundance (Flowerdew 1976, Gurnell and Gipps 1989, Kikkawa 1964). If traps are placed too far apart then small-ranging animals will be missed, but it is an inefficient use of resources if placed too close together. A 10-metre trap-spacing is considered suitable for the range of species of small mammal found within deciduous woodland (Flowerdew 1976, Gurnell and Flowerdew 1994).

One Longworth trap was placed at each trap point. The grid covered an area of 250 m^2. With a buffer strip, the effective trapping area becomes 360 m^2. One trap was placed within a metre of each grid point at a suitable location, *e.g.* alongside logs, at the base of trees etc. (Gurnell and Langbein 1983). Ideally, more than one trap should be placed at each grid point so that one capture does not prevent a subsequent one (Flowerdew 1976) but the available resources precluded this. Each trap contained hay for warmth and bedding, and was baited with whole wheat and sunflower seeds for rodents, and blowfly pupae for shrews (Churchill 1990, Gurnell 1975, Little and Gurnell 1989). Traps were camouflaged by placing them well into the undergrowth wherever possible and covering with leaves and/or other vegetation. This helped to insulate them during harsh weather conditions, conceal them from recreational users of the woods and blend them more readily into their natural surrounding to reduce neophobic responses from small mammals. Different sides of the same road were trapped separately on alternate nights to reduce any regulatory effect on individuals either because of confinement or because of an attraction to baited traps. Traps that were not in use were shut and left *in-situ,* in readiness for the next trap round. No bait was left outside the traps and care was taken not to spill bait that might attract individuals and distort distribution patterns (Sutherland 1996).

Trapping periods were roughly three months apart (November, March, June, September) to enable data on the small mammal communities to be collected across the yearly cycle. Each trapping period consisted of three to five days and generally, there were two trap rounds every 24 hours.

With the exception of shrews, which are notoriously difficult to sex and age accurately in the field (Searle 1985), all individuals were weighed and sexed and breeding condition was noted. Bank voles and wood mice ≤15.5g were classified as juveniles and above this weight as adults (Flowerdew and Gardener 1978). Individuals for each species were also given a unique fur clip so that they could be subsequently identified. To readily identify animals that crossed the road, animals on side A at each of the sites, were given an additional fur clip at the base of the tail. Fur clipping is a method of marking that is convenient in the field, is sufficiently durable for short-term studies (Twigg 1975) and also subscribes to an ethical code that advises that marking protocols should minimise pain and stress to the individuals within a research study (Murray and Fuller 2000). The persistence of the marks depends on the age of the animal and the time of the next moult and, although some marks did persist through to the next trapping period, fur clipping is not a reliable form of marking for a long term capture-mark-recapture study. All individuals were therefore given a new mark at each trapping period, irrespective of whether they had been previously marked.

The aim of the exercise was to study the movements of animals in relation to the road, so multiple captures were a critical element within the study. To maximise trapping efficiency within the constraints of available resources, the trapping protocol was modified during the course of the study (pers. comm. J Gurnell 2000) and the duration of the trapping periods and the trapping design varied accordingly (Figure 3.1).

Table 3.1 The trapping protocol for each of the four trapping sessions.

trapping session	total no. of trap rounds	total no. of trap nights	no of prebaiting nights
November	6	3	2
March	10	5	0
June	5	5	0
September	10	6	0

Thus, for the November trapping period the traps were pre-baited for two nights to encourage entry and maximise the catch on the following three nights. (Pre-baiting is a method designed to reduce the delay in first-time trap entry for small mammals caused by new and unfamiliar objects). Trap entry is encouraged by baiting the traps with appropriate food and setting the door of the trap to remain open even if an animal enters). On all trapping periods subsequent to November (March, June and September), instead of pre-baiting, the first two days were devoted to marking the maximum number of animals in an attempt to increase the number of multiple captures (Gurnell 1980). This entailed setting traps overnight on both sides of the road simultaneously. Thus, on these occasions, each trap round consisted of 144 trap inspections (two sites x two sides) for the first two days. Traps were emptied the following morning after which they were shut until being re-set in the evening. This was followed by three days of trapping alternate sides of the roads when traps were set and emptied twice each day. There was a further change to the trapping regime during the peak breeding period in June when only one trap round (overnight) was undertaken during a 24-hour period. This was intended to reduce the amount of time that any captured lactating female might be separated from her young. Traps were again closed between trap rounds. Randomness of capture is a criterion of many statistical tests and in order to enhance the randomness of the catch, the traps were rotated in the March and June trapping periods. This entailed relocating the trap after each inspection 5 metres beyond its current position, following a clockwise circuit, so that on the fourth rotation the trap returned to its original position (Figure 3.1). However, as there was no apparent or corresponding change in results for the increase in effort, the procedure was discontinued for the September trapping period.

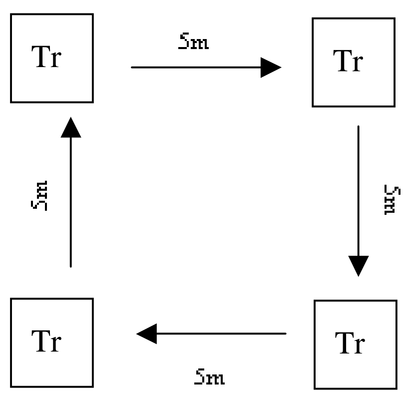


Figure 3.1 The method for trap rotation

Apart from the specific departure from the regime in June, traps were emptied every 12 hours. Depending on the season, this meant many of the trap inspections were carried out during the hours of darkness. This inevitably extended the length of the trapping round. The twice-daily routine was designed to optimise trapping efficiency for both nocturnal and diurnal species. There was some seasonal variation to the timings but the morning trap round started between 06:30hrs and 08:00 hours and never later than 2 hours after sunrise. The evening trap round started approximately 12 hours later. The core three days consisted of setting and emptying traps on just one side of the road for each trap round, at two different study sites. Seventy-two traps were inspected at each trap round. The time taken to complete each trap round varied according to the nature of the study-site, familiarity with the study-site, the number of captures and new captures (which varied with the season) and, to a lesser extent, the weather. The experience and number of helpers also influenced the amount of time taken to complete each trap round. The longest time taken to complete one trapping round (this involved trap inspections at two sites) was approximately five hours, the shortest, one and a half hours.

3.2.3 ***Data analysis***

The computer programme Diversity (Henderson and Seaby 1998) was used to calculate species diversity. Both Shannon Wiener, which emphasises common species, and Simpson D Index, which emphasises rare species (Simpson 1949), have been calculated. Equitability J was used to determine the evenness of distribution of species across the sites. Ranges V (Kenward and Hodder 1995) was used to estimate range and movement parameters of individuals that had been captured on three or more occasions. Minimum convex polygons (MCP) were selected to estimate home ranges. Other statistical analysis used either SPSS or Minitab.

For the analysis of capture frequency at different distances from the road, just the records of first-captures were generally used because trap-prone animals may skew data that includes recaptures. To compare the number of individuals from different trapping periods, the convention of calculating individuals per 100 trap-nights was employed. One trap-night is equal to one 24-hour period multiplied by the number of set traps. Due to the short duration of each trapping period, the minimum number alive (MNA) was used as the most suitable estimate of population. It is a basic enumeration method widely used in small mammal studies (Krebs 1999).

All data submitted for parametric analysis was tested for normality using the Kolmogorov-Smirnov test and Levene's test for homogeneity of variance was also applied. Where data sets met the required assumptions, differences in abundance were investigated using analysis of variance (ANOVA). Some of the data was transformed (log+1) to meet the assumptions of the test. When data could not be normalised the non-parametric Mann-Whitney U test was used.

Seasonal variation in the abundance of wood mice and bank voles was explored with one-way ANOVA. To avoid Type 1 error that may arise from repeated analysis of the same data sets (Krebs 1999), General Linear Model (GLM) univariate analysis was employed to investigate the effects both within and between different variables. Tukey's pairwise comparison was used to identify the significant variable. Abundance was used as the dependent variable and habitat and traffic volume were the two independent variables. Habitat classifications were based on an assessment of the ground-cover and amount of scrub at each habitat, with a variation between 1, where there was no ground-cover or scrub, to 3 where there was considerable ground cover and scrub. Road types were classified as either high or low volume. The roads at Loxley and Oakley were classified as low volume roads and at Wellesbourne and Wiggerland they were classified as high volume roads.

Chi-square test (χ^2) was used to investigate patterns of distribution across the trapping grid at each of the sites and to test for inter-site differences in community structure. Linear regression was used to detect any influence of roads permeating the adjacent woodland habitat.

3.3 Results

3.3.1 Community description

A total of 1082 individuals was caught during the four separate trapping periods (Table 3.2) with each individual being caught an average of 2.5 times. The combined total of captures and recaptures for all four trapping periods was 2694.

Table 3.2 The capture and recapture rate of different species for the four seasonal trapping periods

English name	Scientific name	Number of individuals captured	% of total individuals	Number of individuals per trap 100 trap nights	Total captures and recaptures	Mean capture frequency
wood mouse	*Apodemus sylvaticus*	576	53.2	7.41	1570	2.7
bank vole	*Clethrionomys glareolus*	283	26.1	3.64	649	2.3
common shrew	*Sorex araneus*	129	11.9	1.66	264	2.0
pigmy shrew	*Sorex mimutus*	27	2.5	0.35	40	1.5
yellow-necked mouse	*Apodemus flavicollis*	64	5.9	0.82	165	2.6
field vole	*Microtus agrestis*	1	0.1	0.01	2	2.0
water shrew	*Neomys fodiens*	1	0.1	0.01	2	2.0
weasel	*Mustela nivalis*	2	0.2	0.03	2	1.0
	sum	**1083**	**100.0**	**13.93**	**2694**	**2.5**

..

Eight different species were captured at the four sites: wood mice (*Apodemus sylvaticus*), bank voles (*Clethrionomys glareolu*s), common shrews (*Sorex araneus*), pygmy shrews (*Sorex minutus*), yellow–necked mice (*Apodemus flavicollis*), field voles (Microtus agrestis), water shrews (*Neomys fodiens*) and weasels (*Mustela nivalis*). Wood mice and bank voles were the dominant species. Wood mice represented over 50% of the total number of individuals caught during the four trapping periods, bank voles accounted for 26% of the total captures, common shrews 12%, yellow-necked mice 6% and pigmy shrews 2.5%. The first five of these species were found at all the sites. Pigmy shrews were missing from Loxley A and Wellesbourne A. The three remaining species, water shrew, field vole and weasel, were rare captures; a water shrew and field vole were captured once at Wiggerland A, a weasel was also captured once at Wiggerland A and again at Loxley A (possibly the same individual as that caught previously at Wiggerland A as the two sites are within 200 metres of each other).

There was little variation in species-richness across the sites with the exception of those sites where the uncommon species were captured. Overall, when the results for the four trapping periods are totalled, Wiggerland A had the highest species diversity; this is the site at which a field vole, water shrew and a weasel (rare captures) were trapped, and Loxley A had the lowest species diversity (Table 3.3). The measure of evenness shows Loxley A as being a relatively poor site.

Table 3.3 A comparison of different sites showing the level of species diversity (Shannon Wiener and Simpson's D index of diversity), and evenness (Equitability J).

Site	Shannon W	Simpson's	Eveness Index
Loxley A	0.96	2.33	0.46
Loxley B	1.08	2.52	0.52
Oakley A	1.24	2.51	0.59
Oakley B	1.20	2.60	0.58
Wells A	1.19	2.59	0.57
Wells B	1.19	2.95	0.57
Wigg A	1.39	3.34	0.67
Wigg B	1.18	2.51	0.57

When species abundance for all species at each site was compared, it indicated significant variability in community structure, both between study sites on either side of the same road and between those that were more remote (Table 3.4). With the exception of Oakley A and B, all the divided sites (the A and B study sites), have significantly different communities.

Table 3.4 Differences in community structure at each of the sites divided by roads (*i.e.* A and B sites) The November trapping period provided 864 trap-nights for the eight sites, March 1440, June 1440 and September 1728.

S	chi	p
Loxley A	10.	0.
Oakley A	1.	0.
Wellesboune A	12.	0.
Wiggerland A	11.	0.

Table 3.5 and Table 3.6 show the overall number of captures for the five most commonly occurring species for each site and each season. Mean abundance per 100 trap-nights at each of the different field sites is given. Overall, Loxley A had the highest number of wood mice, Oakley A the least. The highest number of bank voles was found at Loxley B and the least at Oakley. Wellesbourne B had the greatest number of yellow-necked mice and common shrews; pigmy shrews were most common at Wiggerland B.

Predictably, there were differences in the catch totals for the different trapping periods. Differences in abundance of the two dominant species for each trapping period were highly significant (Table 3.7). The wood mouse population was at its most abundant in November and September. Bank voles numbers peaked in September as did the numbers for common and pigmy shrews. Yellow-necked mice were caught most frequently in the November trap period.

Table 3.5 The abundance and mean abundance *per* 100 trap nights for wood mice and bank vole at the different field sites for each of the four trapping sessions. (One trap night is equal to the number of individuals per 24 hour period divided by the number of baited traps).

Site	Nov	Mar	Jun	Sep	Sum	% of grand total	s.d of trapping sessions	Calc. n per 100 trap nights	mean ave annual density per ha
				Wood mouse					
Loxley A	20	24	17	34	95	16.6	7.4	13.9	36.0
Loxley B	15	20	25	28	88	15.3	5.7	12.9	33.3
Oakley A	24	10	5	12	51	8.9	8.1	7.5	19.3
Oakley B	31	14	11	25	81	14.1	9.4	11.8	30.7
Wellsborne A	24	10	7	20	61	10.6	8.1	8.9	23.1
Wellsborne B	20	14	10	20	64	11.1	4.9	9.4	24.2
Wiggerland A	17	9	17	19	62	10.8	4.4	9.1	23.5
Wiggerland B	31	6	8	27	72	12.5	12.8	10.5	27.3
Total	182	107	100	185	574	100.0			
% of grand total	31.7	18.6	17.4	32.2	100.0				
s.d.	5.9	6.0	6.7	6.8	15.1				
n per 100 trap nights	21.1	7.4	6.9	10.5	10.5				
				Bank vole					
Loxley A	15	14	11	13	53	18.7	1.7	7.7	20.1
Loxley B	29	19	7	17	72	25.4	9.0	10.5	27.3
Oakley A	0	1	3	8	12	4.2	3.6	1.8	4.5
Oakley B	8	2	3	17	30	10.6	6.9	4.4	11.4
Wellsborne A	7	4	1	4	16	5.7	2.4	2.3	6.1
Wellsborne B	14	13	5	18	50	17.7	5.4	7.3	18.9
Wiggerland A	6	6	3	21	36	12.7	8.1	5.3	13.6
Wiggerland B	6	1	1	6	14	4.9	2.9	2.0	5.3
Total	85	60	34	104	283	100.0			
% of grand total	30.0	21.2	12.0	36.7	100.0				
s.d	8.8	6.9	3.4	6.3	21.6				
n per 100 trap nights	9.8	4.2	2.4	6.0	5.2				

Table 3.6 The absolute and mean abundance per 100 trap nights for yellow-necked mice, common shrew and pigmy shrew (One trap night is equal to the number of individuals per 24 hour period divided by the number of baited traps).

site	Nov	Mar	Jun	Sep	Sum	s.d of trapping sessions	% of grand total	Calc.n per 100 trap nights	Mean ave annual density per ha
Yellow necked mouse									
Loxley A	0	0	1	0	1	0.5	2.0	0.1	0.4
Loxley B	1	0	0	1	2	0.6	4.1	0.4	0.8
Oakley A	3	0	0	3	6	1.7	12.2	1.5	2.3
Oakley B	2	0	0	3	5	1.5	10.2	0.9	1.9
Wellsborne A	4	2	3	1	10	1.3	20.4	1.6	3.8
Wellsborne B	7	3	2	0	12	2.9	24.5	1.8	4.5
Wiggerland A	0	2	1	5	8	2.2	16.3	2.0	3.0
Wiggerland B	1	0	2	2	5	1.0	10.2	1.0	1.9
Total	18	7	9	15	49				
% of grand total	36.7	14.3	18.4	30.6	100.0				
s.d.	2.4	1.2	1.1	1.7	3.8				
n per 100 trap nights	2.1	0.8	1.0	1.7	5.6				
Common shrew									
Loxley A	0	5	4	5	14	2.4	15.6	2.8	5.3
Loxley B	5	0	0	6	11	3.2	12.2	1.8	4.2
Oakley A	1	1	2	2	6	0.6	6.7	1.2	2.3
Oakley B	10	1	0	3	14	4.5	15.6	2.5	5.3
Wellsborne A	1	2	1	4	8	1.4	8.9	2.0	3.0
Wellsborne B	5	2	0	4	11	2.2	12.2	2.5	4.2
Wiggerland A	1	1	2	7	11	2.9	12.2	2.8	4.2
Wiggerland B	5	0	3	7	15	3.0	16.7	3.4	5.7
Total	28	12	12	38	90				
% of grand total	31.1	13.3	13.3	42.2	100.0				
s.d	3.4	1.6	1.5	1.8	3.1				
n per 100 trap nights	3.2	1.4	1.4	4.4	10.4				
Pigmy shrew									
Loxley A	0	0	0	0	0	0.0	0.0	0.0	0.0
Loxley B	3	0	1	1	5	1.3	22.7	1.0	1.9
Oakley A	1	0	0	3	4	1.4	18.2	0.6	1.5
Oakley B	1	4	1	1	7	1.5	31.8	1.2	2.7
Wellsborne A	0	0	0	1	1	0.5	4.5	0.4	0.4
Wellsborne B	0	0	0	0	0	0.0	0.0	0.0	0.0
Wiggerland A	0	0	2	0	2	1.0	9.1	0.7	0.8
Wiggerland B	0	1	2	0	3	1.0	13.6	3.9	1.1
Total	5	5	6	6	22				
% of grand total	22.7	22.7	27.3	27.3	100.0				
s.d.	1.1	1.4	0.9	1.0	6.3				
mean n per 100 trap nights	0.6	0.6	0.7	0.7	4.4				

Table 3.7 Results of one-way ANOVA to test for differences between the four different trapping periods for the two dominant species

Species	Df	SS	F	p value	Tukey's pair-wise comparison
wood mouse	3	870.6	10.11	0.001	Nov diff to Mar & June
bank vole	3	788.8	7.11	0.001	Sept diff to Mar & June

3.3.2 The effects of roads on the distribution of species

Using GLM univariate analysis to investigate the effects of habitat and traffic flow on species abundance, habitat was found to have a highly significant effect ($p<0.001$) on bank vole abundance and a significant interaction ($p<0.05$) was found between road type and habitat (Table 3.8). For wood mice neither road type nor habitat was significant ($p>0.05$).

To investigate further the effects of roads on activity, the distribution of species across the trapping grid was examined (Figure 3.2). Trapline 1, nearest the road, was selected disproportionately by three out of the four commonly captured species. Over 33% of bank voles were first captured at trapline one; a high proportion of common shrews and yellow-necked mice were also captured there (34% and 40% respectively). Mice were more evenly distributed across the grid and showed no particular attraction for different areas of the trapping grid.

When differences in the distribution of the two dominant species (wood mice and bank vole) were compared, there was a significant difference in the distribution of the two species in relation to the road (χ^2 = 11.47, d.f. = 5, p-value =0.043). Voles favoured traplines nearest the road whereas wood mice favoured traplines furthest from the road. When age and sex categories were examined, no significant differences were detected for wood mice (p = 0.05), neither were differences between male and female bank voles significant.

Table 3.8 The results of univariate analysis of variance (General Linear Model). Abundance was used as the dependent variable and habitat and traffic volume were the two independent variable

Tests of Between-Subjects Effects

Dependent variable: mouse

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected Model	3.165[a]	4	0.791	2.402	0.60
Intercept	225.838	1	225.838	685.714	.001
Road	4.594E-03	1	4.594E-03	0.140	0.91
Habitat	1.687.	2	0.843	2.561	0.86
Road * Habitat	1.081	1	1.081	3.283	0.75
Error	19.431	59	0.329		
Total	285.968	64			
Corrected total	22.596	63			

[a]R Squared = .140 (Adjusted R Squared = 0.082)

Tests of Between-Subjects Effects

Dependent variable: bank vole

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected Model	12.371[a]	4	3.093	6.736	0.001
Intercept	104.148	1	104.148	226.838	0.001
Road	0.288	1	0.229	0.627	0.432
Habitat	9.011	2	4.506	9.814	0.001
Road * Habitat	2.430	1	2.430	5.293	0.250
Error	27.089	59	0.459		
Total	167.659	64			
Corrected total	39.460	63			

[a] R Squared = .314 (Adjusted R Squared = 0.267)

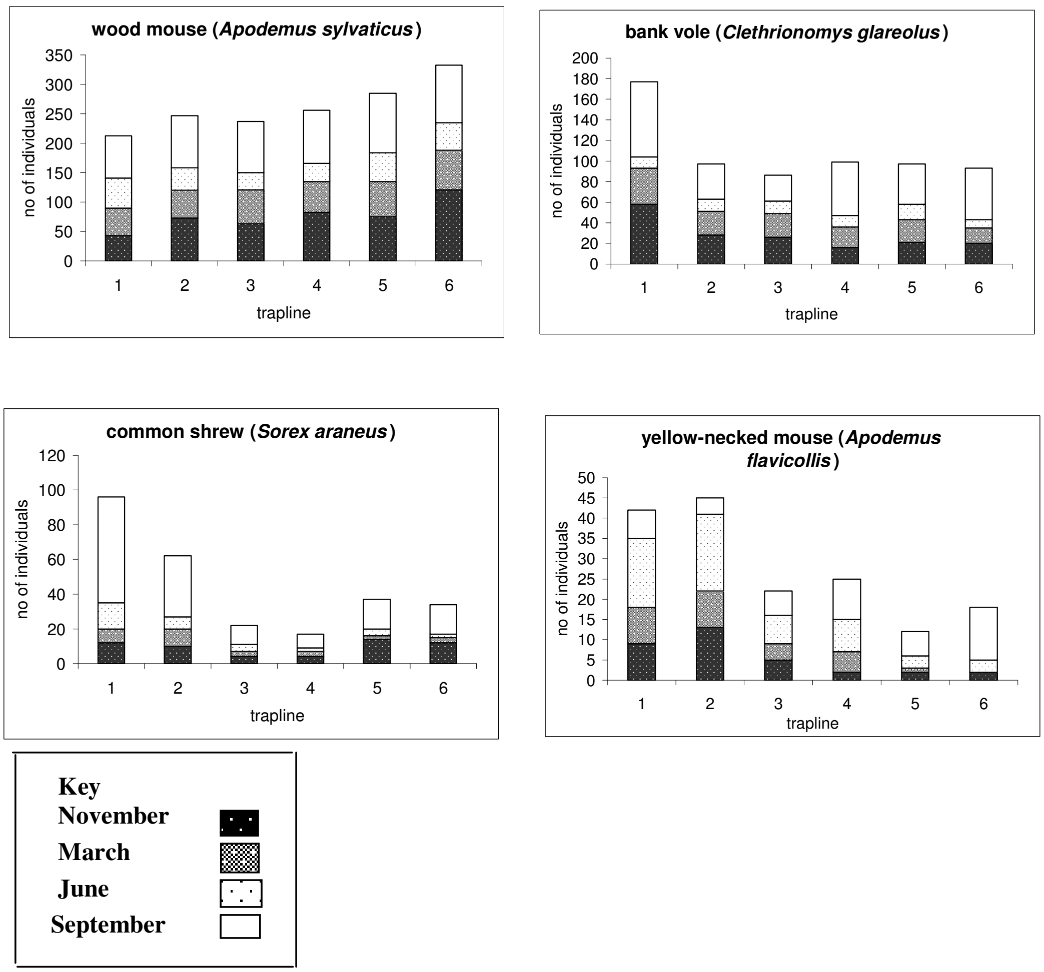


Figure 3.2 The distribution of the commonly caught species across the six traplines. (NB different scales have been used for different species, reflecting differences in abundance)

However, there was a highly significant difference between the observed and expected distribution of adult and juveniles bank voles across the six traplines ($\chi2 = 15.79$, df=5, $p = 0.007$) with juvenile bank voles favouring the traplines nearest the road more often than adult bank voles.

Using the number of individuals captured on each trapline (first captures only), regression analysis revealed no significant relationship between any of the species and distance from the road ($p > 0.05$), but the number of first-time captures dispersed across the six traplines was small. The analysis was therefore repeated using the total number of individual captures (*i.e.* captures and recaptures) for each species. Using these data, regression analysis indicated a positive and highly significant relationship between the abundance of wood mice and distance from the road ($p = 0.007$) (Table 3.9) and there was a significant but negative relationship between the abundance of yellow-necked mice and distance from the road ($p = 0.025$). There was no significant effect for bank voles or for common shrews (p = >0.05).

Table 3.9 The relationship between species' abundance and distance from the road using traplines as the measure of distance from the road.

Species	Regression equation	r^2	d.f.	p value	significance
wood mouse	189+20.9 x distance	0.867	5	0.007	*
bank vole	149 - 11.6 x distance	0.409	5	0.172	NS
common shrew	83.7 = 11.1 x distance	0.495	5	0.119	NS
y-n mouse	48.9 - 6.17 x distance	0.755	5	0.025	*

NS = not significant
* = significant @ 95% confidence level

3.3.3 Home range and distance moved.

Ranges V calculated the home range areas and distances moved for all individuals that were trapped three or more times. The results for different classes of wood mice and bank voles are given at Table 3.10. Of the two species, wood mice had slightly larger home ranges and travelled greater distances than bank voles. In the case of wood mice, male adults had the larger home ranges and moved greater distances, whereas in the case of bank voles, female juveniles recorded the greatest distance moved but adult males had the largest home ranges. The maximum distance moved by any individual was 37 metres, recorded for an adult female wood mouse that had been captured on four separate occasions in March. An adult female bank vole, trapped a total of four times, travelled a distance of 35 metres in September. The largest home range of 0.4ha was recorded in November for an adult male wood mouse caught on five occasions. The largest home range for a bank vole was just 0.09ha, recorded in the September trapping session for an individual that was captured on four occasions. Wood mice moved furthest in September, bank voles in June.

Table 3.10 A comparison of area coverage and movements of wood mice and bank voles classified by age and sex (only individuals that had been captured on more than three occasions are included).

Wood mouse	**all**	**female**	**male**	**adult**	**juvenile**	**male adult**	**fem adult**	**male juv**	**fem juv**
ha	0.016	0.013	0.018	0.017	0.007	0.019	0.015	0.009	0.006
max dist	14.630	13.307	15.275	15.079	10.957	15.519	14.283	11.700	10.385
mean	9.296	8.507	9.683	9.577	7.391	9.805	9.083	8.100	6.846
Bank vole									
ha	0.013	0.012	0.013	0.016	0.008	0.017	0.014	0.007	0.011
max dist	13.022	13.694	11.463	12.566	12.054	11.821	13.400	11.077	14.364
mean	7.744	8.444	7.278	7.774	7.703	7.464	8.120	7.077	9.182

Road crossings were rare events for all species and at all times of year (Table 3.11). Out of 1082 individuals, of which 395 made multiple trap entries, just five individuals were recorded

Table 3.11 The total number of recorded road crossings for the four trapping sessions.

Trapping session	Site	Daily traffic volume	Road width	Total verge width	Species	Sex	Age	Weight
November	Nil	-	-	-	-	-	-	-
March	Loxley	2000	5.9	3	wood mouse	male	adult	22
March	Wellesbourne	13500	7.5	3	wood mouse	male	adult	25
June	Loxley	2000	5.9	3	wood mouse	female	adult	27
September	Oakley	650	5.3	2	wood mouse	female	adult	18
September*	Loxley	2000	5.9	3	bank vole	female	adult	17

crossing the road. Wood mice crossed most frequently (four wood mice crossed out of a total of five recorded crossings), and more crossed on the low-traffic roads (three crossings) than on the high-traffic roads (one crossing). There was only one confirmed crossing of a bank vole (on a low-traffic road) for the four trapping periods. This individual was seen crossing the road after release but it was not subsequently recaptured. There was no other supporting evidence, such as road-kills, to indicate that more individuals crossed the road than those recorded.

3.4 Discussion

3.4.1 Experimental design.

The minimum-number-alive (MNA) has been used to estimate population size because the trapping histories derived from short duration studies render them unsuitable for other more sophisticated methods of estimation. MNA is a basic enumeration method but is likely to provide population estimates with a large negative bias if trappability is low (Greenwood 1996, Krebs 1999).

Most animals are neophobic to some degree resulting in variability in trap response (Barnett 1958, Myllymaki et al. 1971, Andreassen and Bondrup-Nielson1991). Latency to first capture indicates that pre-baiting of traps was effective in reducing this neophobic response by both wood mice and bank voles in the November trapping session, even though Gurnell (1980) found that pre-baiting for these species is generally unnecessary when the study period is short, *i.e.* in the order of one or two nights. The alternative strategy, of trapping more intensively for more days, which was employed in the later trapping periods, did not achieve the same number of captures. In the June and September periods, a greater resistance to trap entry from the two dominant species, particularly from bank voles, was evident but other factors such as the availability of food, competition for traps, and population density may also explain some of these differences (Kikkawa 1964, Tanton 1965). Despite the increased latency to first capture when traps were not pre-baited, captures during the final trap rounds, irrespective of the trapping period, still consisted mainly of animals that had been previously caught, suggesting that a high proportion of the trappable population had been marked.

A concern that only one trap at each grid point may be insufficient for the study appears to have been ill-founded. Generally, 40% or more of the traps were left empty, sufficient to ensure additional captures had not been precluded because too many of the traps were already occupied (Kikkawa 1964). Only in the November and September trapping sessions at the peak of small mammal abundance did the number of occupied traps occasionally reach 60% - 70%.

Overall, MNA estimates probably underestimate the true population, particularly during the summer months, when the low numbers may partly reflect trapping inefficiency. However, even during these periods the numbers of animals captured appears to be broadly in keeping with expectations when compared with the relative capture rates for the remainder of the year. Furthermore, because there was always consistency in the trapping regime at each site, it is reasonable to assume that the relative numbers for each site, used to examine the effects of roads, should not be compromised.

3.4.2 Community Structure

The number of small mammal species found during the course of this study and their relative abundance is typical of woodland habitats (Flowerdew 1993). With the exception of pigmy shrews, most of the commonly occurring woodland species were found at all the sites. The sites were fairly uniform in the relative composition of the four dominant species but species abundance varied considerably between sites and between trapping periods. Species richness and community stability may be indicators of site favourability but few sites were equally favourable to all species. Wiggerland A, a large mature woodland with wide grassy verges was the most species-rich and most even in composition. Loxley A, a small, scrubby fragment, was the least species-rich. This suggests that the older, more established sites may be more suitable for a wider range of species, but no such pattern emerges when the calculated diversity scores are inspected.

The considerable intra-site seasonal fluctuations largely reflect the breeding seasons but some sites were more volatile than others. At the more volatile sites, species that were locally uncommon, frequently disappeared altogether. Absences from specific sites appear to be a temporary phenomenon however, with species returning at subsequent trapping periods. This suggests that either these sites were part of a wider metapopulation and connected to other source sites from which they recruited (Boorman and Levitt 1973, Hanski *et al.* 1995, Kozakiewicz 1993, Levins 1970), or that the trapping regime was not reliable in detecting species when numbers were small. Either way, the fluctuation in numbers at different sites suggests that the populations of some species are fragile. If connectivity to source sites is reduced by further fragmentation, population persistence becomes less certain and some of these less common or patchily distributed species could become locally extinct.

Habitats that remain intact may have differences in the distribution of species because of the niche requirements of different animals. However, the intergradations of mature, intact habitats are subtle, and the end of one habitat type and the beginning of another is generally difficult to detect. Equally subtle are changes in the dynamics and composition of the attendant small mammal communities. This is not the case where anthropogenic structures such as roads are created, where the abrupt surface change constitutes a 'hard' edge (Stamps *et al*, 1987). Lidicker and Peterson (1999) observe '… habitat edges that we readily perceive, particularly those that are anthropogenic, will be sufficiently meaningful to cause many other kinds of organisms to respond to them as well'. Road construction fragments small mammal populations, changing the community dynamic and, because of the permanence of the barrier imposed by roads, it is questionable whether these severed communities can ever fully recover their previous status. Frequently, the extant habitats on either side of a road will evolve separately because of differences in the size of the remnant habitats and their positioning within the landscape matrix. The distinctiveness of the boundaries created by roads also provide convenient boundaries for different management regimes and consequently, alternate sides of the road are frequently managed differently, making one side more or less favourable to extant populations. When the community structure of A and B sites (those sites that are located on either side of the road) were compared, there were highly significant differences in three out of the four site locations. This confirms and emphasises the disruption caused to small mammals communities by roads, indicting that not only do roads alter the community structure by their direct impact on the populations, but they are also instrumental in maintaining those differences.

3.4.3 Factors influencing road crossings.

The absolute and relative number of trap entries is important when assessing small mammal movement. Not only are multiple entries a prerequisite to assessing movement and home range, but the distance moved and the range of individuals increase with the number of catches up to a certain threshold (Kikkawa 1964). Ten catches are recommended for precise estimates. The duration of each trapping period in this study limited the number of potential captures. Thus the distances estimated by Ranges V probably underestimates by an unknown factor the actual distances moved, but as a relative measure, the derived figures are still useful and still allows testing of the hypothesis that states that the propensity of animals to cross the road relates to their level of activity.

The findings in this study support the conclusions of other work that wood mice make longer movements, are more mobile and are more trappable than bank voles; that adult, male mice move further than female juveniles, and that inter-trap movements are longer in spring and summer than in winter. (Crawley, 1969, Gurnell 1982, Gurnell and Gipps 1989, Kikkawa

1964, Wolton and Flowerdew 1985). Male adult wood mice had the greatest home ranges and moved a greater distance than other species. They also moved further during the breeding season than at other times. The hypothesis states that individuals moving the greatest distances are most likely to cross roads. The findings support this hypothesis, with adult wood mice making the greatest number of road crossings. Four out of five crossings were by wood mice, although males and females crossed in equal numbers. Additionally, crossings by males were undertaken in March at the beginning of the breeding season when there is a significant increase in the range size of males (Attuquayefio *et al.* 1986, Crawley 1969, Kikkawa 1964). In this study, female bank voles moved further than males, and juveniles moved further than adults. This is contrary to findings elsewhere (Kikkawa 1964) but it is possible that the accuracy of the findings here may be impaired because of the low number of trap re-entries (a result of the short duration of the trapping periods). Certainly, the calculated distances moved and the calculated home ranges for bank voles and for wood mice are below results recorded by others for the same species (Dickman and Doncaster 1989, Tew 1988, Wolton 1985, also see Flowerdew 1993 and Szacki *et al* 1993). The single bank vole observed crossing was a young (17g.) female, but with only one recorded crossing for the species, no reliable conclusions can be drawn. Overall, the number of animals that crossed roads is small and care is needed in the interpretation of the results. Based on the available data, animals that travelled the greatest distances appear to cross roads more often but larger data sets are required to make predictions with any certainty.

3.4.4 The width of the road moderates the barrier effect.

The results support previous findings that roads pose a barrier to the natural movement of small mammals and that these barriers, for some species at least, are restrictive rather than totally prohibitive (Korn 1991, Kozel and Fleharty 1979, Oxley *et al* 1974, Richardson *et al.*

1998). It is important to note however, that at two sites, pigmy shrews were absent for the whole of the study period although they were present, albeit in small numbers, at sites on the opposite side of the road. It may be that roads present an even more formidable barrier to this species than they do to others. Shrews were more patchily distributed than either wood mice or bank vole and it is possible that their absence from the two sites was merely an expression of a more exacting habitat requirement rather than their ability to move freely between sites.

Oxley *et al.* (1974) concluded that clearance (the distance across the road separating adjacent habitats was the most important constraint on small mammal movements across a road, to which Richardson *et al.* (1998) added traffic density as a distinct and separate influence. There has been no attempt in this work to distinguish between the effects of traffic density and road clearance; rather, the general premise that wider roads carry proportionally greater volumes of traffic is accepted.

The study spanned the course of a full year to allow for seasonal variation in the distances moved. During the course of the twelve-month study, however, there were only five confirmed crossings. Four out of the five recorded crossovers were on the two smaller roads. These smaller roads had a surface width of 5.3m and 5.9m and clearances of 7m and 10m compared to the more heavily trafficked roads that had a surface width of 7.5m and a total clearance of 14.4m. Road crossings were few and, as a result, it is difficult to draw reliable conclusions about the influence of different factors. However, the 4:1 ratio in favour of the narrower roads could be an indication that they may pose less of a barrier to movement than larger roads.

3.4.5 The disturbance of roads on small mammals distribution

The ecological effects of roads are believed to extend outwards beyond their immediate surroundings into adjacent habitats covering an area many times wider than the road and its associated verges (Forman and Deblinger 2000). Adams and Geis (1983) found roads not only significantly affected small mammal communities but the structure of these communities varied at different distance from the road and varied also between county roads and interstate highways.

Species abundance did vary between sites but the population densities were within the range of other studies of small mammal communities in woodland habitats (Wolton 1985, Wolton and Flowerdew 1995). The exception to this was yellow-necked mice that appear to be under-recorded in Warwickshire; they had only been recorded in three tetrads in the county prior to this survey. Their status in Warwickshire is recorded as being in the west of the county (these study sites were in the north of Warwickshire) and 'very local' (Woodhouse and Roch 1999).

All species were found on all the traplines but species were not evenly distributed across the trapping grid. Bank voles, common shrews and yellow-necked mice were all attracted to traplines that were nearest to the road, indicating an edge effect for these species (Weins 1976). Regression analysis shows a significant linear relationship between the frequency at which wood mice and yellow-necked mice were trapped at different distances from the road (positive for wood mice and negative for yellow-necked mice), but there was no significant effect for either bank voles or common shrews. These results contrast with the results of univariate analysis that provide no evidence of any road-effect on the abundance of the two dominant species. GLM analysis does show, however, that habitat significantly affects the numbers of bank vole, and that the interaction between habitat and road type is significant. The interaction between habitat and road may be explained in two ways. Firstly, the high-volume roads tend to have wider road-verges and this alternative habitat has been found to be an attractive resource for many small mammals (Adams and Geis 1983, Bellamy *et al.*2000). Secondly, roads with higher traffic volumes are wider and will thus allow more light to penetrate the woodland edge. This will precipitate greater vegetation growth and additional ground-cover. Bank voles and common shrews prefer habitat with good ground-cover and this may explain why the area is selected by these species. Neither of these explanations account for the high proportion of yellow-necked mice however. Yellow-necked mice are a species generally associated with mature woodland (Montgomery 1978) and their abundance at locations adjacent to the roads requires further investigation. Similarly, the significant linear relationship between wood mice and distance from the road is unclear. They are considered generalist species and are found in most habitats. However, given the abundance of other species at roadside locations it is possible that their distribution is related more to the element of competitive exclusion (Kikkawa 1964) than to a positive selection for areas furthest from the road.

There is no compelling evidence therefore, to support the hypothesis that small mammals are adversely influenced by disturbance from roads. On the contrary, one of the effects of habitat severance is an increase in edge habitat and in other habitat types and this may be to the advantage of some small mammals species, even, it seems, to those which have previously been thought of as specialist species of interior habitats.

3.5 Conclusions

The effect of roads on small mammal activity is considerable and greatly inhibits access to habitats that lie on the opposite side of a road. Road crossings, irrespective of the size of the road, are rare events for small mammals. Roads carrying up to 15,000 vehicles a day are occasionally crossed by wood mice, less so by bank voles less and never by shrews. The species and class of species most likely to attempt road crossings are generally those that move the furthest distances (as indicated by the mean distance moved). Small mammals were found to cross roads with less traffic more frequently than roads with high traffic loads. However, this does not necessarily define traffic as the causative factor, other factors may also explain these crossing. Due to the very few road crossings recorded, these results should be considered as preliminary findings that would benefit from further investigation.

There is no substantive evidence showing any adverse effects from roads permeating the adjacent habitat. Indeed, the evidence is somewhat contrary to this, with certain roads providing an indirect and positive effect for small mammals. Almost all roads have some form of verge, and those associated with roads of higher traffic volumes tend to have wider road-verges that may provide additional and alternative resources attractive to many small mammals, even those that are not commonly associated with edge habitat.

CHAPTER 4. CHADDESLEY WOOD. AN EXTENDED CAPTURE-MARK-RECAPTURE STUDY ON SMALL MAMMALS

4.1 Introduction

The previous capture-mark-recapture study undertaken at the four Warwickshire sites monitored the movements of small mammals in relation to roads carrying different volumes of traffic. It comprised a series of short duration (three to five day) trapping sessions that were repeated at three-monthly intervals to cover a full year's cycle of small mammal populations at the selected sites. This enabled seasonal differences in the activities of small mammals to be detected and provided information on inter and intra-species differences.

This chapter provides information about an extended, more intensive study of the populations and movements of small mammals adjacent to a minor road. It entailed continuous live-trapping for a period of 30 days over a larger area with the expectation of generating longer trapping histories for more individuals than the previous study (chapter 3).

4.1.1 Study Purpose

It was expected that more conclusive evidence could be obtained about the activities of small mammals in relation to the road by conducting a more intensive trapping study. The spatial distribution and dynamics of woodland small mammals in road-adjacent habitats are again considered, but in greater detail, in an attempt to distinguish more decisively between the effects of roads and the effects of habitat. This part of the research also seeks additional evidence to corroborate the suggestion that small mammals modify their behaviour in the vicinity of roads (Adams and Geis 1983).

Specifically, the two hypotheses investigated here are:

- roads have no direct effect on the spatial organisation of small mammal communities found in habitats adjacent to roads.

- roads have no direct effect on the structure of small mammal communities found in habitats adjacent to roads.

4.2 Method

4.2.1 Study sites

Chaddesley Wood covers approximately 100 ha of which approximately 90% is designated ancient woodland. It is designated as a National Nature Reserve and a Site of Special Scientific Interest (SSSI) and is part of a more extensive woodland complex which altogether covers an area of some 270 ha. There is a comprehensive management plan for the woodland (Pryor and Rickett Silviculture, 1998) from which some of the following description has been extracted. The wood is situated in the northern part of Worcestershire, Ordinance Survey grid reference, SP 915 738 (Figure 4.1). It has been partially fragmented by minor roads and tracks. There is public access to the wood but the activity of most recreational users is confined to the main footpaths and to weekends. The study sites lie on either side of a minor road that carries an estimated 250 cars per day. Personal observations indicate that it was rare for cars to travel along this road between midnight and 6am. Clearance across the road, including the road verge, is approximately seven metres. The road-verge width at the study sites is approximately three metres. The study sites located on opposite sides of the road are identified as side A and side B.

Side A is centrally located within a 9.3ha oak high-forest compartment of Chaddesley Wood. Records indicate the site was planted circa 1900. The understorey includes holly (*Ilex aquifolium*), birch (*Betula pendula*) and hazel (*Corylus avellana*), the latter last coppiced in the 1980s. Coppicing has denuded the understorey in places and there is a large section of open ground with only occasional standards. There is a dense summer covering of bracken. Footpaths run through the area but these are not heavily used and are mainly confined to light weekend use. A small road bounds the eastern perimeter of side A. There are no other obvious site perimeters.

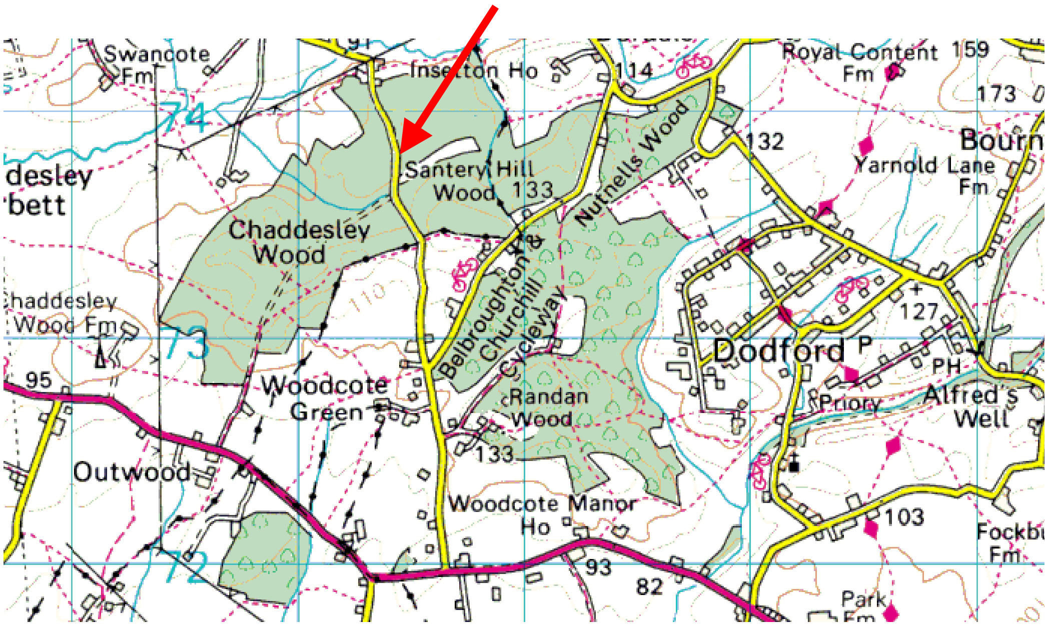


Figure 4.1 The location of the Chaddesley Wood study site, Worcestershire.

Side B is within a 9.1 ha compartment of mature oak, again planted in 1900. Hazel, oak coppice and holly form the understorey. It is an area set aside for non-intervention, and remains unmanaged with a dense understorey which is difficult to penetrate in parts. There is occasional bracken where there are gaps in the canopy but generally, there is little or no ground cover. There is both standing and lying deadwood. There are no footpaths in this section of the wood and therefore little disturbance. The same road that forms the eastern perimeter of Side A forms the western perimeter of this study-site. The southern perimeter borders an unimproved grass meadow designated as a Site of Special Scientific Interest (SSSI). The western and northern boundaries connect with more deciduous woodland.

4.2.2 Trapping Design

A square grid, similar in design to that used for the trapping studies in Warwickshire, was marked out on both sides of the road at Chaddesley Wood. This time, however, the grid had 10 x 10 trapping points. Trapping points were at 10 metre intervals with one Longworth trap within 1.5 metres of each trap point. The grid covered an area of 810 m^2. With a buffer strip, the effective trapping area is enlarged to 1000 m^2. Each trap was stocked with bait and bedding and camouflaged by covering with plant material. To reduce any regulatory effect on individuals traps, the practice adopted on the previous trapping studies, of setting on alternate days only, was adopted (see 3.2 Methods section). The intended duration of the study obviated the need to pre-bait (Gurnell 1980). The trapping regime followed the protocol used at Warwickshire with twice-daily trap inspections.

The study extended over a period of 30 days, providing 15 days trapping on both side A and on side B. There were twice-daily trap-rounds specifically scheduled to reduce the amount of trap emptying during the hours of darkness when marking, handling and identification of previously marked animals is very much more difficult.

Traps were set at approximately 04:00hrs. The setting of the 100 traps each morning took approximately one hour. The first trap inspection started at approximately 07:30hrs with each trap-round taking between 1.5 and 4.5 hours to complete. Each captured animal was weighed, sexed and given a unique fur clipping. As before, bank voles and wood mice $\leq$15.5g were classified as juveniles (Flowerdew and Gardener 1978) and others as adults. After inspection and recording of captures, the traps were reset. The second trap-round was started at approximately 15:00hrs, after which the traps were closed but left *in-situ* until the next trap round on that side of the road.

4.2.3 Data analysis

Where it is practical Krebs (1999) advises use of one of the mark-recapture population methods to complement enumeration. The minimum-number–alive (MNA) method estimates populations on the assumption that if an animal is captured both before and after a given sampling point then it must also be present during the intervening period. Ease of calculation makes it a routine method for calculating small mammal populations (Krebs 1999) but accuracy is dependent on the fraction of the population trapped (Hillborn and Rodd. 1976*)*. The Jolly-Seber (JS) model eliminates much of the negative error inherent in other assessment methods and it is described by Southwood and Henderson (2000) as the traditional approach to long-term capture-mark-recapture (CMR) studies. JS not only allows for loss and recruitment in a population but also estimates survival rates of individuals. However, the JS model is not suitable for small populations and will not be reliable when capture probabilities are heterogeneous (Krebs and Boonstra 1984). For this study, both Jolly-Seber and MNA estimates were calculated. The computer program RECAP (Buckland 1980) was used to calculate Jolly Seber populations. The average for trapping days 3 –13 was selected as an estimate representative for the sites for the whole of the 30-day trapping period. This selection omits the initial two days when animals are unfamiliar with traps and may be resistant to entry. It also omits the final two days trap results because the method of calculation relies on recapture data, the chance of which is significantly reduced towards the conclusion of a trapping programme.

Ranges V computer program (Kenward and Hodder 1995) was used to calculate home ranges, distances moved and habitat utilisation. Only animals that had been captured a minimum of four times were used for Ranges V modelling. The minimum required frequency from which home ranges can be calculated is three (Howard and Hodder 1995) but Bowers *et al.* (1996) suggested a minimum of four captures were required when estimating home ranges by convex minimum polygons for meadow voles (*Microtus pennsylvanicus*). Habitats on the two sites were categorised into four broad types, characterised predominantly by the amount of ground cover. These were: areas of 1) bare ground, usually below coppice or high canopy, 2) sparse ground cover of grasses and forbs, 3) bracken, and 4) edge habitat at the woodland/road-verge interface. The area of edge habitat was arbitrary and comprised the section between trapline one and two on both sites. The natural intergradations of habitat types makes it impossible to accurately and precisely map habitat boundaries and the 10 metre grid points were therefore used as convenient intervals by which to express demarcation boundaries between the various habitat types. SPSS and Minitab statistical packages were used for all other data analysis.

Manly's selection index *(*Manly *et al.* 1993*)* was used to detect preferences by different species for different habitats within the trapping grid selection index. The index assesses usage of specified habitats based on their relative availability. Chi-squared test (χ^2) was used to investigate differences in community structure, *i.e.* the number of species and the abundance of each species. Linear regression was used to test the effects of roads on species abundance. The trapline locations from which individuals were recovered were used to determine distances from the road.

4.3 Results

The weather was variable during the trapping period with daytime temperatures ranging between 4.5ºC and 17ºC. It was often overcast with frequent light showers. There was heavy rain during one trap round (side A trap round 7) which made it impossible to identify and record captured animals. This trap round was abandoned after only half of the traps had been inspected and the remaining animals were released without recording.

4.3.1 Community Description

There was a total of 3000 trap nights (15 nights x 200 traps), 1500 for each of the two sites. A total of 292 different individuals comprising five different species were trapped at the two sites; wood mice (*Apodemus sylvaticus)*, bank voles (*Clethrionomys glareolus*), common shrews (*Sorex araneus*), pigmy shrews (*Sorex minutus*) and yellow-necked mice (*Apodemus flavicollis*). The total number of captures for these five species was 925 (Table 4.1).

Table 4.1 The total number of captures and recaptures for all species at the two sites

	Side A			Side B			Side A & B		
Species	Number of individuals	Total (captures and recaptures)	Captures per 100 trap night	Number of individuals	Total (captures and recaptures)	Captures per 100 trap night	Number of individuals	Total (captures and recaptures)	Captures per 100 trap night
wood mouse	38	108	7.2	50	158	10.5	88	266	8.9
bank vole	77	299	19.9	15	33	2.2	92	332	11.1
common shrew	30	122	8.1	20	64	4.3	50	186	6.2
pigmy shrew	23	54	3.6	8	22	1.5	31	76	2.5
y-n mouse	16	30	2.0	15	35	2.3	31	65	2.2
Total	184	613	12.27	108	312	7.20	292	925	30.83
Mean average	37	123	0.07	22	62	0.42	97	308	13.21
Stand deviation	23.9	105.6	7.04	16.4	55.7	3.71	29.9	116.7	3.9

There were differences in species' abundance on side A and side B and the small mammal communities were significantly different on the two sides (χ^2 = 35.321, d.f. = 4. p = 0.001). On Side A, 184 individuals were trapped, providing 613 captures. Each individual was captured an average of 3.3 times. Bank voles were the dominant species on side A (42% of the total number) followed by wood mouse (21%), common shrew (16%), pigmy shrew (23%) and yellow-necked mouse (9%). On side B, 108 individuals were trapped giving a total of 312 captures, almost half the number trapped on side A. Individuals were caught an average of 2.9 times on this side of the road. Wood mice were the dominant species (46% of individuals), followed by common shrews (19%). Yellow-necked-mice and bank voles were in equal numbers (14%) and pigmy shrews (7%) were the least abundant species.

The proportions of males and females were similar on Side A and Side B (Table 4.2) Shrews were not classified by age or sex because of difficulties in accurate determination. The age structure (adults:juveniles) of wood mice was similar on the two sides, whereas juvenile bank voles constituted 43% of the bank vole (trapped) population on side A but accounted for only 27% on side B. No juvenile yellow-necked mice entered traps.

Table 4.2 The sex and age profiles of species at each site (N.B. shrews were not aged or sexed)

		Male			Female		
	Species	adult	juvenile	sum	adult	juvenile	sum
side A	wood mice	12	6	18	12	8	20
	bank vole	19	24	43	25	9	34
	common shrew	30	-	30	-	-	0
	pigmy shrew	23	-	23	-	-	0
	y-n mice	6	2	8	8	0	8
side B	wood mice	20	9	29	12	9	21
	bank vole	5	2	7	6	2	8
	common shrew	20	-	20	-	-	0
	pigmy shrew	8	-	8	-	-	0
	y-n mice	7	0	7	8	0	8

Maximum trap occupancy for any one trap round was 36 out of a possible 100 captures. The number of captures *per* 100 trap-nights was 30.8 (s.d.$\pm$7.8) but there were considerable differences between side A (40.9 $\pm$7.04) and side B (20.8 $\pm$3.71).

Where adequate trapping histories were available, population estimates were calculated using Jolly-Seber. Table 4.3 provides the average daily population estimates for the trapping period. The figures are greater than the calculated MNA estimates because JS calculates survival rates and does not suffer the inherent high negative bias encountered with the MNA estimates (Jolly and Dickson 1983). These population estimates also equate to average species density per hectare (the trapping grid and buffer strip equalled one hectare). The results are within the range given in the literature (see Harris *et al.* 1995) but at the lower end. Using the JS output, the populations on Side A and B were significantly different (χ^2 = 10.47, d.f. = 2, p-value = 0.005) as were the MNA estimates (χ^2 = 26.33, d.f. = 3, p-value = 0.001).

Table 4.3 The estimated average populations derived from Jolly Seber analysis and minimum-number-alive.

	wood mouse		bank vole		common shrew		pigmy shrew		y-n mouse	
	JS	MNA	JS	MNA	JS	MNA	JS	MNA	JS	MNA
Side A	NA*	12	43	32	13	2	18	7	NA	3
Side B	25	19	9	4	13	9	13	3	NA	3

*Not applicable. Capture histories were not appropriate for the model

4.3.2 Trappability

Frequency of capture varied between species and between side A and side B. The average number of trap entries for each species is given at Table 4.4. The average number of trap entries was always greater on the study site which had the greater abundance of the focal species, but many individuals were captured only once and there were few individuals captured four or more times (Figure 4.2).

Table 4.4 The average number of trap entries for each species

Species	Side A	Side B	Side A&B
wood mouse	2.8	3.2	3.0
bank vole	3.9	2.2	3.7
common shew	4.0	3.2	3.7
pigmy shrew	2.3	2.8	2.5
yellow-necked mouse	1.9	2.3	2.1

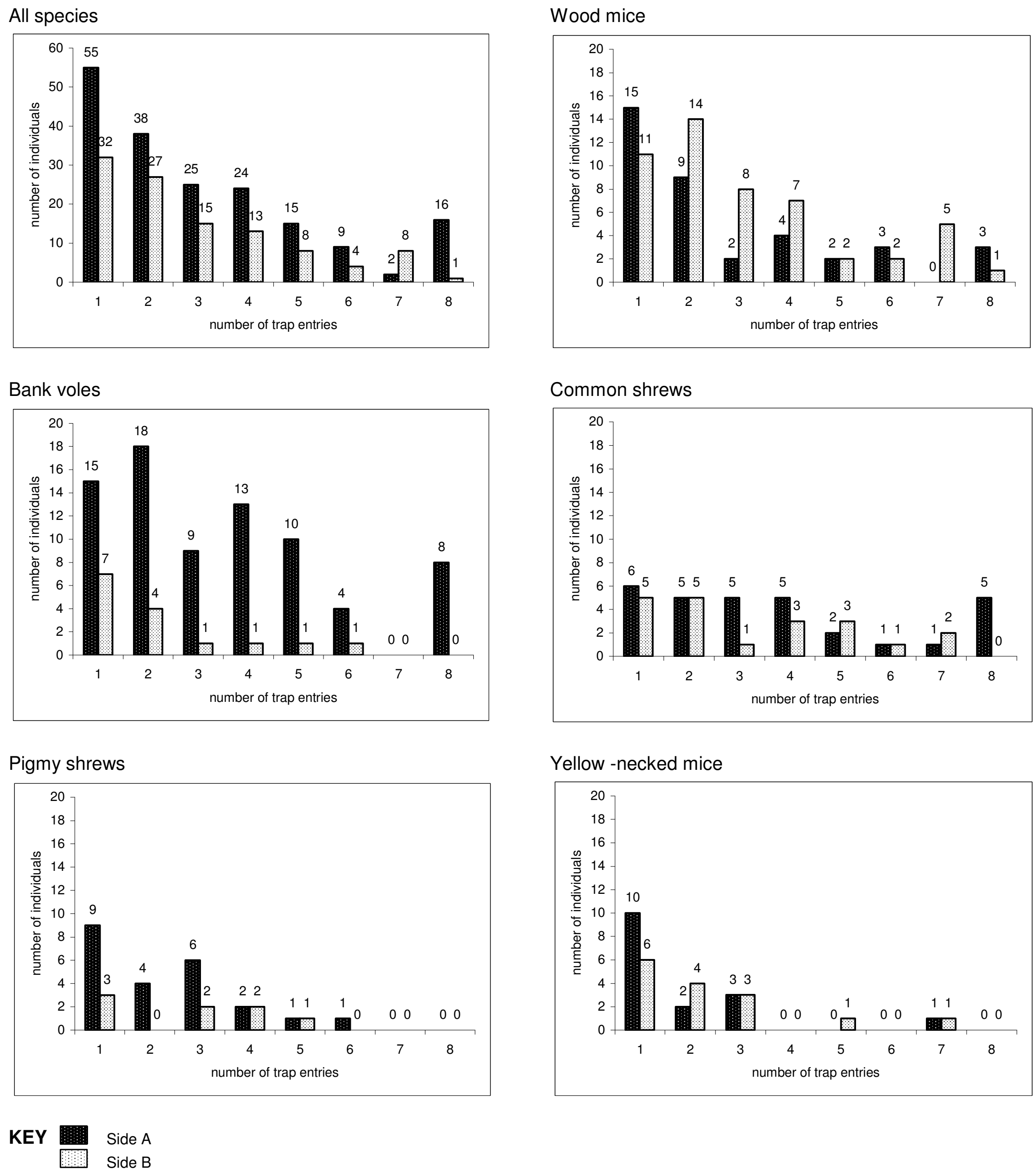


Figure 4.2 Frequency of trap entry.

There was some variation between species in the time-lag before initial trap entry with few entries on trap night one (with the exception of bank voles on Side B). The weighted average shows the recruitment trend (Figure 4.3). The cumulative total indicates that between trap night four to six, the recruitment trend starts to plateau although bank voles on Side A continued to recruit new individuals throughout the trapping period (Figure 4.4).

4.3.3 Habitat usage

The habitat maps generated by the computer program Ranges V provide a crude representation of the habitat layout on the two sites onto which the minimum convex polygons have been superimposed for the dominant species. A notable difference between the two sites was the lack of bracken or any other dense ground cover on side B. In contrast, bracken covered almost a quarter of the study-site on side A.

Figure 4.5 shows the home ranges for individual wood mice, bank voles and common shrew, plotted as minimum convex polygons. Additional home ranges for wood mice and bank voles classified by age and sex are shown at Appendix D1-D3. There were clear inter- and intra-species range overlaps and, although all species utilised all the different habitats, different species, and males and females of the same species, exhibited selection preferences in relation to habitat. The distribution and clustering of individuals across the trapping grid are apparent on the plotted central point of individual ranges at (Figure 4.6). The central points show the core location of each individual based on the complete range of locations from which an individual was captured. Wood mice on Side A were clustered to one side of the grid and were largely absent from the central portion of the trapping area; on side B they clustered more toward the central portion of the grid; roadside areas were avoided. In contrast, bank voles on Side A were frequently located in areas closer to the road.

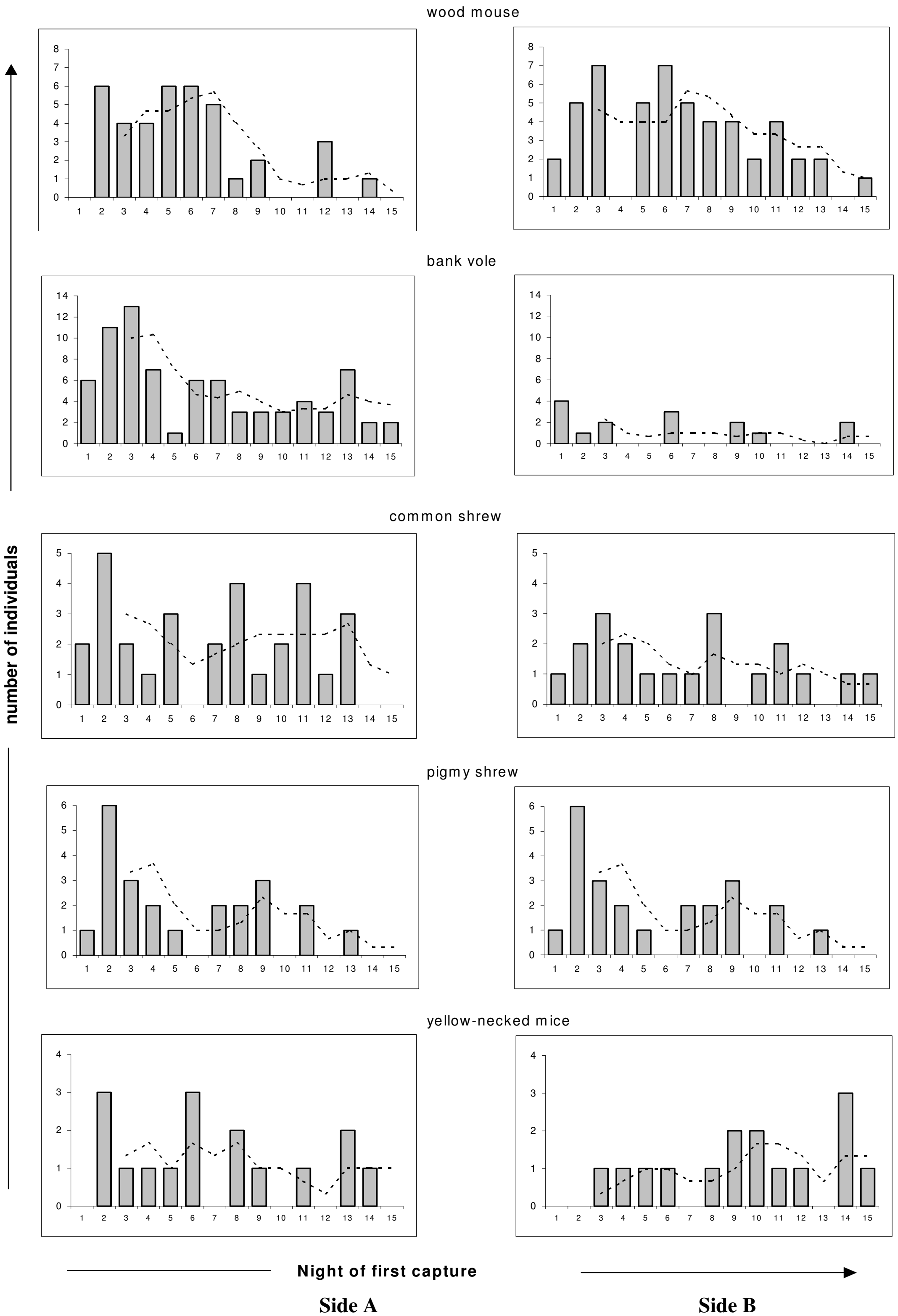


Figure 4.3 Latency of first capture demonstrated by the trap proneness of individuals. The dotted line shows the weighted average calculated over three periods.

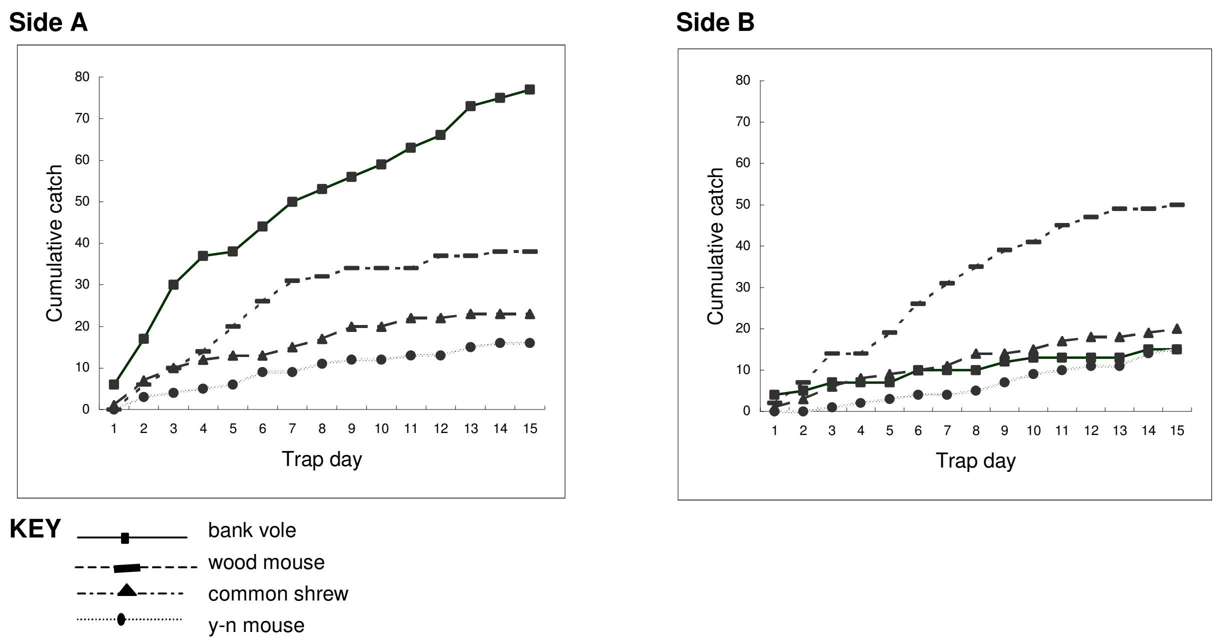


Figure 4.4 The cumulative capture of each species for both sites over the 30 day trapping period.

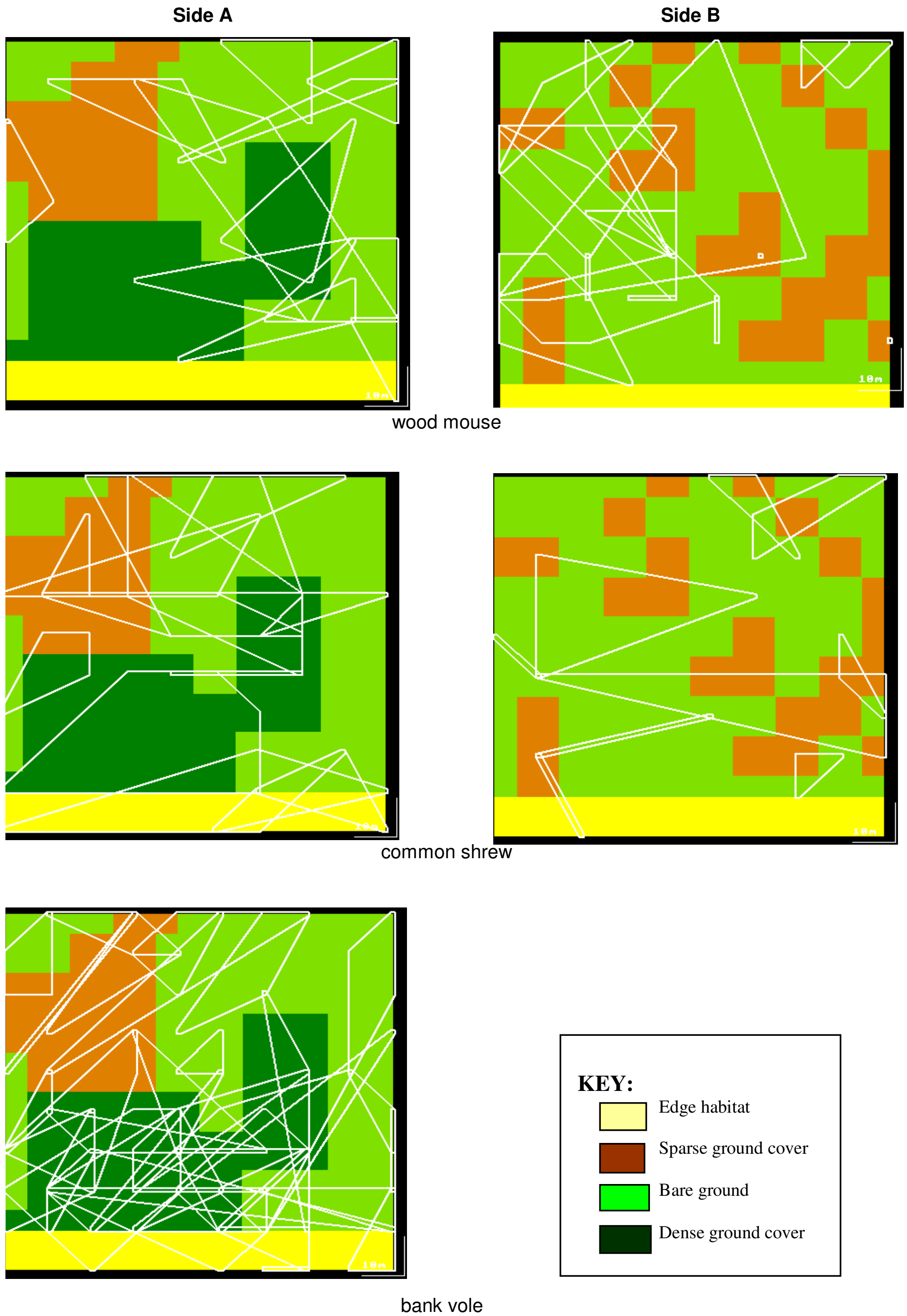


Figure 4.5 The calculated home ranges of the dominant species, superimposed onto the habitats on the two trapping grids on Side A and Side B. The road is to the bottom of each grid, beyond the linear edge habitat. *NB* There was insufficient multiple captures of bank voles on Side B to calculate home ranges.

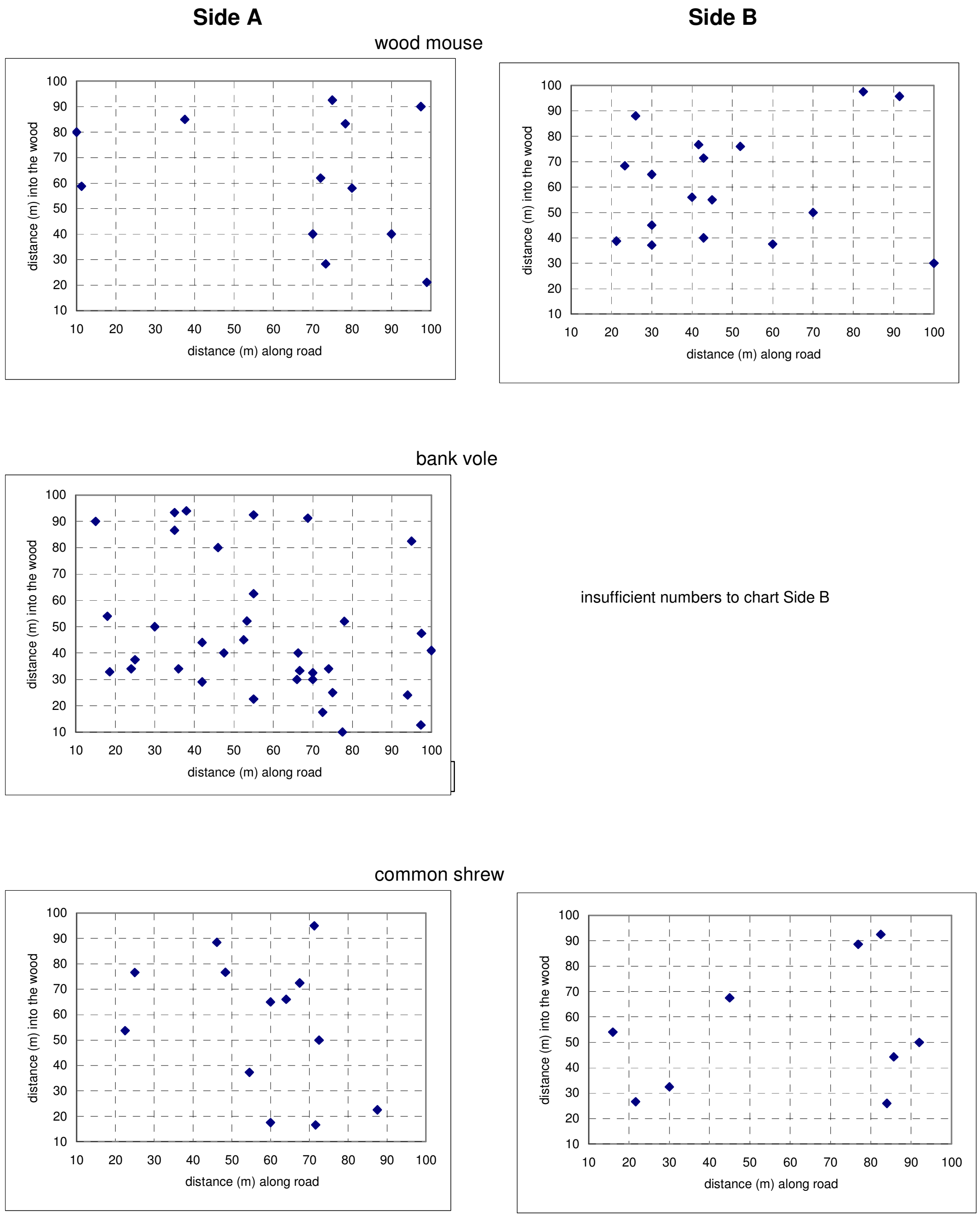


Figure 4.6 The distribution of central points of individual home ranges across the trapping grid.

Female bank voles tended to have a more general distribution than males and males had smaller home ranges. There were too few bank voles on Side B to examine distribution. There were no distinct patterns for common shrews but there were large areas from which they were absent.

Table 4.5 gives the calculated use of each habitat by the different species. The roadside area accounted for over 15% of bank vole captures whereas only 5% of wood mice captures were accounted for in this habitat. On Side B avoidance of the roadside area by wood mice is even more marked, with only 0.4% of the species being captured there. There were some demographic differences in habitat selection for the bank vole population, but only between sparse and densely vegetated ground cover, not between ground cover and no ground cover.

The data derived from habitat usage was used to calculate a selection index for the dominant species on both sides of the road (Table 4.6). The selection of habitat for each of the three dominant species was consistent on both sides. Wood mice were found to select for habitats that were predominantly coppiced and without ground cover. They avoided areas where there was dense bracken and they avoided the edge/roadside areas. Bank voles predominantly selected for areas that had sparse ground cover, but they were also found at the roadside/edge habitat and in the bracken covered areas. They avoided areas with no ground cover. Common shrew, like bank voles, also selected for areas that had sparse ground cover.

Table 4.7 shows the calculated spatial parameters. The average home ranges and distances moved were larger on Side A than Side B. There are also inter-species differences. Common shrews moved the greatest distance on Side A (mean average = 30.3m) but on Side B, it was pigmy shrews that moved furthest (mean average = 29.7m), followed by common shrews and then wood mice.

4.3.4 The disturbance of roads

As noted above, levels of activity in relation to the road by different species is variable. Based on the frequency of capture at different traplines (only initial captures were counted) there is a positive and significant linear relationship between wood mice and distance from the road ($y = 0.461x + 1.267$, $R^2 = 0.422$, $p = 0.036$) *i.e* wood mice abundance increased with greater distance from the road, and there is a negative and significant relationship between bank vole and the distance from the road ($y = -0.812x + 0.12.267$, $R^2 = 0.413$, $p = 0.043$ trapline), *i.e.* bank vole abundance increased with proximity to the road. Values for other species are not significant.

An examination of the data relating to the location of all captures across the trapping grid (not just those that have been captured four or more times) confirms that some species are found much more frequently at roadside locations (*i.e.* at trapline one) than elsewhere. For yellow-necked mice 37% and 33% of first time captures, at study site A and B respectively, were at trapline one. For common shrews, 17% and 15% of individuals were found at trapline one on the two respective study sites. The proportions of pigmy shrews found at trapline one were 9% and 13%, for bank voles 13% and 7%, and for wood mice 8% and 2% of individuals. If individuals were equalled distributed across the 10 traplines, 10% of the captures would be the expected recovery rate for each trapline.

Table 4.5 The distribution of the most abundant species on Side A and Side B at Chaddesley Wood for each of the four classified habitats.

Cover			Roadside/Edge habitat	Dense ground cover	Sparse ground cover	Bare ground
				Side A		
	area (ha)		0.09	0.25	0.13	0.35
	proportion of total cover		10.90	30.40	15.80	42.30
wood mouse		*n*	%	%	%	%
	all	12	5.09	7.4	12.2	75.3
	male	8	2.08	11.2	15	71.7
	female	4	11.1	0	6.25	82.6
	adult	10	6.11	4.5	9	80.4
	juvenile	2	0	0	50	50
bank voles						
	all	35	15.6	36.4	36.4	11.5
	male	17	9.9	54.6	22.4	13.1
	female	16	19.8	15.4	53.6	11.2
	adult	17	20.6	13.9	52.1	13.4
	juvenile	12	6.25	57.9	21.3	14.5
common shrew						
	all	13	13.5	25.5	34.4	25.5
				Side B		
	area (ha)		0.09	0	0.22	0.52
	proportion of total cover		10.90	0.00	26.30	62.90
wood mouse						
	all	17	0.4	0	26	73.6
	male	11	0.6	0	24.8	74.7
	female	6	0.0	0	28.3	71.7
	adult	6	0.0	0	19.4	80.6
	juvenile	11	0.6	0	29.7	69.8
common shrew						
	all	9	5.5	0	34.7	59.2

Table 4.6 The selection preference of different habitats calculated for the dominant species on Side A and Side B at Chaddesley Wood

SIDE A

habitat	proportion available.	population proportion available	selection index	standardised selection index
wood mouse				
roadside	0.109	0.051	0.467	0.143
bracken	0.304	0.074	0.243	0.075
sparse	0.158	0.122	0.772	0.237
bare	0.423	0.753	1.780	0.546
sum	0.994	1.000	3.263	1.000
common shrew				
roadside	0.109	0.135	1.239	0.255
bracken	0.304	0.255	0.839	0.173
sparse	0.158	0.344	2.177	0.448
bare	0.423	0.255	0.603	0.124
sum	0.994	0.989	4.857	1.000
bank vole				
roadside	0.109	0.156	1.431	0.275
bracken	0.304	0.364	1.197	0.230
sparse	0.158	0.364	2.304	0.443
bare	0.423	0.115	0.272	0.052
sum	0.994	0.999	5.204	1.000

Standardised selection indices above (1/4, i.e.0.25) indicates preference

SIDE B

habitat	proportion available.	population proportion available	selection index	standardised selection index
wood mouse				
roadside	0.109	0.004	0.034	0.015
sparse	0.263	0.260	0.989	0.451
bare	0.629	0.736	1.170	0.534
sum	1.001	1.000	2.192	1.000
common shrew				
roadside	0.109	0.055	0.503	0.182
sparse	0.263	0.347	1.319	0.477
bare	0.629	0.592	0.941	0.341
sum	1.001	0.994	2.763	1.000

Standardised selection indices above (1/3, i.e.0.33) indicates preference

Table 4.7 The combined results for range and movement variables for the three most abundant species trapped on Side A and Side B at Chaddesley Wood.

Site	Species	number of animals	ave capture freq. (min/max)	ave home range (ha) (min / max)	ave span of range (min / max)	ave mean dist. moved (min / max)	ave median dist. moved (min / max)	ave max. dist. moved (min / max)
Side A	**wood mouse**	12	5.75	0.07	37.92	14.42	15.00	22.17
			(4 - 9)	(0.01 / 0.5)	(22 / 84)	(6 - 30)	(2 - 32)	(12 - 42)
	bank vole	35	6.34	0.03	34.63	12.89	14.00	22.94
			(4 - 21)	(0.01 / 0.1)	(10 - 78)	(3 - 34)	(2 - 80)	(7 - 55)
	comm. shrew	13	6.69	0.09	45.38	16.08	16.69	30.31
			(4 - 13)	(0 / 0.6)	(3 - 90)	(8 - 28)	(7 - 40)	14 - 50)
Side B	**wood mouse**	17	5.65	0.03	29.29	10.35	10.18	17.71
			(4 - 10)	(0 / 0.21)	(0 -78)	(0 - 30)	(0 - 25)	(0 - 55)
	comm. shrew	9	5.22	0.02	34.67	12.11	10.67	22.89
			(4 - 7)	(0 / 0.09)	(14 - 82)	(5 - 27)	(2 - 27)	(7 - 65)
	pigmy shrew	3	4.00	0.03	48.67	14.33	15.67	29.67
			(4 - 4)	(0 - 0.05)	(28 - 60)	(7 - 20)	(12 - 21)	(14 - 38)

Of 292 individuals captured over the thirty day trapping period, there were no recorded crossovers from side A to side B or from side B to A. This is despite the fact that nearly all animals moved distances greater than that needed to cross the road.

4.4 Discussion

4.4.1 Experimental design

The design of the trapping grid can seriously affect movement patterns and estimates of animal densities (Faust *et al.* 1971, Gurnell and Gipps 1989, Gurnell and Langbien 1983, Kikkawa 1964). The 10-metre trap spacing used for this study was the same as the previous exercise undertaken on the Warwickshire sites where there was no indication that trappability had been impaired. However, for this part of the study, the trapping effort was increased so that there were 100, rather than 60 traps at each site. This allowed the constituent population from a much larger area to be investigated. The larger trapping grid also gives the potential to record greater distances moved by individuals.

The twice-daily trap openings were designed to accommodate the different activity periods for the expected range of species whilst avoiding trap opening during the hours of darkness. The timings of trap openings were considered the best compromise to accommodate the frequency of trap inspection required for shrews and the amount of time for which traps needed to be open for all potential captures to enter. The short period for which the traps were open during the hours of darkness limited the amount of time nocturnal species were exposed to set traps and, given that wood mice are predominantly nocturnal, it is possible that this reduced the overall number of mice that were trapped. This would not impair the comparative analysis between the two study sites at Chaddesley Wood because both Side A and Side B were treated in the same manner, but it could affect comparisons with other study sites. However, when the results for wood mice here are compared with the results at the Warwickshire sites at a similar time of the year, results were consistent. For the Warwickshire sites in June there was an average of 6.9 wood mice captures per 100 trap nights compared with 7.2 for Chaddesley Side A and 10.5 for Chaddesley Side B, indicating that the amount of time for which traps were open at Chaddesley was adequate for capturing both nocturnal and diurnal small mammal species.

The downward trend in the number of new captures recovered over the course of the trapping period is evidence of the efficiency of the trapping regime, indicating a large proportion of the population was successfully trapped. This is corroborated by the ratio of captures to traps at each round. The proportion of traps left empty at each trapping round infers that few, if any, animals should have been excluded because they were unable to enter a trap due to prior trap occupancy (Flowerdew 1976, Gurnell and Flowerdew 1994). With regard to the frequency of capture, it is interesting to note that the dominant species on each study site (bank vole on Side A and wood mouse on Side B) continued to accumulate some new individuals throughout the trapping period. This could indicate reluctance by some individuals to enter traps and this would compromise trappability. However, the large number of juveniles that made up the population shows that much of this later recruitment was a result of new-borns entering the population rather than trap avoidance early in the trapping session.

The extended trapping period of 30 days was designed to increase the number of multiple entries for individuals in order to obtain more precise and more accurate records of actual distances moved; this is important when assessing distances moved and home range sizes (Kikkawa 1964). Many more multiple trap entries were recorded in this study than at the Warwickshire study sites, but a high proportion of animals still entered traps only once. With the exception of pigmy shrews, higher average frequency of capture always coincided with the side of the road where the species was most abundant. This may be because the chance of recovering more trap-prone animals is increased with the greater abundance of animals but it may also be a reflection of quality of the habitat. Gliwicz (1989) and van Appledoorn *et al.*

(1992) for instance, found that residency times for small mammals in sub-optimal habitats were shorter than in more favourable habitat. If residency is a manifestation of habitat suitability, and if frequency of capture is treated as an index of the amount of time an animal remains in an area, Side A, with its higher level of ground cover, would be expected to demonstrate higher capture frequency for bank voles, and Side B would be expected to have a higher capture frequency for wood mice. The findings here confirm this. The findings also infer that the two sides are distinctly different in the resources they offer.

4.4.2 ***Community structure***

The community of animals found at Chaddesley Wood is typical of this type of woodland site (Flowerdew 1993, Capizzi and Luiselli 1996). Krebs (1999) states that the single most important variable in community ecology is the estimation of the population, but population estimates are difficult to assess accurately as they depend on certain basic assumptions that can be difficult to meet in practice (Southwood and Henderson 2000). The conservative estimates calculated here, based on the average daily population size, probably underestimate the actual population.

Nevertheless, regardless of whether the absolute counts or the population estimates are used in analysis, the abundance of different species on Side A and Side B are strongly and significantly different. This is consistent with the findings of road-separated communities at the study sites in Warwickshire. Differences in bank vole abundance and the demographic structure of the bank vole populations at Side A and Side B are particularly influential in this respect. Indeed, when bank voles are omitted from the datasets, differences in the community structure on the two sides of the road are no longer significant. Bank voles may be particularly sensitive to the results of fragmentation, although differences are not confined to this species; there are also differences in the numbers of pigmy shrews on Side A and Side B; wood mice and yellow-necked mice less so. Differences in the two communities demonstrate the long-term effects and disruption that frequently occurs when populations are separated by major barriers and are subjected to the changeable conditions arising from fragmentation of habitat.

4.4.3 The spatial organisation of populations at road-adjacent sites

The central points of individual home ranges show that particular species have a general proclivity for, or aversion to, certain parts of the trapping site and certain habitat types. Manly's selection index, calculated from the Ranges V output, indicates clear habitat selectivity for those species for which there are sufficient data (wood mice, bank voles, common shrew). These selections correspond with habitat preferences found in other studies for the same species (Flowerdew1993, Kotzageorgis and Mason 1997, Southern and Lowe 1968). Overall, the spatial organisation of species and individuals across the trapping grid seems to be driven strongly by habitat, with evidence of clustering in favoured habitats. Wood mice selected for areas of bare ground beneath coppice canopy, and shrews and bank voles favoured areas with vegetated ground cover. These habitat preferences help to explain some of the differences in the relative abundance of species at Side A and Side B, with bank voles more prevalent on the side of the road that has larger areas of vegetated ground cover and wood mice more common on the side of the road where the canopy precludes such ground cover. Differences are not just species-specific; there were also intra-species differences in distribution. For instance, the home ranges of both female wood mice and female bank voles are well separated. There is little sign of clustering and they demonstrate only moderate habitat faithfulness. For males there was no discernible demarcation between territories. Their ranges show a high degree of overlap and a tendency to cluster in specific habitats. These findings agree with those elsewhere (Bowers *et al*, 1996, Tew, 1988, Wolton and Flowerdew 1985) which show that female rodents, and bank voles in particular, maintain exclusive territories during the breeding season whilst males are generally less constrained by home-range boundaries.

The Ranges V output also seems to suggest a 'road effect'. In respect of the three dominant species selection for roadside areas, wood mice demonstrated some aversion to this part of the trapping grid, more strongly on Side B than on Side A. Bank vole and common shrews demonstrated a neutral response according to the Manly selection index (Manly *et al.* 1993). This spatial distribution is apparent on the plot of central points (Figure 4.6). Indeed, when the data for all animals are analysed (Ranges V uses only those animals that were caught four or more times), there is a distinct attraction for trapline one, *i.e.* the trapline nearest to the road. This is particularly noticeable for yellow-necked mice - over one third of all yellow-necked mice were caught at this location. Common shrews also had a higher than average number of animals at this location. There appears to be further evidence of roads influencing small mammal distribution from the results of regression analysis that predicts a relationship between species abundance and distance from the road for the two dominant species. Wood mice were found to increase in numbers at distances further from the road, whilst the opposite was true for bank vole. These findings agree with those for the Warwickshire study sites.

The greater abundance at trapline one of some species may be explained by a response to the edge habitat at the road/woodland interface. It could also be a result of the barrier effect of roads. Because roads act as barriers that inhibit directional movement, movement of individuals, once they reach the road, may be channelled parallel to the road, thereby increasing their residency times at this location. Increased residency would increase the likelihood of capture. The avoidance of the roadside area by wood mice may be a response to the high numbers of other species found here; as generalists, mice may be able to exploit more readily the resources available in areas further into the woodland interior where competition is less intense. However, whilst this may explain the selection and avoidance, of road adjacent areas, it does not wholly explain the linear relationships between species abundance and distance from the road. Although Adams and Geis (1983) found a road-effect on the distribution of small mammals that permeated some distance into adjacent habitats, this does not explain the distribution patterns at this site where traffic is at such a low level. Neither do the results of their work explain the differences in response by the various species.

The work undertaken here suggests that the distribution of small mammals in road adjacent habitats is driven by a combination of several factors. Predictably, habitat provides a powerful influence and differences in habitat confounds the effect of roads. Further work is required to adequately discriminate between them.

4.4.4 The barrier effect and the ability of individuals to cross the road

Most of the calculated home ranges are less than the size given for the species in the literature (Churchill 1990, Crawley 1969, Flowerdew 1993, Gurnell and Gipps 1989, Kikkawa 1964). The smaller home-range sizes and the reduced distances moved are likely to be a consequence of the small number of high multiple-trap entries or the size of the grid (Andreassen and Bondrup-Nielson 1991, Crawley 1969, Flowerdew 1976, Kikkawa 1964). Nevertheless, for those animals where distances could be estimated (39 mice, 44 bank voles, 22 common shrews and 3 pigmy shrews all made a minimum of three moves) the average home-range span and mean distance moved between captures, easily exceeds the distance needed to travel from one side of the road to the other. Despite this, there was not one recorded crossover of the road; a key finding of this research.

It is worth considering that in both this study and the previous study at Warwickshire, a high proportion of animals were captured only once and it could be argued that for these animals, crossovers did occur but the animals were not recaptured. It may be further argued that the animals most likely to cross roads are animals that are moving through a territory and that these would be unlikely to stop to explore traps or are perhaps less familiar with traps and therefore more trap-shy (Watts 1970). Certainly work here and elsewhere (Barnett 1958, Flowerdew 1976) indicates that there may be a neophobic response from some individuals, but conversely, many animals in this study, did enter traps on the first or second trapping night. There were certainly sufficient individuals that made multiple entries (205 out of 292) to ensure that if road crossing were anything but a very rare phenomenon they would have been recorded. It is also likely that animals moving through a habitat would demonstrate greater opportunistic tendencies than resident animals, precisely because they are less familiar with the territory and would therefore explore baited traps. Indeed, if animals that crossed roads behaved significantly differently in their response to traps than those that did not, it is unlikely that the few animals caught at the Warwickshire study would have been recaptured and recorded. Given the findings at Warwickshire and findings elsewhere (Mader 1984, Oxley *et al.* 1974) it is reasonable to conclude that it is a behavioural response to roads rather any inherent weakness of the trapping studies that results in an absence of crossovers for small mammals

4.5 Conclusions

The findings of this study consolidate the work that was carried out at the suite of Warwickshire sites in the preceding year. There were remarkable similarities between the two studies in the spatial organisation of animals across the trapping grid. This included the selection by voles and yellow-necked mice for trapline one, the avoidance of trapline one by wood mice and the linear relationship between abundance and distance from the road for both wood mice and bank vole. The replication of these distribution patterns in relation to the road, across different sites, and in quite different localities, enables greater confidence to be placed in the general application of the findings.

Importantly, the increase in trapping effort at Chaddesley allowed additional information to be gathered about the effects of habitat as well as the effects of roads. Consequently, it was possible to distinguish between road effects and habitat effects although it was not always easy to fully discriminate between the two. Roads clearly disrupt the movements of small mammal communities and they may affect spatial distribution. However, there is no clear evidence to show that roads are more important than habitat in influencing small mammal distribution. Indeed, some small mammals species positively select for areas closest to the road. This is important because it sets small mammals apart from many larger animals, which demonstrate avoidance of areas close to roads often because of the noise generated by traffic (see Forman and Deblinger 2000).

In respect of the barrier effect of roads, the results are unequivocal. The findings fully substantiate the findings of the Warwickshire study and provide even greater support for the proposition that small mammals do not cross roads as part of their normal day-to-day activities, irrespective of the size of road or the amount of traffic. The low density of traffic at this site suggests that the biggest deterrent to movement across the road is probably not traffic but other factors associated with the road, such as, lack of cover or the hostile terrain of the road itself.

5 A CAPTURE-MARK-RECAPTURE STUDY TO INVESTIGATE THE SPATIAL DISTRIBUTION AND MOVEMENTS OF SMALL MAMMAL COMMUNITIES ON WIDE ROADSIDE VERGES.

5.1 Introduction

Various studies have indicated the intrinsic value of roadside verges to small mammals either as habitat, as refugia or as a means of connectivity between habitats (Adams 1984, Adams and Geis 1983, Bellamy *et al.*2000, Bennett 1990, Davis-Born and Wolff 2000, Downes *et al*. 1997, Mader 1984, Meunier *et al*. 1999, Oxley *et al.* 1974, Way 1977). Connecting verges may also function as a source for (re)colonisation provided there is suitable source habitat from which this can occur (Rich 1994). Research undertaken earlier in this study (see chapter 3 and 4) found that the woodland / road-verge ecotone was particularly attractive to some small mammal species and species diversity was found to be highest on wider road-verges. This is consistent with findings elsewhere that shows dense or tall grassy vegetation may accentuate the edge-effect response (Adams 1984, Bellamy *et al.*2000, Dickman and Doncaster 1987, Getz *et al.* 1978). Where the habitat of the grass verge is continuous, it is likely that some of these animals are able to expand their range, provided the habitat is not interrupted.

The barrier-effect of roads for mammals is incontrovertible but questions remain about the extent and the intensity of these effects and about the significance of different factors that may contribute to such an effect. None of the work so far has found convincing evidence that traffic density interferes with, alters, or disturbs small animal movement within (woodland) habitat adjacent to the road. Similarly, the degree to which an absence of cover contributes to the barrier effect is unclear. This part of the study extends the research that investigated the disturbance effect of traffic in woodland-adjacent habitat, explores the relative significance of traffic and absence of cover as contributory factors in the barrier effect and investigates the possibility of establishing effective connectivity to a fragmented habitat. In addition, the work detailed here contributes more generally to our understandings of the value of road-verge habitat for small mammal communities.

5.1.1 Study purpose

In the UK, dual carriageways and motorways generally have wide vegetated roadside verges but one of the features of high-volume highways is that they invariably have bridges intermittently crossing them. The Highways Agency of the Department for Transport, Local Government and the Regions (DTLR) is responsible for 10,000 bridges and over 30,000 ha of soft estate as part of its remit for the maintenance of 6,500 miles of trunk roads and their associated structures (Department of Transport, London and the Regions 2001). Other roads are the responsibility of local government and these have additional bridges and other structures. The area directly beneath many of these bridges is frequently concreted and, because of this, and the lack of direct sunlight beneath the canopy of the bridge, the area generally lacks any form of plant cover and thus it interrupts the vegetated road-verge. If road-verges act as linking habitat and/or corridors for small mammals, then these concreted areas present a potential barrier to such movement. The work described here investigates whether these interruptions have an inhibiting effect on small mammal movement and, if so, whether treatments can be applied to ameliorate the barrier effect and facilitate crossings by small mammals.

Three hypotheses were investigated as part of the study:

- Traffic disturbs small mammal activity. (This continues the work described in chapter 2 and 3). If traffic is a source of disturbance, then small mammals will be less likely to occupy areas in close proximity to roads and there will be a negative relationship between small mammal abundance and distance from the road. If the effect is species-specific, then the small mammal community structure will alter accordingly.

- Traffic contributes more significantly to the barrier effect for small mammals than does the absence of cover. If traffic is the more important factor then small mammals will move more frequently across similar hard, exposed areas without traffic than across traffic-carrying roads.

- Areas lacking in cover pose a barrier to small mammals, fragmenting small mammal habitat and restricting movement. However, fragmented areas can be (re)connected to facilitate a greater range of movement and enhance a possible corridor effect that road-verges may provide.

5.2 Methods

A capture-mark-recapture regime, similar to those previously undertaken at woodland study areas, was instigated on two dual carriageway study areas in Worcestershire. Provisos relating to capture-mark-recapture techniques that were discussed in previous chapters also apply here.

5.2.1 Study sites

Two study areas, on two dual carriageways in Worcestershire were selected for this study; the A441, Alvechurch Bypass (OS grid ref. SP 028726) and the A448, Bromsgrove to Redditch Highway (OS grid ref. SP041 660). Four study sites made up each of the two study areas. Clearance across the road between the vegetated verges is 29 and 31 metres respectively. The central strip that separates traffic flow is not vegetated on either of the two highways. Worcestershire County Council provided traffic count data (as at 1999). Between 07:00 hrs and 19:00 hrs there are 12,000 vehicles for Alvechurch (the A441) and 22,500 vehicles for Redditch (the A448). Each of the study areas is traversed by a road bridge approximately 12 metres wide, below which is a concreted, non-vegetated expanse, equal to the width of the bridge.

The Alvechurch Highway is a recently built road (1992). The road-verge has been planted with native shrubs, including blackthorn (*Prunus spinosa)*, hawthorn (*Crataegus monogyna*) and field maple (*Acer campestre*). At the time of this study the shrub vegetation was about 1.5 to 2 metres high but is generally insufficient to shade out the rough grassland ground cover beneath. With the exception of a 1-2 metre sightline along the border of the road, the verges are unmown. Sightlines are mown approximately every 2-3 months during the growing season but mowing was suspended during the study period. Ground cover is predominantly rank grass, cock's foot (*Dactylis glomerata*), false oat-grass (*Arrhenatherum elatius*), rough meadow grass (*Poa trivialis*) and Yorkshire fog (*Holcus lanatus*), with some stands of creeping thistle (*Cirsium arvense*). Three of the study sites of the Alvechurch study area have a gappy (*Crataegus monogyna*) hedgerow separating them from the adjoining landscape, one of the four study sites has post and wire fencing. Abutting the verges on two of the study sites are arable fields (Figure 5.1) that were lying fallow at the time of this study, the other two study sites lie adjacent to semi-natural grassland, used as rough pasture for grazing stock and horses.

The Redditch highway was built in 1972. The road-verges here are generally more mature, more species-rich and structurally more diverse than at Alvechurch. They consist of a mix of various grasses; false oat-grass (*Arrhenatherum elatius*), Yorkshire fog (*Holcus lanatus*), rough meadow-grass (*Poa trivialis*), and forbs including: colt's-foot (*Tussilago farfara*), ribwort plantain (*Plantago lanceolata*), self-heal (*Prunella vulgaris*), yarrow (*Achillea millefolium*) oxeye daisy (*Leucanthemum vulgar*e), wild carrot (*Daucus carota*), Vetches (*Vicia* spp.), Herb Robert (*Geranium robertianum*), broad-leaved willowherb (*Epilobium montanum*), yellow centaury (*Cicendia filiformus*) and stitchwort (*Stellaria holostea*). Only the sightlines are mown. Unlike the Alvechurch site, mowing continued during the study period and the sightlines were mown twice during the three-month study period. There is also remnant hedgerow vegetation at the perimeter of the study area, predominantly hawthorn (*Crataegus monogyna*) and some blackthorn (*Prunus spinosa).* At the time of this study, scrubby, immature woodland areas, including the hedgerow remnants, were approximately 3-4 metres high. On one of the four study sites at Redditch, there is a small (approximately 10m x 20m), immature plot of Scot's pine (*Pinus sylvestris*). Both the conifer and the scrub are sufficiently dense to shade out most of the groundcover. A post and wire fence, which had presumably acted as a perimeter boundary at some time, had been erected at one of the study sites, but there is no obvious vegetational demarcation between the road-verges and the adjacent landscapes. There is a minimum of 75 metres of scrubby, immature woodland landscape abutting all of the Redditch highway sites but the built environment within 100 metres of two of the study sites. The other two study sites adjoin predominantly scrubby landscapes and both have small (approximately 1 ha) deciduous woodland areas within 100 metres. On three of the four study sites the road-verge continues into immature woodland/scrub that features a variety of tree and shrub species including bramble (*Rubus fruticosus*), oak (*Quercus robur*), wild cherry (*Prunus avium*), ash (*Fraxinus excelsior*), hazel (*Corylus avellana*), and birch (*Betula pendula*).

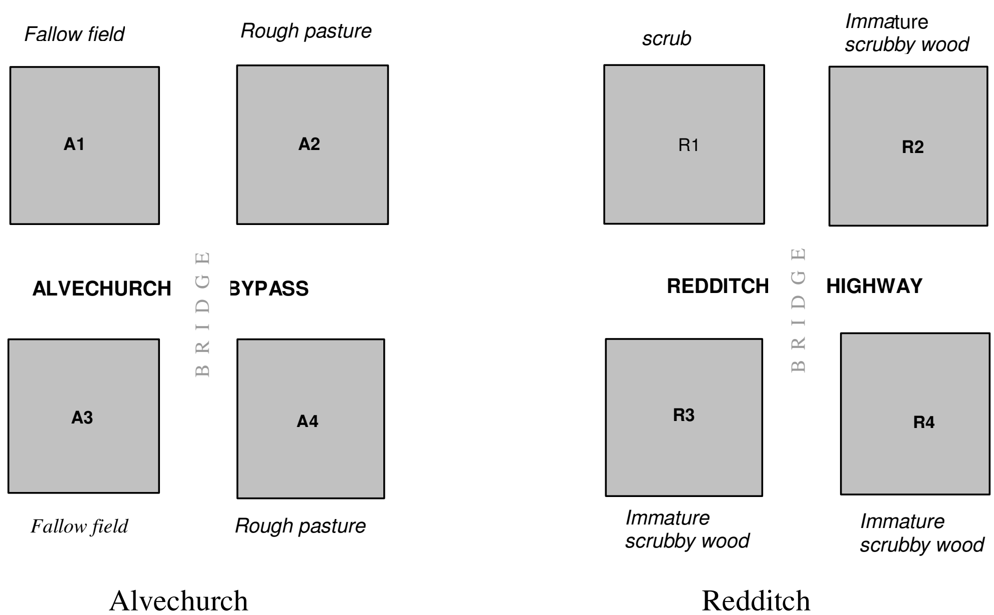


Figure 5.1 The layout of the four study sites at the Alvechurch and Redditch study areas indicating the type of habitat in adjoining areas.

5.2.2 Trapping design

A grid of 25 Longworth live traps was installed on each study site *i.e.* on the road-verges either side of the road, and either side of the intersecting concrete expanse that covers the area beneath the road bridge. A replicate grid was installed on the opposite side of the dual carriageway, creating four study sites at each of the Alvechurch and Redditch study areas (Figure 5.1)

Field voles (*Microtus agrestis*) are one of the most frequent small mammals to be found in rough grassland habitats and the 5 metre spacing interval between grid points reflects the distances moved by this species which are generally shorter than those moved by other small mammals (Kikkawa 1964, Gurnell and Fowerdew 1994, Wolton and Flowerdew 1985). No traps were installed on the separating concrete expanse beneath the bridges. When small mammal runways coincided with grid points, traps were placed at right angles to them to optimise trapping success (Gurnell and Langbein 1983). The trapping grid covered an area of $20m^2$ on each study site. With a buffer strip on two of the four sides (the road and concrete expanse border the other two sides), this is equivalent to $22.5m^2$. One study site, on each side of the dual carriageway, was trapped simultaneously. Thus, at each trap round, 100 traps were inspected (two study areas, each with two sites of 25 traps.).

Field voles are thought to be more trap resistant than either wood mice or common shrews and trap avoidance may reduce the number of times this species is caught, thereby reducing the likelihood of observing significant movements. Although many factors can influence trappability (Kikkawa 1964, Sutherland 1996), pre-baiting is a method often used to reduce initial reluctance of individuals to enter live traps (Sutherland 1996, Gurnell 1980), so in the

July and August trapping periods all traps were pre-baited. The June period, when traps were not pre-baited, served as a control.

Traps were set and inspected two times each day, and to enable unrestricted movement of animals between trap rounds, they were set only on alternate days. Traps were left *in situ,* but closed when not in use. Baiting was the same as in the previous woodland studies with whole wheat, sunflower seeds and casters (blow-fly pupae) to sustain captured individuals. A small quantity of hay was placed in each trap for bedding. Traps were well covered with grass to shelter them from the excesses of summer-time temperatures and to make them less conspicuous. Individual records of weight, breeding condition and sex for voles and mice were noted (shrews were not sexed), and individuals were given a unique fur clipping for subsequent identification. Weight was used to classify adults and juveniles of the three most common species. Juveniles were distinguished as follows; wood mice $\leq$ 15.5 gms, field voles $\leq$ 17.5 gms and common shrews $\leq$7gms.

It was anticipated that because of the time of year when the study was undertaken, juveniles would constitute a sizeable proportion of the population and, because of post-juvenile moult (Flowerdew 1993), the persistence of individual markings would vary. New marks were therefore given at each trapping period. Any animals found retaining marks from a previous trapping period were re-marked.

High afternoon temperatures during the study period (occasionally in excess of 25°C) and an anticipated high abundance of shrews, dictated the amount of time for which the traps could be left between inspections. It also necessitated trapping being undertaken during the cooler part of the day. For overnight trapping the traps were set after 20:30 hrs each day. The first trap round was started at first light, approximately 04:00hrs at which time each trap was inspected, restocked as necessary, and reset. The second trap round was started at approximately 10.00hrs after which the traps were closed until the following day. At each trap round 100 traps were checked (25 traps per site on each of the two sides of each study area). Each complete trap round took between 1.5 hours and 4.5 hours depending on the number of animals caught and the proportion of new animals that required marking.

There were three separate trapping periods of five days each. This provided 1000 trap nights per trapping period (5 days x 200 traps), 3000 trap nights in all. The first trapping period was undertaken between 21st and 30th June 2000 with no treatments installed. At the end of the first trapping period, natural cover, including tree trunks and brashings, was placed across the top and the bottom of the concreted expanse beneath the bridges to connect the verges either side (Figure 5.2). The width of the cover was approximately 2m. It was installed only on one side of the road at each of the two study areas. The corresponding area on the opposite side of the road was left in its original state to act as a control. Each of the two study areas was treated in the same way. The second trapping period commenced on 10th July, when the treatment had been installed for 10 days and continued until 19th July. The third trapping period was carried out between 14th and 23^{d} August, five weeks after the treatment had been installed.

5.2.3 Data analysis

Abundance of each species was calculated as the number of individuals captured, with the number of known deaths deducted to give the minimum number alive (MNA). In addition to these estimates, densities and numbers of individuals per 100 trap nights were also calculated.

Figure 5.2 Installing cover beneath road bridges.

Densities were calculated for each trapping period based on the area covered by the trapping grid plus a boundary strip of one half the distance between trapping stations (Gurnell and Flowerdew 1994). The number of animals for each trap-night was calculated by dividing MNA for each species by the number of traps (25 for each trapping grid) for each trap night (five nights for each trapping period).

Multiple captures are a prerequisite for tracking the movements of small mammals. The more times an individual is captured the more reliable the collected data will be in respect of an individual's normal activity and the more likely it is that forays across the road and other barriers will be detected. Conversely, the fewer the number of recaptures the more limited the available information. The propensity of an animal to enter a trap (trappability) has been assessed using latency to first capture and the frequency of capture. Latency to first capture is a good indication of whether the species data are representative of the population (if new captures are increasing rather than decreasing then it is probable that the population has been inadequately sampled); it is also important as a measure of initial resistance to trap entry. The frequency of capture is an indication of overall trap-proneness or avoidance.

The computer programme Diversity (Pices Conservation Ltd, 1998) was used to calculate diversity indices, evenness and diversity ordering. Whilst limited in their application, diversity indices are nevertheless useful as a measure of comparison between different communities (Southwood and Henderson 2000). Test output can differ between indices depending on the method of calculation (Tóthméresz 1995), therefore two different indices were employed for comparison, Simpson's D, which emphasises rare species, and Shannon Weiner, which emphasises common species. Evenness, or equitability scores, relate to the pattern of distribution of individuals between the species. Reyni's diversity ordering is used to identify communities that are consistent in their relative diversity and are therefore amenable to ranking.

Ranges V (Kenward and Hodder 1995) was used to assess small mammal home range size, distances moved and habitat utilisation. The low number of high multiple entries dictated that the minimum convex polygons (MCPs) were calculated for animals on the minimum number of captures (three) from which home ranges can be calculated (Kenward and Hodder 1995). Output from the data in this study is likely to underestimate the area actually covered by many of the individuals because of the short trapping histories of many of the individuals (see Data Analysis 4.2.3) but is useful as a relative measure of home range. The centre point of home ranges was plotted from MCP data using the recalculated arithmetic mean of the location co-ordinates. The recalculated mean excludes the furthest fix from the array of coordinates in order to provide the point on the area where most fixes are recorded.

SPSS and Minitab were used for other statistical analysis. Sector and trapping period data were pooled where there were insufficient captures for statistical analysis. One-way analysis of variance (ANOVA) was used to test for differences in abundance between the different trapping periods. Kolmogorov-Smirnov one-sample test was used to test for normality and the Levene statistic was used to test for equality of variances. Chi-squared test was used to investigate inter- and intra-study area distributions and inter and intra-species distributions. Linear regression was used to test for a relationship between the abundance of animals and proximity to the road. Abundance at traplines was used as the measure of distance from the road but, to avoid error resulting from the localization of trap-prone individuals (Gurnell and Gipps 1989), only the first night of capture was used for analysis.

5.3 Results

5.3.1 Community Description

Over the course of the three trapping periods in June, July and August 2000, 445 animals were trapped a total of 1253 times (mean average capture rate = 2.8) Table 5.1. There were eight known deaths during the three trapping periods, comprising one field vole, four common shrews and three pigmy shrews. All were found dead in the traps. Dead shrews were invariably found with trap doors still open but with bedding pushed into the opening. Seven of the eight deaths occurred on the east-facing slope at Alvechurch that was exposed to the sun for longer periods and where there was no shade. Cause of death is thought to be an indirect result of the high summer temperatures to which shrews are particularly sensitive (Churchill 1990).

Table 5.1 The cumulative number of individuals captured during the three study periods.

Alvechurch site

	Session			
Species	1	2	3	Total
wood mouse	13	10	20	43
field vole	32	25	48	105
common shrew	30	40	26	96
pigmy shrew	6	14	9	29
water shrew	0	0	3	3
y-n mouse	0	0	0	0
Grand Total	81	89	106	276

Redditch site

	Session			
Species	1	2	3	Total
wood mouse	12	13	17	42
field vole	24	25	35	84
common shrew	9	16	12	37
pigmy shrew	0	0	1	1
water shrew	0	0	0	0
y-n mouse	4	1	0	5
Grand Total	49	55	65	169

Six different species were caught on the eight different trapping grids during the three trapping periods (Appendix E1-E4 gives the full breakdown of the numbers captured). Species composition broadly reflects the rough grassland habitat of the highway embankment. However, only the three dominant species, field vole, common shrew, and wood mouse, were common to all the sites (Table 5.2). Field voles were the most abundant species, with

Table 5.2 The number of individuals (common species) captured on each trapping grid for each of the trapping periods.

	Alvechurch							Redditch					
	June		July		August			June		July		August	
	n	per ha	n	per ha	n	per ha		n	per ha	n	per ha	n	per ha
wood mouse							**wood mouse**						
A1	4	(18)	3	(13)	4	(18)	R1	3	(13)	2	(9)	2	(9)
A2	2	(9)	0	(0)	2	(9)	R2	2	(9)	4	(18)	3	(13)
A3	3	(13)	1	(4)	7	(31)	R3	1	(4)	3	(13)	3	(13)
A4	4	(18)	6	(27)	7	(31)	R4	6	(27)	4	(18)	9	(40)
Total	13	(15)	10	(11)	20	(23)	Total	12	(14)	13	(15)	17	(19)
field vole							**field vole**						
A1	10	(44)	8	(36)	23	(102)	R1	8	(36)	8	(36)	5	(22)
A2	7	(31)	9	(40)	10	(44)	R2	4	(18)	4	(18)	7	(31)
A3	7	(31)	4	(18)	0	(0)	R3	9	(40)	6	(27)	8	(36)
A4	8	(36)	4	(18)	15	(66)	R4	3	(13)	7	(31)	15	(67)
Total	32	(36)	25	(28)	48	(54)	Total	24	(27)	25	(28)	35	(39)
common shrew							**common shrew**						
A1	4	(18)	11	(49)	8	(18)	R1	1	(4)	0	(0)	1	(4)
A2	6	(27)	11	(49)	8	(18)	R2	4	(18)	8	(36)	6	(27)
A3	12	(54)	9	(40)	3	(13)	R3	1	(4)	4	(18)	3	(13)
A4	8	(36)	9	(40)	7	(31)	R4	3	(13)	4	(18)	2	(9)
Total	30	(34)	40	(45)	26	(29)	Total	9	(10)	16	(18)	12	(14)

densities up to 102 ha^{-1}, wood mice were trapped at densities up to 40 ha^{-1}, and common shrews reached 49 ha^{-1}.Of the uncommon species (Table 5.3), pigmy shrews were present on three of the four Alvechurch study sites but, out of a total of 28 pigmy shrews, only one came from the Redditch study area. Water shrews were uncommon (*n* = 3) and trapped only on two of the Alvechurch study sites during the August trapping period. Yellow-necked mice were also rare captures (*n* = 5), trapped at just one of the Redditch study sites, four in the June trapping period and just one individual in July.

Table 5.3 The number of individuals (uncommon species) captured on each trapping grid for each of the trapping periods.

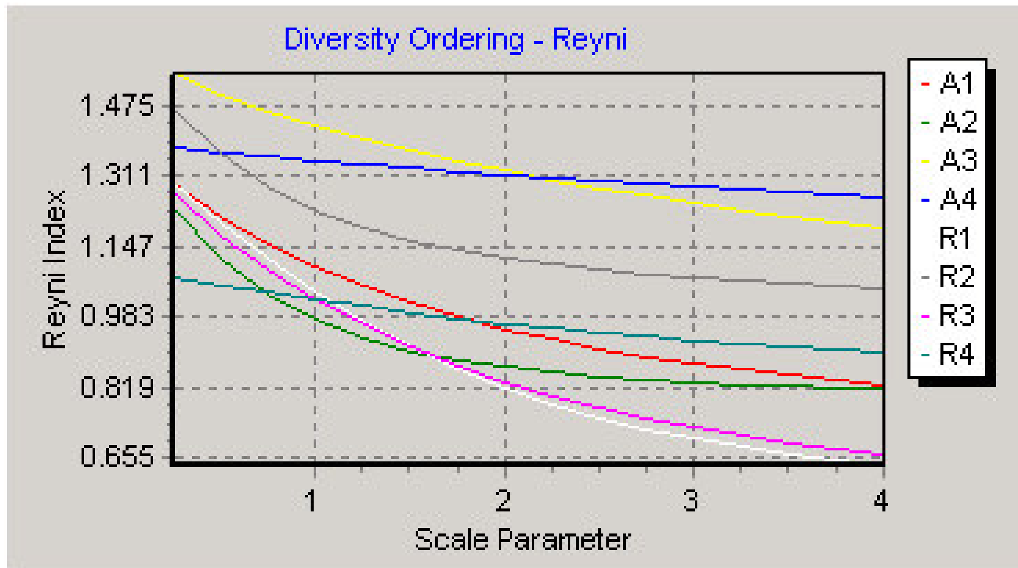
	Alvechurch				**Redditch**		
	June	July	August		June	July	August
			pigmy shrew				
A1	1	2	0	R1	0	0	0
A2	0	0	0	R2	0	0	0
A3	2	5	4	R3	0	0	1
A4	3	7	3	R4	0	0	0
Total	6	14	7	Total	0	0	1
			water shrew				
A1	0	0	0	R1	0	0	0
A2	0	0	1	R2	0	0	0
A3	0	0	2	R3	0	0	0
A4	0	0	0	R4	0	0	0
Total	0	0	3	Total	0	0	0
			yellow-neck mouse				
A1	0	0	0	R1	4	0	0
A2	0	0	0	R2	0	1	0
A3	0	0	0	R3	0	0	0
A4	0	0	0	R4	0	0	0
Total	0	0	0	Total	4	1	0

There were variations in the abundance for all species for the different trapping periods, but none was significant (ANOVA, df = 23, $p > 0.05$). Wood mice and field voles show broadly similar results for the June and July trapping periods, which then peak in the August trapping period. Common shrew numbers peak in July, as do pigmy shrews. Water shrews were not considered resident on the study area and the three individuals caught in August were young animals, weighing between 9-10 gms (average weight is between 9-16gms, Churchfield 1990). Similarly, yellow-necked mice were only present in small numbers and are not thought to be resident in the rough grassland habitat of the road-verge.

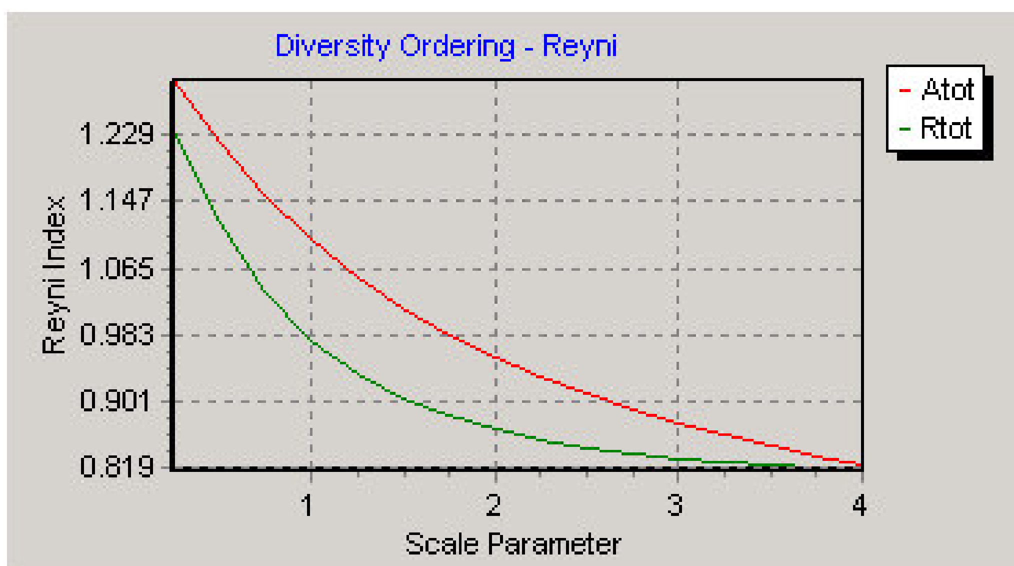
Of the species that are common to both study areas, all of them are more abundant at the Alvechurch study sites. The calculated indices (Table 5.4) do not indicate large differences in species diversity between the eight study sites but the Alvechurch sites scored more highly than the Redditch sites in terms of evenness. Of the eight study sites, A3 and A4 (Alvechurch) and R2 (Redditch) were the most species-diverse, but the ranking of other sites is complicated because of community heterogeneity (only similar communities can be ordered) (Figure 5.3).

Table 5.4 Diversity indices for the eight study sites

Alvechurch	Shannon weaver	Simpson's	Evenness	**Redditch**	Shannon weaver	Simpson's	Evenness
A1	1.0100	2.6552	0.6138	R1	1.0414	2.3571	0.5812
A2	0.9766	2.4406	0.5451	R2	1.2291	3.2177	0.6860
A3	1.4263	3.9550	0.7960	R3	1.0229	2.3831	0.5709
A4	1.0414	3.8526	0.7523	R4	1.0233	2.7179	0.5711
All	1.3105	3.3489	0.7314	All	1.1795	2.8460	0.6583



a)



b)

Figure 5.3 The Reyni diversity ordering charts identifies communities that are consistent in their relative diversity. The charts above rank, a) each study site and b) the two study areas (for which the data has been pooled). Lines that cross indicate communities that cannot be ranked because of inconsistencies in their relative order. Relative diversity is achieved by producing an expression (scale parameter) that can generate the various indices by changing the value of preferably a single parameter (Southwoood & Henderson) and is based on the concept of eutrophy (Reyni 1961).

There were also variations in the community structure between the study sites at the main study areas (species abundance for each trapping period was pooled). Differences are not significant at Alvechurch (χ_2=17.685, df = 6, p = 0.07), but they are significant at Redditch (χ^2=20.27, df = 6, p = 0.02).

5.3.2 Trappability

5.3.2.1 Frequency of trap entry

The pattern of multiple entries was similar for all the common species with an inverse relationship between the number of animals and capture frequency. (Figure 5.4 to Figure 5.6). Overall, common shrews demonstrated the greatest propensity for trap re-entry with an average capture rate of 3.6. Sixty-seven percent of common shrews entered traps more than once, 51% more than twice, 45% more than three times, and 27% entered traps six or more times during the five day trapping period. Two common shrews entered the maximum number of 10 times, the only species to do so. Wood mice averaged 2.5 entries with 63.5% ≥2 trap entries, 40% ≥3 and 26% ≥4. Field voles averaged 2.5 trap entries, with 59% ≥2, 36% ≥3 and 27% ≥4. Pigmy shrews were not common but still averaged 2.5 entries, the same as wood mice and field voles.

5.3.2.2 Latency to first capture

Species varied in their propensity to enter traps on the first night of trapping. In general, there was a downward trend in the number of new animals captured with each successive trap night (Figure 5.7 to Figure 5.9). For the three dominant species, there was no significant difference in the night of first capture (χ^2 = 8.02, d.f. = 8, p-value = 0.431).

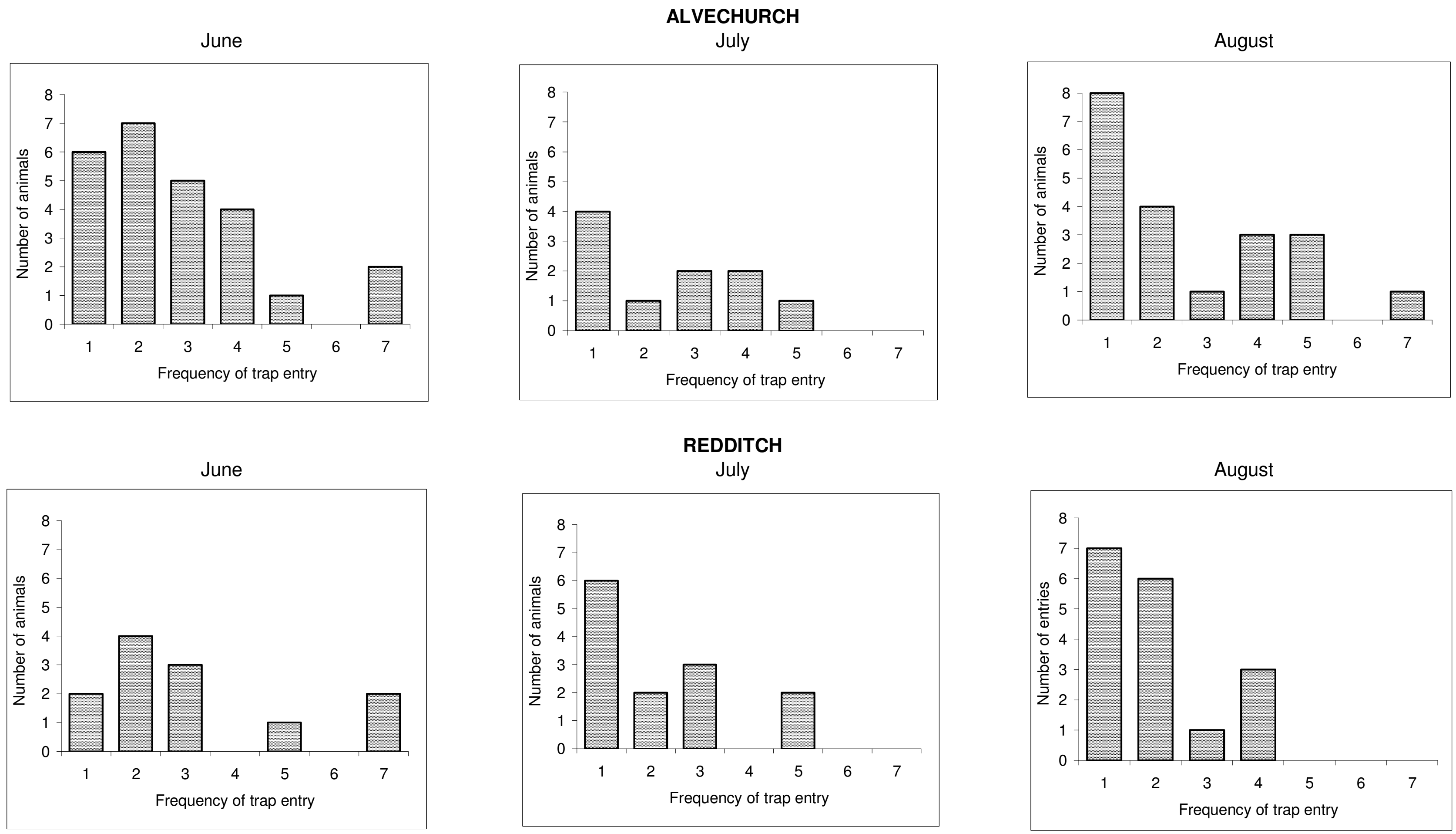


Figure 5.4 Frequency of capture for wood mice at Alvechurch and Redditch. Data from the four study sites has been pooled. (For frequency of 7, read 7 or greater.)

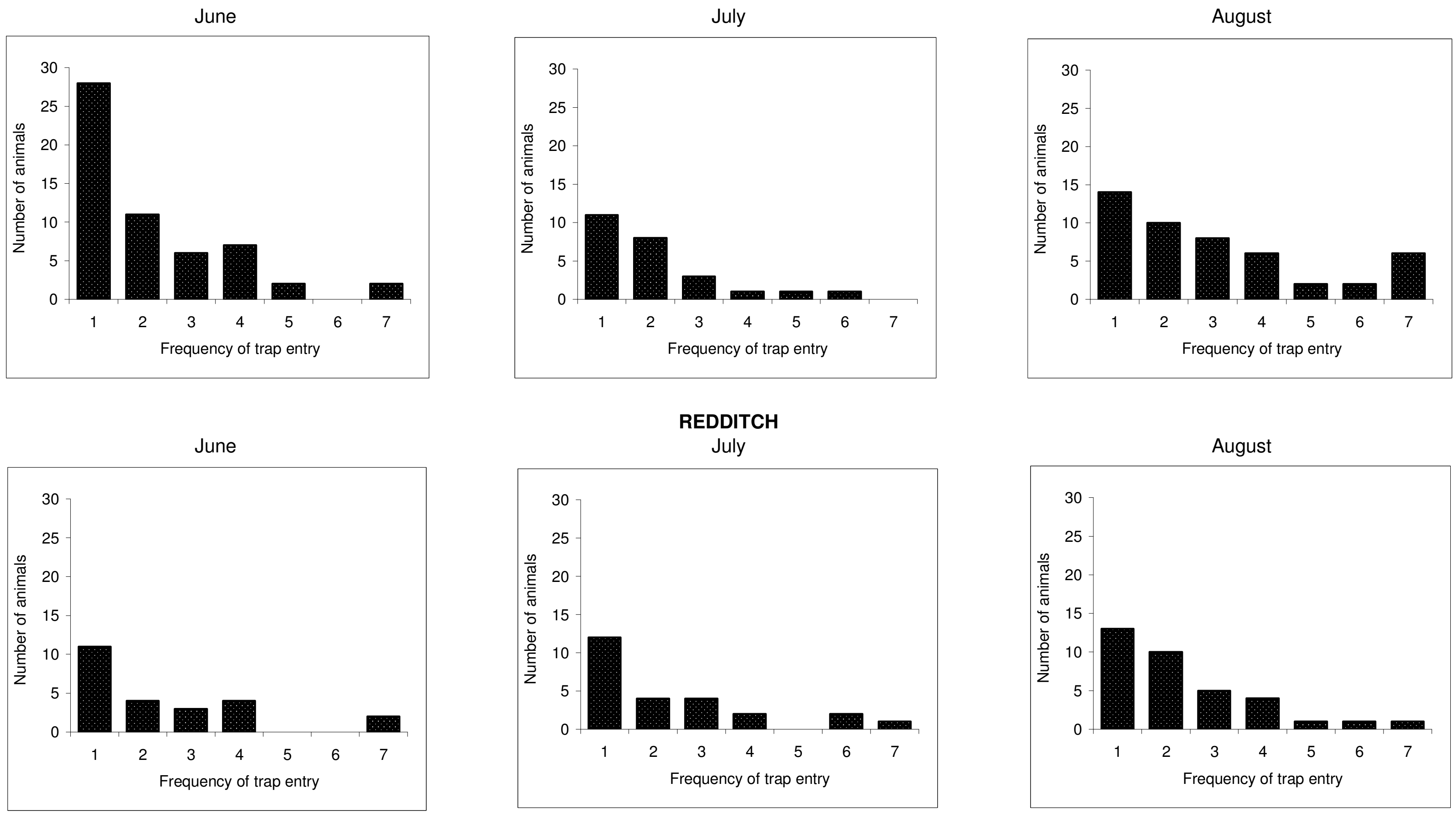


Figure 5.5 Frequency of capture for field voles at Alvechurch and Redditch. Data from the four study sites has been pooled. (For frequency of 7, read 7 or greater.)

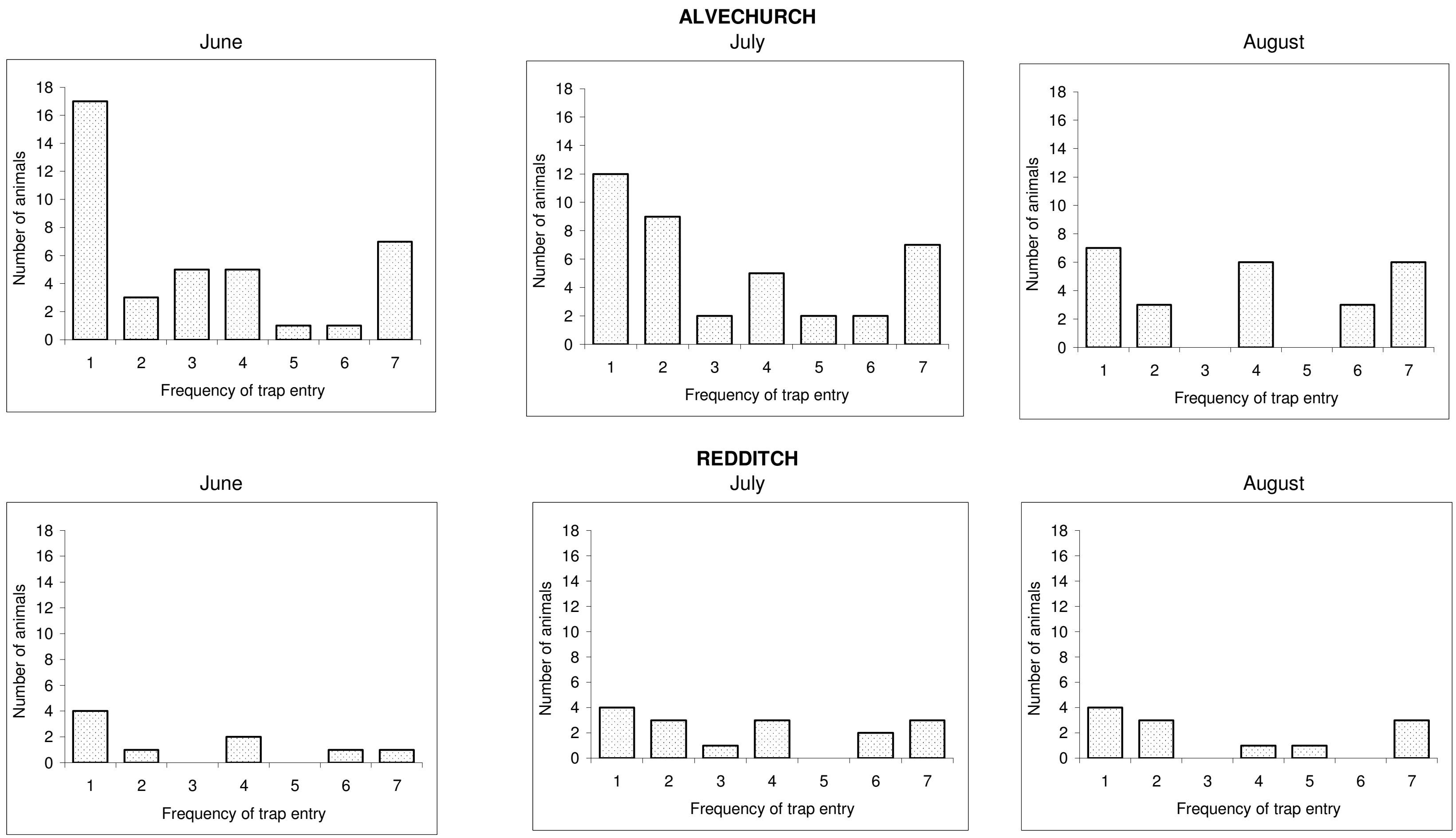


Figure 5.6 Frequency of capture for common shrews at Alvechurch and Redditch. Data from the four study sites has been pooled. (For frequency of 7, read 7 or greater.)

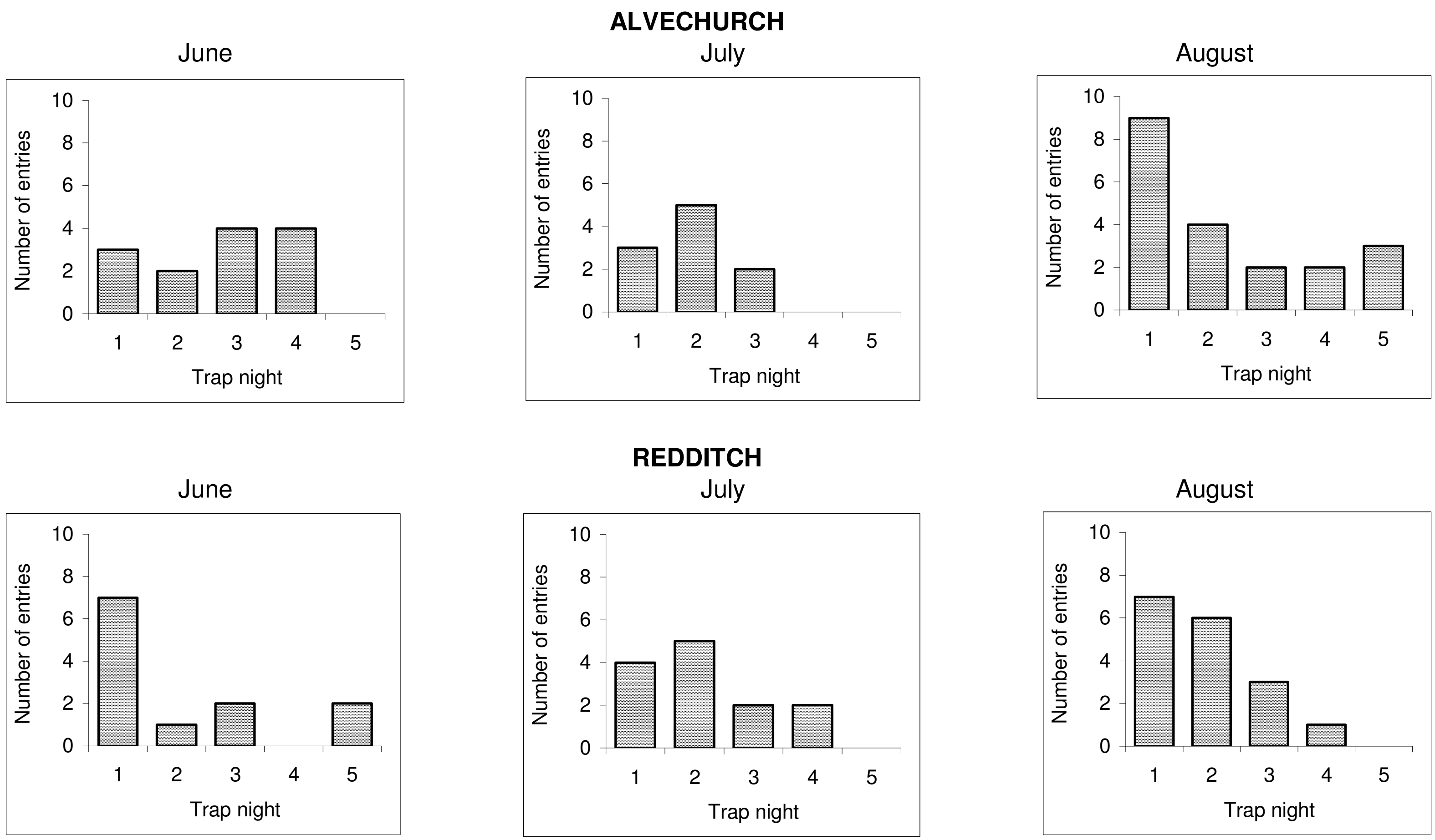


Figure 5.7 The night of first capture for wood mice at Alvechurch and Redditch (data for the four study sites has been pooled) for each of the three trapping periods.

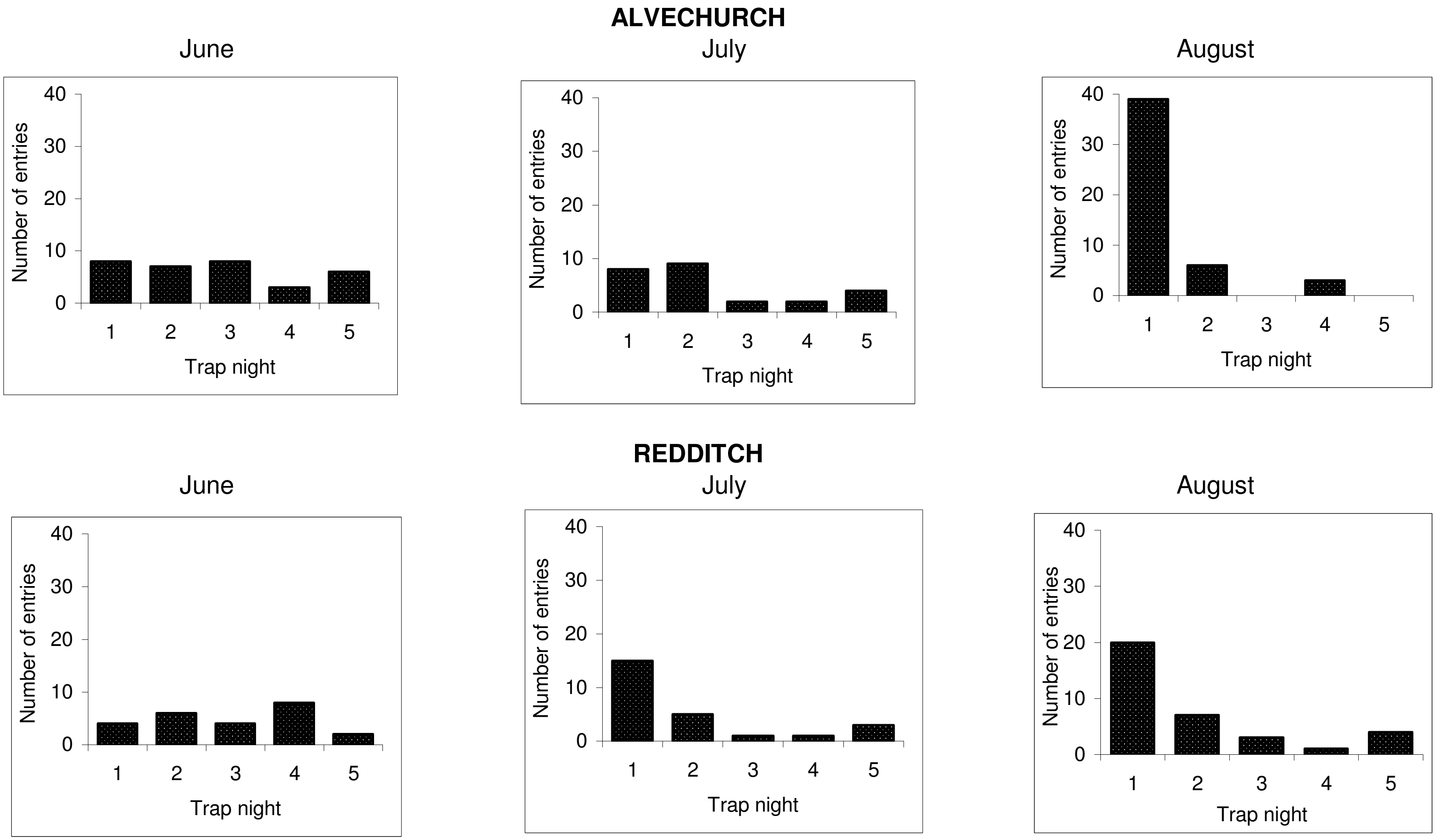


Figure 5.8 The night of first capture for field voles at Alvechurch and Redditch (data from the study sites has been pooled) for each of the three trapping periods

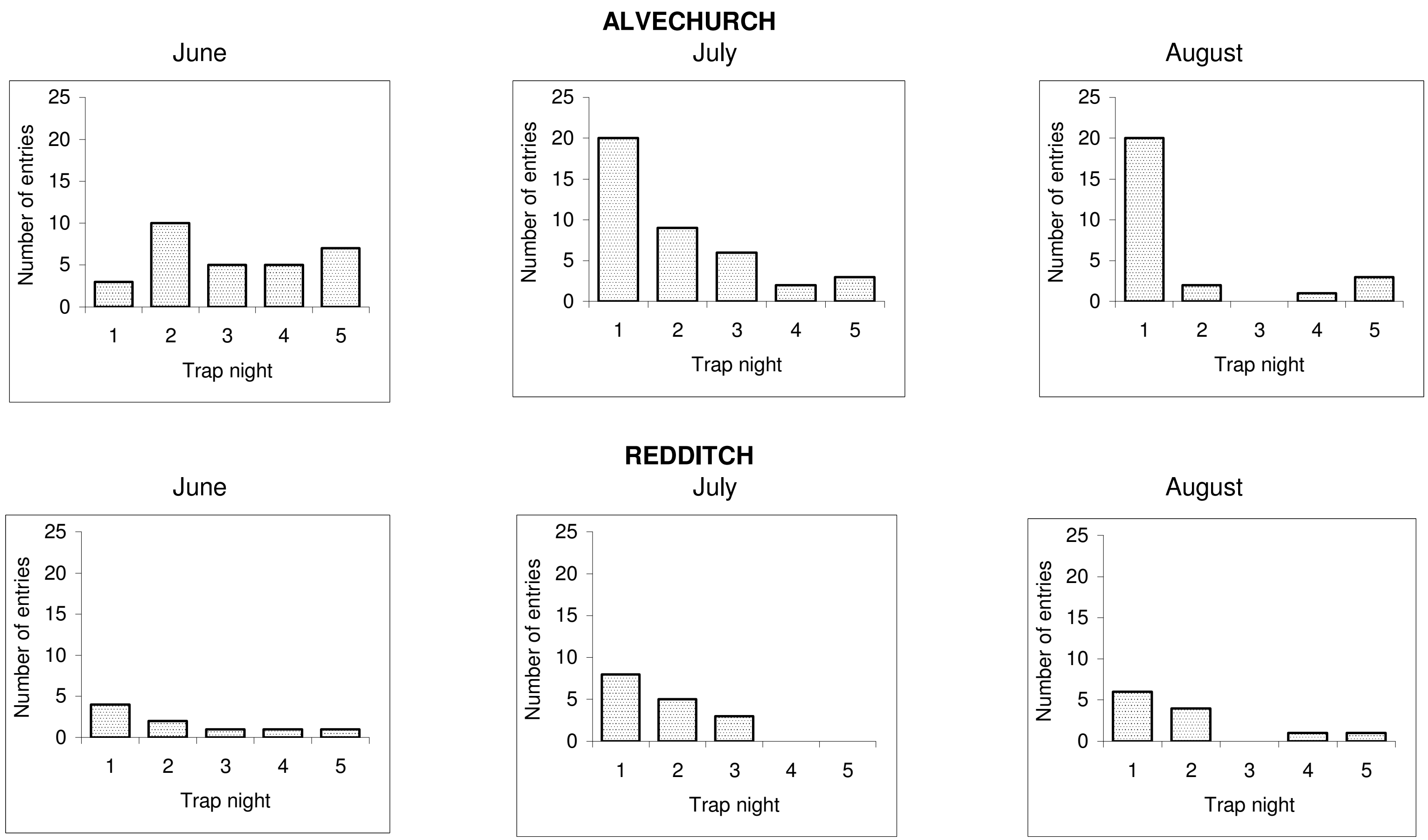


Figure 5.9 The night of first capture for common shrews at Alvechurch and Redditch (data from the study sites has been pooled) for each of the three trapping periods

In addition to differences in latency to first capture between the species, differences were investigated between males and females and between adults and juveniles for the same species. For wood mice, there was no significant difference in trap response ($\chi^2 = 1.514$, d.f. = 3, p = 0.679). There are too few wood mice juveniles to test for differences in the age classes. For field voles, differences between males and females were not significant ($\chi^2 = 4.475$, d.f. = 4, p value = 0.346), but there was a highly significant difference between adult and juvenile trap entry ($\chi^2 = 15.064$, d.f. = 2, p value = 0.001). Only 39% of adult field voles entered traps on the first night compared with 65% of juveniles.

When the three different trapping periods are examined separately, differences in the responses between the trapping periods are evident, with a more immediate response being demonstrated in the two later trapping periods (July and August) when the traps were pre-baited. (Table 5.5).

Table 5.5 The proportion of individuals entering on the first night of capture for each of the three trapping periods

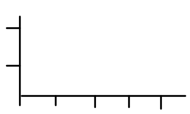
	June	July	August
Wood mouse:	40%	30%	43%
Field vole:	21%	46%	71%
Common shrew:	18%	50%	72%

For wood mice the differences between trapping periods are not significant ($\chi^2 = 7.054$, d.f. = 4, p value = 0.133) but for field voles and common shrews the trapping period had a highly significant effect (field voles, $\chi^2 = 39.76$, d.f. = 4, p value = 0.001, common shrews, $\chi^2 = 24.583$, d.f. = 4, p value = 0.001). Pre-baiting is the most likely explanation of these differences.

5.3.3 Spatial distribution in relation to the road

When the central points for all individual home ranges are plotted onto a representational trapping grid, the patchiness of the species distributions is apparent (Figure 5.10). The plotted home ranges for each species are given at Appendix F1-F6. To investigate the role of habitat on the distribution of species across the trapping grid, utilisation of the three broad habitats, grassland, scrub and wooded, was investigated (Table 5.6). Wood mice did not demonstrate a particular habitat preference ($p = >0.05$) but habitat selection for field voles was highly significant at both Alvechurch and Redditch ($p = <0.001$). Field voles positively selected for grassland habitat and negatively selected for scrub and trees. Habitat preference for common shrews was not significant ($p = >0.05$) but they demonstrated a positive preference for grassland, followed by scrub and they avoided areas where there was tree canopy and no ground cover. Indeed, the wooded areas, which were all devoid of ground cover, were avoided by all species, and there were no animals actually recovered from traps placed here (indications of habitat ranges encompassing this area is a result of the way in which boundaries are drawn using minimum convex polygons).

To test for a disturbance effect generated by roads, the abundance of species at trapline one was compared with the average abundance for the five traplines. Species abundance varied between the different trapping grids and between the different trapping periods, and there were too few animals to analyse each of the data sets separately, so the data was pooled for the two study areas. At Alvechurch, there was no significant difference (One-way ANOVA, d.f.=7, $F = 1.510$, $p = 0.265$) but differences are significant at Redditch (d.f. = 7, $F = 9.002$, $p = 0.024$). To test this road effect further, the abundance of different species at different distances from the road was subjected to analysis by linear regression (Table 5.7).



Scale = 5metres

Figure 5.10 The central point of home range for the three common species plotted onto a representational diagram of the Redditch and Alvechurch field sites. The four sub-sections of the main field sites are illustrated with the dual carriageway orientated horizontally and the bridges orientated perpendicularly in each diagram. Only animals captured three or more times are shown.

Table 5.6 A habitat selection index for the three dominant species at the Alvechurch and Redditch study sites.

	habitat	proportion available	sample count used	sample proportion used	selection index	standardised selection index[1]
Alvechurch						
wood mouse						
	scrub	0.61	69	0.689	1.130	0.586
	grass	0.39	31	0.311	0.797	0.414
	Chi-sq log liklihood test for random selectivity = 1.373, df = 1 p = 0.2395					
field vole						
	scrub	0.61	36	0.363	0.595	0.267
	grass	0.39	64	0.637	1.633	0.733
	Chi-sq log liklihood test for random selectivity = 12.338, df = 1 p = 0.0006					
common shrew						
	scrub	0.61	48	0.482	0.790	0.373
	grass	0.39	52	0.518	1.382	0.627
	Chi-sq log liklihood test for random selectivity = 3.314, df = 1 p = 0.0652					

[1] Standardised selection index above 0.5 indicates preference

	habitat	proportion available	sample count used	sample proportion used	selection index	standardised selection index[2]
Redditch						
wood mouse						
	scrub	0.16	12	0.117	0.731	0.312
	trees	0.76	84	0.843	1.109	0.474
	grass	0.08	4	0.040	0.500	0.214
	Chi-sq log liklihood test for random selectivity = 2.459, df = 2 p = 0.2921					
field vole						
	scrub	0.16	4	0.040	0.247	0.164
	trees	0.76	96	0.961	102638.000	0.837
	grass	0.08	0	0.000	0.000	0.000
	Chi-sq log liklihood test for random selectivity = 21.223, df = 2 p = 0.001					
common shrew						
	scrub	0.16	12	0.120	0.750	0.323
	trees	0.76	84	0.843	1.109	0.478
	grass	0.08	4	0.370	0.463	0.199
	Chi-sq log liklihood test for random selectivity = 2.621, df = 2 p = 0.2688					

[2] Standardised selection index above 0.33 indicates preference

Table 5.7 The relationship between species abundance and distance from the road. ('All species' includes the common and uncommon species).

	Species	Regression equation, y =	R^2	p-value
Alvechurch	wood mouse	3.40x - 1.60	0.631	0.108
	field vole	2.30x + 14.1	0.291	0.348
	common shrew	0.80x + 16.8	0.157	0.509
	all species	6.10x + 36.9	0.962	0.003**
Redditch	wood mouse	-0.80x + 10.8	0.333	0.308
	field vole	-7.60x + 39.6	0.919	0.010**
	common shrew	-3.10x + 16.7	0.820	0.034*
	all species	-12.0x + 69.8	0.921	0.010**

* result significant at 95% CI

** result signifcant at 99% CI

The results indicate positive and significant relationships for both field voles and common shrews at the Redditch study area. When the data for all species are pooled for both study areas the results for Alvechurch and Redditch are highly significant (p -= <0.01).

5.3.4 Movements and barrier crossings

The mean and maximum distance moved for each species was calculated for the three dominant species to see if trap-revealed movements were of sufficient distance to cross the road and to cross the area beneath the bridges (Table 5.8).

Table 5.8 Maximum distances moved by different species and by different classes of species at Alvechurch and Redditch sites.

Alvechurch

Maximum distance moved

Species	Adult male	Adult fem	Juvenile male	Juvenile fem
wood mouse	19	30	3	11
field vole	25	26	13	12
c. shrew	19	0	0	0
p. shrew	15	0	0	0

Redditch

Maximum distance moved

Species	Adult male	Adult fem	Juvenile male	Juvenile fem
wood mouse	14	16	15	13
field vole	14	15	5	16
c. shrew	15	0	0	0

Distances varied between species, between study areas and between trapping period, but overall, wood mice travelled greater mean distances than the other two species (14.6m), field voles moved the next greatest distance (13.4m), whilst common shrews averaged the shortest distances (12.3m). At Alvechurch, 33 animals (5 mice, 9 field voles, 17 common shrews and 2 pigmy shrews) moved distances ≥ 12 metres (the width of the concreted expanse beneath the road bridge). At Redditch, 9 individuals (3 mice, 2 field voles and 2 common shrews) recorded distances ≥ 15 metres, the width of the unvegetated span beneath the road bridge. No animals were recorded as moving sufficient distances to traverse the 31 metres needed to cross the dual carriageway.

No crossings of the road were recorded at either of the two study areas, but out of 445 individuals, there were eleven confirmed crossings of the concreted spans beneath the bridges, ten at Alvechurch and one at Redditch (Table 5.9). Three of the ten crossings at Alvechurch took place prior to the installation of cover that was used to connect the divided road-verges beneath the bridges. Of the other seven, all but one of the crossings were made on the side of the road where cover had been placed. At Redditch, individuals from each of the three common species (field vole, wood mouse and common shrew) crossed the concreted span beneath the road bridge, as well as two pigmy shrews. The number of crossings for the different species was not proportional to the number of individuals of each species trapped, nor was it proportional to the number that was recorded as covering distances equal to or greater than the distance required to traverse the span beneath the bridges. In order of frequency, wood mice made the most crossings, followed by pigmy shrews, field voles, and then common shrews. Two wood mice made multiple crossings.

Table 5.9 The number of recorded crossovers of the concreted expanse beneath the bridge for the Alvechurch and Redditch study areas.

Alvechurch

Redditch

Untreated side

Alvechurch:

Species	Trap session 1	2	3
wood mouse	0	0	1
field vole	0	0	0
common shrew	0	0	0
pigmy shrew	0	0	0
water shrew	0	0	0
	0	**0**	**1**

Redditch:

Species	Trap session 1	2	3
wood mouse	0	0	0
field vole	0	0	0
common shrew	0	0	0
pigmy shrew	0	0	0
yellow-neck mouse	0	0	0
	0	**0**	**0**

Treated side[1]

Alvechurch:

Species	Trap session 1	2	3
wood mouse	1	3	1
field vole	1	0	0
common shrew	1	0	0
pigmy shrew	0	2	0
water shrew	0	0	0
	3	**5**	**1**

Redditch:

Species	Trap session 1	2	3
wood mouse	0	0	0
field vole	0	1	0
common shrew	0	0	0
pigmy shrew	0	0	0
yellow-neck mouse	0	0	0
	0	**1**	**0**

[1]On the treated sides, cover in the form of tree trunks and brashings was placed across the top and the bottom of the concreted expanse beneath bridges to connect the road-verge either side.

5.4 Discussion

5.4.1 Experimental design

Species found at the two study sites reflect those frequently found in grassland habitats (Flowerdew 1993, Bellamy *et al.* 2000). Yellow-necked mice and water shrews, uncommon in this habitat type, were also recorded. The abundance of all species tended to fluctuate across the trapping grids and across the trapping periods. Generally, the Alvechurch study sites were more densely and more evenly populated than those at Redditch. Densities of the different species were comparable with the densities reported in a recent UK study of nine separate roadside verges (Bellamy *et al.*2000), but were less than peak population densities in prime habitat (Harris *et al*. 1995).

Wood mice entered traps fairly readily from the first night of trapping onwards regardless of whether the traps were pre-baited, but there was initial resistance by field voles and common shrews to early trap entry; this was reduced by pre-baiting. The high frequency of once-only captures and the low number of high-frequency trap entries suggests that initial trap entry may have provoked trap-avoidance behaviour in some individuals. Generally, 50% or less of the traps were occupied at any one trap round; only very occasionally did occupancy exceed 75% and this was only on one trapping grid. It is unlikely therefore, that the high number of once-only entries was due to of an insufficiency of traps.

The spacing of the traps was designed to accommodate the shorter movements of field voles that tend to be less far-ranging than wood mice and shrews (Gurnell and Langbein 1983). The disadvantage of these short spacing intervals, however, is that it limits the amount of information that can be derived from trap-revealed movement in contrast to normal movements of the animals; this difficulty is compounded by the short trapping periods. The fact that movement and territories all tended to be smaller than those recorded in the literature (see Harris *et al.* 1995) suggests that the calculated distances were compromised by the low number of multiple trap entries and the short trap spacing.

5.4.2 Community structure and the value of road-verges

There are considerable differences between the two main study areas both in character and in the abundance of the different species, but only at the Redditch study area were species numbers significantly different between the four study sites. The obvious character difference between the two study areas was the availability of different habitats, both in adjoining landscape and on the study areas themselves. There were also differences between the Alvechurch and Redditch study areas in terms of the structural diversity of vegetation. Structural diversity is often considered a positive factor because it can accommodate species with a range of habitat preferences, but the study sites at Redditch, where the scrubby, immature woodland area is tall enough to provided a canopy and eliminate ground cover, there was a negative impact on the small mammal community. Even ubiquitous, generalist species such as wood mice rejected the dense mature scrub areas in favour of rough grassland habitat. Conversely, areas that are patchily distributed with young scrub that is insufficiently dense to shade out ground cover, as at Alvechurch, support an abundant community of small mammals. However, differences between the vegetation on the two study areas may only partly explain the differences in small mammal abundance; there is approximately 24% more favourable habitat at Alvechurch than at Redditch when the selection index is used to determine preferred habitat, but there is almost 50% difference in small mammal abundance. Recruitment from neighbouring habitat of a favourable and similar type may account for these differences in abundance. The Alvechurch study area is situated in arable and rough grassland whereas the Redditch study area is located within more of the same type of dense scrubby habitat that was avoided by the small mammal community in this study. There are differences in traffic levels at the two study areas but earlier studies indicate that this does not affect small mammal abundance.

Redditch is the less species diverse study area but it was here that yellow-necked mice, an uncommon species, were found. The study site on which they were trapped eventually joins to a small fragment of mature deciduous woodland. The recorded presence of yellow-necked mice in the Midlands has already been discussed in earlier chapters (chapters 3 and 4). They are thought to be threatened by habitat fragmentation (Bright 1993) and are unusual in habitats isolated from extensive broadleaf woodlands by distances of more than 2km. They are generally considered habitat specialists favouring mature, often semi-natural, deciduous woodland where they have an average density of about 2 *per* ha, and are rarely found away from this habitat (Harris *et al*. 1995, Marsh *et al.*(2001). Those individuals found on the Redditch road-verge may be transients, originating from the neighbouring woodland. This suggests that not only is adjoining landscape an important factor in determining species abundance but it is also important in terms of species diversity. However, the earlier studies within this research also found yellow-necked mice to be abundant at woodland edge ecotones and Montgomery (1978) found yellow-necked mice utilising other marginal habitat. They clearly benefit from habitats other the interior woodland habitat described by Harris *et al.* (1995) but their presence in rough grassland, on the road-verge, was nevertheless unexpected and suggests that even species with exacting habitat requirements can benefit from the landscape heterogeneity provided by wide road-verges.

These findings have clear implications for the management of road-verges. New embankments are generally planted to stabilise the soils and structurally diverse road-verges are considered an important aspect of visual amenity (Department of Transport 1993).

However, the management of these areas has direct repercussions on small mammal communities and therefore indirectly affects predator species. Management needs to be species specific, for often, what benefits one species will penalise another. For instance, tall vegetation at roadsides, which apparently discourages small mammals, has been found to assist birds travelling from one side of the road the other, because the height they gain from flying over these features prevents them from being sucked into the traffic stream by turbulent air currents (Reijnen *et al*. 1997). Consideration of the wider community that may be found in the adjoining landscape matrix is, therefore, an important factor in optimising the potential of the road-verge for small mammals and other fauna.

Species richness was increased at Alvechurch by the occasional presence of uncommon species. The three water shrews trapped at Alvechurch were not considered to be resident. Water shrews are an uncommon species on road-verges with only sporadic appearances there, but their presence has been recorded on other road-side study areas, some of which are quite distant from aquatic habitat (see chapter 4 and also Bellamy *et al.*2000 who recorded water shrew present on the road-verge). Water shrews are believed to be widespread in the UK but existing at low populations levels; they are more mobile than other shrew species (Churchfield 1990, Harris *et al* 1995). Their location at first point of capture, *i.e*. adjacent to the road, their capture rate and their movements between captures, all suggest that the three individuals trapped at Alvechurch were animals moving along the road-verge, temporarily held up by the concreted expanse beneath the road bridge. Although they were not recaptured on the far side of the concreted area beneath the road bridge, it is probable that they were able to successfully negotiate a passage across this inhospitable terrain. If this were the case, two of the individuals would have had the benefit of the installed 'cover' treatment that connected the road verge, one would not. It is also interesting to speculate that, as they all appeared at exactly the same trap round, at the same side of the bridge and had the same body weight, they were, in fact, related family members, all travelling in the same direction. However, they were not all captured on the same side of the road and this means that at least one of them must have crossed the dual carriageway (the bridge at this study area is the only crossing point on this road).

Tew and Mac Donald (1994) found water shrews in hedgerows and suggested that they used linear features in farmland as movement corridors. Road-verges appear to function in a similar fashion and the enclosing features of roads on the one side, and unfavourable habitat on the other, appears to direct movement and enhance the corridor effect as has been suggested by others (Mader 1984, Merriam 1991).

5.4.3 The disturbance arising from traffic.

All the species were patchily distributed across the study area, and there were significant differences in distribution across the five traplines. The clustering that was apparent from trap results indicates that occupancy of certain parts of the study area is resource driven and not a function of the road or vehicular traffic. This is consistent with the earlier findings at the Warwickshire woodland studies. Field voles exercise habitat-specificity and results generated from the Ranges V programme indicate their preference for rough grassland habitat. Wood mice are a generalist species and their more even distribution across the light scrub and grassland habitats reflects their less demanding habitat requirements. Common shrews are prevalent across the Alvechurch study areas but more clustered on the Redditch study areas; they select for areas that are rich in invertebrate prey and, on this basis, are possibly selecting for areas that have a higher level of ground cover and therefore higher humidity levels that would be favoured by invertebrates (Churchfield 1990).

There is a clear attraction for some small mammals to road-adjacent locations at Redditch; this was demonstrated by the significantly greater abundance of animals at trapline one and the significant and positive relationship between species abundance (field voles and common shrews) at locations nearest to the road. It indicates, as did the woodland studies before, that the effects that can be directly attributed to road do not appear to adversely influence small mammals distribution. This is consistent with the findings elsewhere (Garland and Bradley 1984). Unlike the previous studies that featured a woodland/roadside verge interface, there is no pronounced ecotone on the roadside verge. However, there were differences in the vegetation at trapline one, created by the mowing of the sightlines, and this might explain the attraction of animals to the roadside edge. Grass cutting will stimulate new growth that will be attractive to herbivorous field voles and it may positively influence invertebrate richness that would be attractive to common shrews. The fact that mowing of the sightline was a more frequent occurrence at Redditch than at Alvechurch might also explain the stronger attraction to this location at the Redditch study area.

The few water shrews captured in the previous reported and unreported trapping work within this study were also recovered from trapline one. This is important and adds weight to the widely held, but the much debated belief that road-verges act as valuable connecting routes for animals (Andrews 1990, Bieir and Noss 1998, Getz *et al.* 1978, Harris and Scheck 1991, Mann and Plummer 1995, Noss and Beier 2000, Haddad *et al* 2000, Spellerberg and Gaywood 1993, Saunders and Hobbs 1991). The findings also contribute to our knowledge about the value of road-verges *per se* (Bellamy *et al.*2000, Bennett 1988, Bennett 1991a, Garland and Harris 2002, Spellerberg 1998, Spellerberg and Gaywood 1998) and also to our understanding of the distribution and activity of native small mammals for which our knowledge is still incomplete (Harris *et al.* 1995).

5.4.4 Factors contributing to the barrier effect of roads

No animals were recorded as crossing the road during the three trapping periods and the recorded maximum distances moved by individuals precluded such crossings. However, the distances moved by individuals were all less than those recorded elsewhere and the dimensions of the trapping grid and the short distances between grid points, as well as low number of high-frequency multiple captures, are likely to have produced results that underestimate the distances commonly travelled. Wood mice, common shrew and pigmy shrew are all recorded in the literature as having greater mean and maximum distances moved than those recorded here (Harris *et al.* 1995, Wolton and Trowbridge 1985), and these greater distances would have been sufficient to cross the roads. Nevertheless, the distances recorded here were sufficient to traverse the concreted area beneath the bridges, but only eleven individuals did so. Home ranges, illustrated in Appendix F1-F6, show the manner in which the majority of animals avoided movements across this concrete area. Small mammals residing alongside the road generally adopt the road edge as a boundary to their natural home range (Kozel and Fleharty 1979, Bakowski and Kozakiewicz 1988) and it is therefore likely that the home ranges of resident animals on the road-verge will generally be bounded by the similar hostile terrain of concreted areas beneath bridges. Greater numbers of animals crossed the concreted expanse beneath bridges than crossed roads of similar dimensions at other locations (see chapter 3 and 4) but the low numbers and the lack of statistical verification provide only weak support for the hypothesis that traffic density creates a greater barrier to small mammals movement than lack of cover. Indeed, the percentage of animals that actually did cross this area was exceptionally small. This suggests that lack of cover and not traffic is the more important inhibitor of small mammal movement. Thus, these frequent and regular expanses of concrete found throughout the road network may be producing as great a barrier to small mammal movement as traffic-carrying roads themselves.

5.4.5 The reconnection of isolated habitats

The results relating to the effectiveness of the treatments installed to connect the road verge are inconclusive. Cover was installed beneath the bridges between the second and third trap rounds but animals crossed this area on the first trap round (before cover was installed) and they also crossed on the sides of the road that remained untreated. More animals did cross the underpass after treatments had been installed but the numbers are too few for statistical analysis or for reliable conclusions to be drawn. The preference of small mammal for areas with dense ground cover is widely acknowledged (Bolger *et al.*2001, Gurnell and Langbein 1983, Soulé 1997, Southern and Lowe 1968); intuitively, the installation of cover between two disconnected road verges should facilitate small mammal crossing. Modelling studies clearly indicate that any connectivity between isolated patches improves persistence and population size (Henein and Merriam 1990, Meriam 1991), and Szacki *et al.* (1993) provide evidence to show that small mammals move along routes that are covered mainly by weedy species and dense bushes. The shortness of the trapping periods may have contributed to the failure to provide any convincing evidence that these treatments may assist the movement of small mammals. Had it been possible to track animals for longer continuous periods, or by using a more permanent method of marking, or by using radio tracking, more animals may have been found crossing.

5.5 Conclusions

The abundance of animals on the road-verge at these two study areas confirms the value of roadside verges as habitat for small mammals. Species diversity on a road-verge often reflects the species diversity of the surrounding landscape matrix and species richness may occasionally be supplemented by transient species that are using the verge as a linking route between habitats. Community structure and composition is affected by different management protocols however, and structural and vegetational diversity, considered desirable from an aesthetic point of view, may not be compatible with conservation aims for some species. The attractiveness of the roadside habitat, particularly for uncommon species, may require special consideration and needs to be part of an assessment of the surrounding landscape.

There is no evidence to show that small mammals are disturbed by the effects of roads and indeed, because of different management regimes at the roadside edge, areas nearest to the road are frequently favoured.

Road-verges provide a good linking mechanism between habitats and these seem to be utilised by both common and uncommon species, possibly for range expansion or travel between distant habitats. They may fail to fulfil their potential as routes of connectivity, however, because of interruptions to the vegetated road-verge by various highway-related structures. The concreted areas found beneath road bridges fragment the fine-grain habitat of small mammals and restrict directional movement, creating a barrier effect not dissimilar to that of traffic-carrying roads. Intuitively, installation of cover to link road-verges should facilitate crossing of these areas. Unfortunately, the numbers of animals crossing during the study period were insufficient to reliably confirm this assumption.

6 FAUNAL ROAD MORTALITY AND MITIGATION MEASURES FOR THE EFFECTS OF FRAGMENTATION

6.1 Introduction

The effects of the transportation infrastructure on the landscape, its habitats and its associated wildlife are widely acknowledged (see Andrews 1990, Bennett, 1991a, Forman and Alexander 1998, English Nature 1996, Spellerberg 1998) and have been discussed in earlier chapters (see chapters 1-5). The UK government has long recognised the need to protect wildlife and the environment from the detrimental effects of road building and road traffic, and its present commitment to reconcile a safe and efficient transport system with environmental considerations is recorded in the white paper, New Deal For Transport: Better For Everyone (DETR 1998b). The Highways Agency, the network operator for trunk roads in England and Wales, translates this policy in their strategic plan to 'minimising the impact of the trunk road network on both the natural and built environment'. Specifically, they state 'In particular we seek to manage our own estate so as to add to its existing value as a refuge and a linking feature for wildlife' (Highways Agency 1999).

Trunk roads represent only 4% of the UK roads network, but they carry a third of all road traffic and two thirds of freight traffic (Highways Agency 2002a). They have a greater land-take, fragment more of the natural landscape and have traffic that travels at higher speeds than secondary roads. Trunk roads are long distance routes that cut through the landscape. Unlike roads of the secondary system that have their highest concentration in the built environment where wildlife is already severely depleted and where there is little surviving natural or semi-natural habitat, trunk roads and motorways can run through substantial tracts of prime wildlife habitat. The effects of secondary roads are not insignificant, but trunk roads arguably have a greater impact mile for mile than all the other classes of roads.

Wildlife in the UK is protected by a number of statutory instruments including *inter alia*, the Wildlife and Countryside Act (1981) and later amendments, the Conservation (Natural Habitats etc.) Regulations (1994) and the Countryside and Rights of Way Act (2000). Protection is also afforded by key international obligations under the Schedules and Appendices of the Berne Convention on the Conservation of European Wildlife and Natural Habitats (1979), the Ramsar Convention on Wetlands of International Importance Especially as Wildfowl Habitats (1971), the Bonn Convention on the Conservation of Migratory Species of Wild Animals (1979) and the EC Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora (1992) (The Habitats Directive). Following the EC Directive 85/337, environmental impact assessment (EIA) became a statutory requirement in July 1988 for any development that would result in a material change in the use of land; this includes all trunk roads. Where there is no reasonable alternative to a proposed development that will result in loss or damage to a site of conservation importance, the Pan-European Biological and Landscape Diversity Strategy (1994) requires ecological compensation, restoration and re-creation of habitats of conservation interest to mitigate the effects of such development. As a result of domestic and European legislature, greater emphasis is now placed upon the loss and damage to the environment. Consequently, some major road proposals that would have significantly affected areas of conservation value have been abandoned, *e.g.* Oxleas Woods in London, Wytham Woods in Oxfordshire, and Bourne Valley in Dorset, others have been radically modified *e.g.* the M40 motorway in Oxfordshire and the channel tunnel route in Kent. In recent years, the required mitigation and compensation relating to major new roads has been exacting and costly; the A34 Newbury bypass, the M3 at Twyford Down and the

Salisbury Bypass are just some of the many cases, that between them, have cost tens of millions of pounds to recompense for loss and damage to wildlife habitats.

In line with the UK's commitment to the Rio Convention (1992), the Highways Agency has just published its biodiversity action plan (Highways Agency 2002b) for the conservation of specified species that may be affected by highways. A further initiative called 'living bridges' (see Highways Agency 2000), has been developed to investigate and promote measures that will reduce the impact of habitat severance. Such measures will include engineering works to facilitate road crossings by wildlife traversing their home range or moving between habitats (Highways Agency 1999). North America (Canada and the USA) and a number of European countries (France, Switzerland, the Netherlands, Germany) have been actively engaged for some years in constructing purpose-built passages and bridges in an attempt to retain and/or re-establish wildlife connectivity, particularly for large migratory species or for large species that have extensive home ranges. Passageways and bridges have been largely successful when they have been appropriately positioned and are of the appropriate dimensions for the designated species (Veenbaas and Brandjes 1998, Yanes 1994). Three examples of green bridges are given in the UK National State of the Art Report (Highways Agency 2000). The effectiveness of two of these bridges (Figure 6.1) is presently being monitored as part of a separate study funded by the Highways Agency. The first of the bridges is approximately 3-5 metres in width and 20 metres in length and is covered by short turf (in contrast to the rank grass vegetation surrounding the approach to the bridge). The second is a multi-modal bridge, approximately 8 metres in width, which comprises a two-lane road with a grassy vegetated perimeter of approximately one metre, on one side. By comparison, purpose built green bridges that have been constructed in mainland Europe are up to 80 metres wide (Bekker *et al.* 1995 and see Forman and Hersperger 1996). Other measures, introduced to mitigate the detrimental effects of fragmentation on mammals, include passageways to maintain connectivity for deer, and tunnels for badgers, otters and amphibians. These have not been systematically monitored in the UK but studies in the Netherlands (Nieuwenhuizen and van Appledoorn, 1995) show frequent use of passageways by a wide range of large and medium sized mammals.

Figure 6.1 Examples of 'green' bridges across the M40 motorway.

A major effect of habitat fragmentation is the division and isolation of populations into smaller sub-populations, potentially increasing their vulnerability to the long-term risk of extinction. Road fatalities may affect demography and even eliminate local populations of some susceptible species such as badgers, otters, polecat and barn owls (Harris *et al*. 1995). Additionally, there may also be an impact at a community level (English Nature 1996, Penny Anderson Associates 1993), but generally, road-kill has not been found to have a significant effect at the species level (see Forman and Alexander 1998, Spellerberg 1998). Faunal casualties are nevertheless a cause of concern on ethical grounds and as a factor in the reduction of biodiversity; there is also a safety concern for car drivers (Bennett, 1991a, Birks and Kitchener 1999, Forman and Alexander 1998). Oxley (1974), Slater, (1994) and Spellerberg (1998) provide general reviews on roads and wildlife, which include an account of the fatalities inflicted on wildlife by traffic. In the UK, others provide species-specific observations on common taxa (Putman 1997, Clarke *et al.* 1998, Davies *et al.* 1987, Harris *et al*. 1992, Skinner 1991, Reeve and Huijser 1999, Taylor 1994).

There is a variety of mitigation measures available to offset the unacceptable toll on wildlife. Most of these are species-specific and there is no single measure that has been found to be totally effective. Often a series of measures are required to safeguard individual species and sustain connectivity. Tunnels, bridges and underpasses provide a safe alternative route across roads but animals usually need to be funnelled towards these and prevented from accessing the road at other points. Fencing can stop animals wandering onto the roads but, used on its own to stop animals coming into conflict with traffic, fencing can compound the barrier effect of roads (Verboom 1995). Fencing needs to be used in conjunction with an appropriate type of crossing for animals that move through the landscape,. Warning signs for motorists are still the most widely used measure on most roads in the UK despite there being little evidence to show their effectiveness.

6.1.1 Study purpose

The final part of this study investigates the impact of habitat fragmentation on wildlife by recording road-killed animals on the highways network. Also reported here are the results of a monitoring exercise on badger tunnels that were installed beneath the M40 motorway as a measure of mitigation designed to reduce fragmentation. The specific aims of this part of the study are to:

- Assess mortality rates on designated roads to determine common factors for those species most at risk.
- Assess the effectiveness of tunnels in maintaining connecting routeways for badger and other species across an intersecting highway.

6.2 Methods

6.2.1 Count of road-kills

From February to March 1999 a record was kept of all road casualties observed on a defined 60 mile circuit when undertaking other aspects of this research work. The monitored route covered motorways and class A, B and C roads (Figure 6.1). The recording of road-killed animals was incidental to other activities and, as a result, the route was not travelled daily. It is likely therefore, that a proportion of faunal casualties went unrecorded in the intervening periods. The time for which a carcass survives on the road depends on the size of the animal, the type of road, the density of traffic and, to a lesser extent, the presence of scavengers. Carcasses of larger animals *e.g.* badgers and foxes, sometimes remained on the motorway hard shoulder or other undisturbed areas for several weeks, whereas on two-way roads that carried high volumes of traffic, the remains of an animal could be obliterated within a very short period of time. All traces of one dead pheasant, observed on a heavily trafficked road, were totally removed within just 30 mins. The effect of scavengers on the persistence of a carcass is not known, but it is likely to vary according to species and location; rabbits frequently disappeared after just one day. The remains of animals found in habitats adjacent to the road, confirmed that many of these road-traffic victims manage to gain cover after traffic collisions and die away from the road; this too would affect the accuracy of the collected data in the context of the total number of animals killed. The results of this monitoring exercise therefore, do not provide an absolute measure of road-related deaths but rather a relative index of road-kills, categorised by class of road and time of the year.

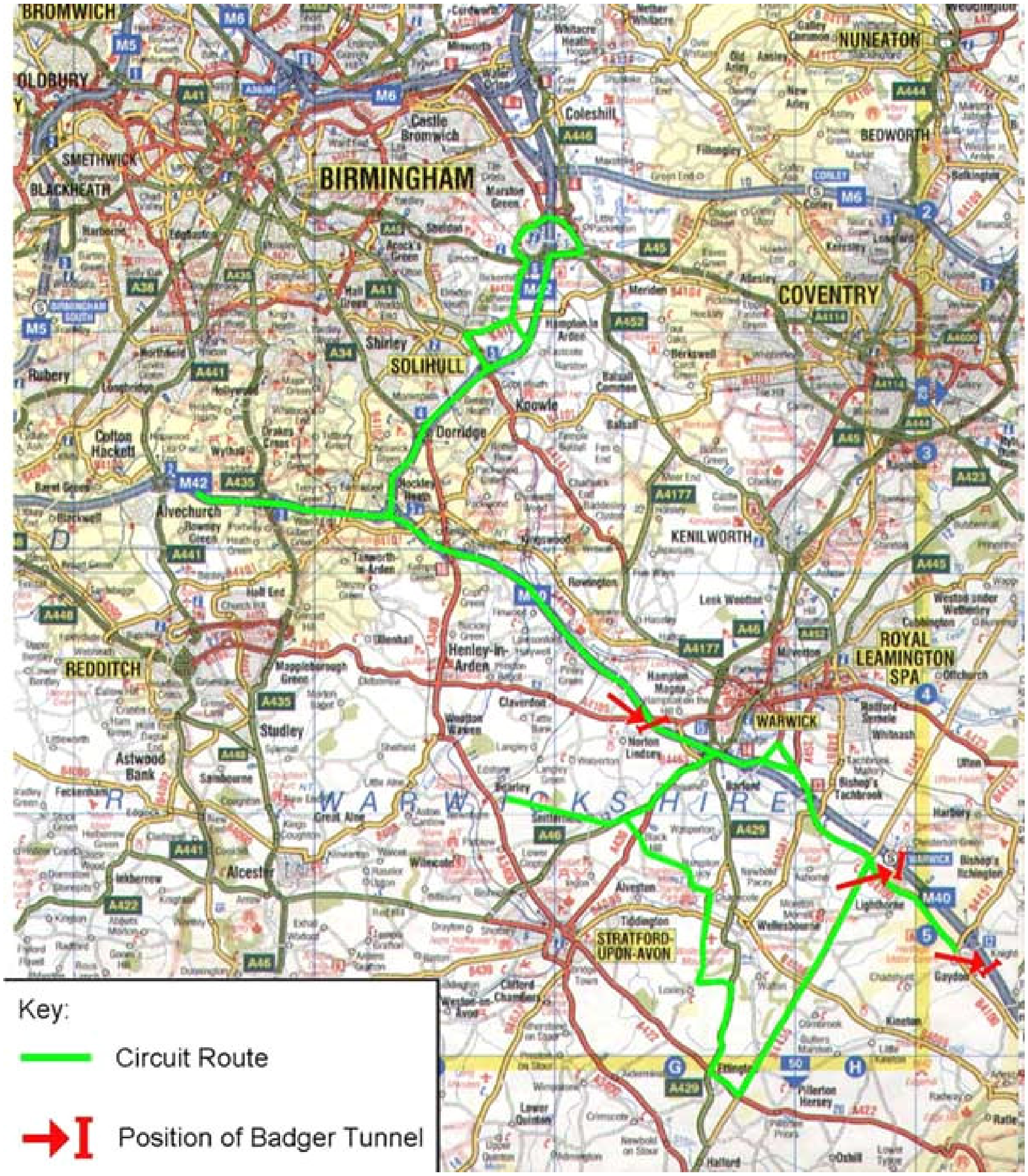


Figure 6.2 A map depicting the 60 mile circular route used when recording animal casualties. The crosses indicate the main part of the route followed. The Bars indicate the approximate site for the badger tunnels that run beneath the M40 motorway

Most of the monitoring was done whilst travelling by car. On roads with little traffic it was possible to travel at low speeds to ensure road-killed animals were not missed. When traffic was heavier, this was not feasible, and it is possible that small animals were missed. Higher speeds also meant that some casualties, especially birds, could not be recorded to species level. At eight field sites where other work was being undertaken the road-verge was inspected on foot for a distance of approximately 200 metres.

6.2.2 Monitoring of badger tunnels

Surveys, undertaken prior to construction of the M40 motorway, indicated 41 separate badger setts within a one kilometre radius of the proposed motorway between Longbridge (junction 15) and Banbury (junction 11) in Warwickshire (Heptinstall, and Blood 1993). The proposed route of the M40 would have severed many of the traditional badger route-ways that linked different parts of their home ranges. Eleven badger tunnels were installed to mitigate these effects. The concrete pipes used for this purpose are of two diameters, 120cm and 60cm. Each of them is about a 100m in length. They traverse the width of the motorway and slightly beyond.

Not all the tunnels were accessible; many were within wired off compounds, and access to the tunnel mouth for investigative purposes was not possible. The tunnels that were selected for monitoring were chosen for their ease and convenience of access (many were considerable distances from the nearest road). Only the larger diameter pipes were chosen for monitoring, as these allowed passage through, and hence inspection of, their entire length. Three of these tunnels were selected as appropriate for the study. Two of the tunnels were straight, and the far side could be seen as a distant circle of light from the entrance point. The third tunnel was curved and there was a shallow gradient to and away from the centre. Each of the tunnel mouths had a shallow lip which helped prevent any ingress of water at the entrances and, with the exception of one or two jointed areas where there was occasionally seepage during long wet periods, the interiors of all of the tunnels remained dry for the duration of the monitoring period. Each of the three badger tunnels was inspected for a minimum of three days each month, between May and October. This provided 23 days of monitoring for each tunnel.

Technical difficulties and resource availability prevented the monitoring of the tunnels by CCTV camera, as had been initially planned. Baited PVC tubing containing an inkpad and paper (Niewenhuizen and van Apledoorn 1995) was tested as a means by which to capture the footprints of small mammals using the tunnels, but in comparison with other mediums it was not successful and its use was discontinued after a short trial. All the data presented here therefore, was obtained from records of footprints and tracks using the method described below.

A bed of fine stone dust, approximately 0.5m in length and 2mm in depth was laid across the width of the tunnel mouth and at both ends of the three tunnels. This medium provided excellent definition, particularly of small prints, but during moist weather, the dust hardened and developed a surface crust that failed to capture the prints. A bed of silver sand, approximately 2 cm deep and one metre in length was therefore laid in addition to the stone dust. During hot weather, prints would lose form in the dry sand but the size of larger prints was sufficient for species identification. The sand and dust was laid before the first day of inspection each month. Following the inspection and recording of prints, the sand and dust recording-pads would be sifted to remove any debris. They were then replenished, as necessary, and smoothed.

There was often only a single set of tracks for large and medium-sized mammals, and in such cases the number of incursions into the tunnel could be assessed with confidence; this was not the case for smaller animals for which there were often innumerable sets of prints. On the occasions when there was considerable small mammal activity, tracks were carefully examined and a best estimate of the number of tracks was recorded. When the tracks of large or medium-sized mammals were found at both ends of the tunnel (indicating travel in the appropriate direction), it was assumed that the animal had made a complete traverse of the passageway but this could not be assumed for small mammals. To overcome this problem and determine the through-passage of small mammals, a sandbed was placed in the centre of the tunnel during the latter part of the monitoring period. Complete passages, *i.e.* from one end of the tunnel to the other, are shown in the results separate to the number of tracks appearing at only one side of the tunnel (incomplete passages).

The location of each of the three tunnels is shown on the map at Figure 6.2. The tunnels all run in an east-west direction. Figure 6.3 show the positioning of one of the tunnels below the motorway, typically enclosed by post and wire fencing. A badger path can be detected leading to the mouth of the tunnel on the second of the two photographs.

6.2.2.1 Tunnel 1

Habitat on the west side of the tunnel is deciduous woodland with a nearby marshy area on a floodplain adjacent to a river. The tunnel entrance on this side of the motorway is enclosed within a fenced but accessible area. There is no shrubby vegetation either within, or at, the perimeter of the fenced enclosure.

Approximately 150 metres north of this badger tunnel there is a wide underpass running

Figure 6.3 The entrance of one of the badger tunnels installed beneath the M40 motorway.

beneath the motorway and connecting the two sides. The underpass is formed by a series of three arches. It was installed to reduce the risk of flooding during prolonged wet weather and high-flow events.

On the east side, the tunnel entrance is situated at the base of an embankment that is part of the soft estate of the motorway. The tunnel exits onto a wide, linear grassland strip that runs alongside the motorway thus forming a vegetated corridor between the motorway and adjacent fenced and hedge-lined rough pasture. An access hole in the fencing leads to rough pasture beyond, but this was wired up when the site was first visited which prevented animals accessing the landscape beyond. There is no scrub at the entrance to the tunnel mouth, but in summer, nettle (*Urtica dioica*) and other rank vegetation grows high enough to obscure the tunnel entrance. There is a mixed woodland plantation 150 metres from the entrance.

6.2.2.2 Tunnel 2

Habitat on the west side of the motorway is managed deciduous woodland. The tunnel mouth is not enclosed or fenced. Shrubby vegetation extends up to the tunnel entrance.

The tunnel on the east side exits to a strip of rough grassland running along the base of an embankment. This grassland strip is separated from an arable field by a hedgerow of hawthorn (*Cratageus monogyna*) and blackthorn (*Prunus spinosa*). Wooden fencing and sheep wire enclose this side of the tunnel. There was no shrubby vegetation within, or around, the perimeter of the fenced enclosure.

6.2.2.3 Tunnel 3

Habitat on the west side of the motorway is mixed. It consists of rough grassland with planted native shrubs, rough pasture and arable fields. Post and wire fencing enclosed the tunnel entrance. There is no shrub vegetation either within, or around, the perimeter of the fenced enclosure. Badgers exited from the enclosed tunnel area by two breaks in the fence, either to farmland, or directly onto the soft estate of the motorway.

Habitat on the east side of the tunnel is semi-improved grassland, used for grazing stock. Post and wire fencing encloses the entrance. There is woodland and scrub within 100 metres of the enclosure but no shrubby vegetation either within, or at, the perimeter of the fenced enclosure on this side.

6.2.3 Data analysis

The tunnel monitoring data was collated but was insufficient for statistical analysis.

The length of the different classes of road on the circuit-route varied. To obtain comparative species data, the mean, per 10 miles of road for each road class, was calculated. The number of days each month for which data was collected also varied, and the mean was again used as the comparative measure. Data were not normally distributed and the Mann-Whitney test was used to investigate monthly differences in the number of road-kills. Kruskal-Wallis was used to explore the effect of road-class on the frequency of species killed, and linear regression was used to explore the relationship between the different road-classes and the frequency of road-kills. For regression analysis, nominal figures were assigned to A, B and C roads to represent average daily traffic-flow. The road-kill data were logarithmically transformed to achieve linearity of residuals along the y-axis (Powers and Xie 2000).

To obtain a general indication of the number of animals killed on roads in the UK, the average figure per 10 miles of road for each species was extrapolated, using the lengths of road for each road class as provided by the Department of Transport, Local Government and the Regions (2001).

6.3 Results

6.3.1 Road-kills

A total of 260 road-kills were recorded during the 52-day study period comprising 24 different species (Table 6.1). Some species were particularly susceptible; fifty percent of all road-kills were rabbits (*n* = 130), many of which were juveniles, and twenty five percent of all road-kills were birds (*n* = 63) including game-birds (pheasant), water-fowl (mallard) and one raptor (kestrel). Of birds that were identified to species level, pheasants were the most frequent casualties (*n* = 18), followed by pigeons (*n* =12). Of the terrestrial mammals, foxes were the most frequent victims (*n* = 17), and they were twice as likely to be killed on the road as badgers (*n* = 9). Hedgehogs also had relatively high casualty rates (*n* = 11). Amphibians were locally distributed and road-kill was attributable to specific times of the year; all the frogs (n = 8) were found on two consecutive days on a road adjacent to a pond and the three newts (common and great crested) were found on just one road, at times corresponding to the breeding season and dispersal.

In addition to the recorded observations, data relating to animals that had been recovered from the M5, M40 and M42 motorways in Warwickshire between April 1998 and March 1999 was supplied by W.S. Atkins, the maintenance and managing agents for motorways in Warwickshire. These are animals reported by members of the public and the Agents are then required to remove the carcasses from the highway. Thirty-four corpses were removed from the motorway during the 12-month period, including 7 dogs, 18 foxes, 4 badgers and 1 deer; others include a sheep, a duck and a goose.

Table 6.1 Absolute and mean number (per 10 mile of road) of road-kills on a 60-mile circuit between February and November 1999

Species		Frequency	Ave per 10 mile	%
Badger		9	1.50	3.46
Fox		17	2.83	6.54
Hedgehog		11	1.83	4.23
Rabbit		130	21.68	50.00
Rodentia		10	1.67	3.85
Roe deer		1	0.17	0.38
Bat		1	0.17	0.38
Mustelid	Polecat	3	0.50	1.15
	Stoat	2	0.33	0.77
	Weasel	1	0.17	0.38
	Mink	1	0.17	0.38
Amphibians	Frog	8	1.33	3.08
	GCN	2	0.33	0.77
	Newt (comm)	1	0.17	0.38
Birds	Bird	17	2.83	6.54
	BlackBird	3	0.50	1.15
	Crow	7	1.17	2.69
	Magpie	3	0.50	1.15
	Mallard	1	0.17	0.38
	Pheasant	13	2.17	5.00
	Pheasant	5	0.83	1.92
	Pigeon	12	2.00	4.62
	Sparrow	1	0.17	0.38
	Kestrel	1	0.17	0.38
	Total	260	43.36	100

September has the greatest mean number of casualties (8.33 $\pm$ 2.51), February the least (1.0 $\pm$ 2.51 respectively) (Table 6.2). However, these average figures are misleading because of the high incidence of road-kills for both rabbits and birds. If rabbits and birds are omitted from the data set, road casualties show a significant increase in the second half of the year (Mann Whitney test: N=4, W=10, p=0.03, two-tailed test) that coincides with the end of the breeding season for many species.

The class of road is indicative of road-width and traffic density. Motorways carry the highest volume of traffic, which travels at higher speeds. They are also considerable wider than the other classes of roads. In terms of, traffic density and clearance, class A roads are generally greater than class B roads which are generally greater than class C roads. Results indicate that the class of road has a bearing on both the number of animals killed and the species involved.

Table 6.2 The distribution of road-kills for different species over the 9 month period from February to March

Date	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Nov	Total	mean	s.d
n days	2	6	5	7	7	6	7	6	6	52	5.78	1.56
Birds	1	10	4	9	10	11	10	7	1	63	7	4
H'hog	0	2	1	1	2	2	2	1	0	11	1.22	0.83
Fox	0	1	0	1	1	3	0	2	9	17	1.89	2.85
Badger	0	4	0	0	0	2	2	0	1	9	1	1.41
Rabbit	1	8	4	24	15	24	19	32	3	130	15.9	10.9
Amphibians	0	8	0	0	1	0	0	2	0	11	1.22	2.64
Mustelid	0	1	0	2	0	1	2	0	1	7	0.78	0.83
Rodentia	0	0	0	0	0	2	3	5	0	10	1.11	1.83
Roe deer	0	0	0	0	0	0	1	0	0	1	0.11	0.33
Bat	0	0	0	0	0	0	0	1	0	1	0.11	0.33
total	2	34	9	37	29	45	39	50	15	260	28.9	16.6
%	0.77	13.1	3.46	14.2	11.2	17.3	15	19.2	5.77	100		
daily mean ave	1	5.67	1.8	5.29	4.14	7.5	5.57	8.33	2.5	5		
sample standard deviation =				2.51								

With the exception of rabbits, terrestrial vertebrates (badger, fox, hedgehog, mustelids and Rodentia) are all killed more frequently on class A and B roads than on class C roads (Figure 6.4 and Table 6.3). In contrast, rabbit, bird and amphibian fatalities were recorded more often on class C roads. There is no significant difference between the A, B and C class roads when all species are included in the analysis (Kruskall-Wallis test: H = 1.15, d.f. = 3, p = 0.764), but when rabbits (60% of all road-kills on class C roads) and other non-terrestrial mammals (birds and amphibians) are omitted from the data set there is a highly significant relationship between road-kill and road-class (y= 0.0427x - 0.028 + traffic, R^2 = 59%, p = 0.004) (Figure 6.5). In contrast to this, there are proportionally fewer animals killed on motorways than on the other classes of roads. There were distinct differences in the results of the two motorways monitored for this exercise (the M40 had a mean average of 32 mortalities per 10 miles whereas the M42 had a average of only 5 mortalities per 10 miles), but neither are consistent with the predictive values obtained from linear regression.

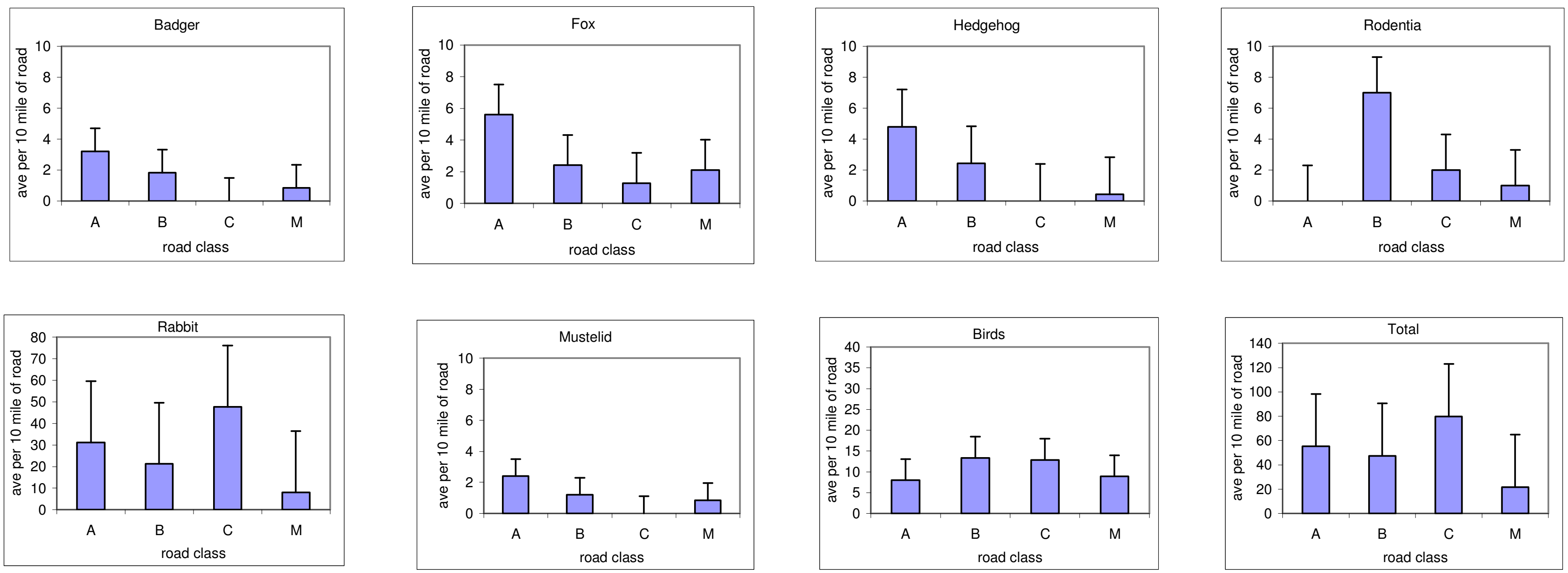
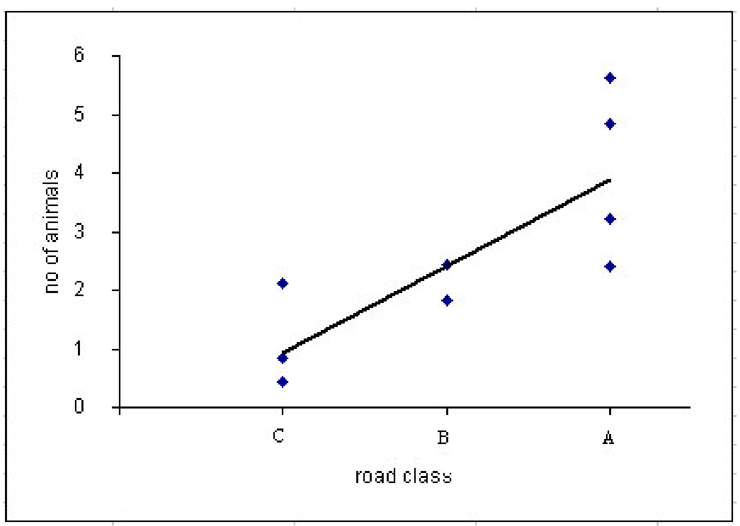


Figure 6.4 A comparison between the mean number of road-kills (per 10 miles) for the four classes of main road, motorways and road classes A, B and C (error bars signify one standard deviation. (NB not all figures are drawn to the same scale)

Table 6.3 The mean number of road-kills (per 10 miles) for the four classes of road A, B and C and motorway (M).

Road class	A	B	C	M	Total	s.d
Badger	3.1	1.9	0.0	0.8	5.9	1.3
Birds	7.7	14.2	12.9	8.9	43.7	3.1
Fox	5.4	2.6	1.3	2.1	11.4	1.8
Amphibians	0.0	0.0	14.2	0.0	14.2	7.1
Hedgehog	4.6	2.6	0.0	0.4	7.6	2.1
Mustelid	2.3	1.3	0.0	0.8	4.4	1.0
Rabbit	30.0	22.6	47.7	8.1	108.3	16.5
Rodentia	0.0	4.5	2.6	0.4	7.5	2.1
Roe deer	0.0	0.6	0.0	0.0	0.6	0.3
Bat	0.0	0.0	1.3	0.0	1.3	0.6
Total	53.1	50.3	79.9	21.6	204.9	23.8
average	5.3	5.0	8.0	2.2	20.5	2.4

Figure 6.5 The relationship between the numbers of road-killed animals for each species per 10 mile of road regressed against the volume of traffic found on class A, B and C roads.



Data for road-killed animals have been extrapolated to give estimates for the number of animals killed on UK roads each year, based on the length of the road for each road class (Department of Transport, London and the Regions, 2001) in the UK (Table 6.4).

Table 6.4 The estimated number of road-kills per annum in England.

Species	UK estimates
Badger	41,952
Birds	379,788
Fox	90,912
Hedgehog	60,490
Rabbit	1,231,688
Polecat	8,165

This UK perspective gives an indication of the size and severity of the problem. Small species have a high probability of being missed when travelling by car and these estimates therefore, have not been calculated. No correction factor has been applied for seasonality, nor has any consideration been factored in to allow for animals that may have died away from the road.

*6.3.2 **Badger Tunnels***

The three selected tunnels installed beneath the M40 motorway were monitored for a total of 23 days over a five-month period (Table 6.5).

Table 6.5 The number of tunnel inspections carried out between May and October at each location.

Month	Inspection frequency
May	6
June	6
July	4
August	4
October	3
Total	23

Six animals were identified to species-level from footprints left in the dust and sandbeds. These included; badger, fox, rabbit, mouse, vole and squirrel but only the commonly occurring larger species are identified separately here. Some footprints were not sufficiently clear to identify to species-level, either because they were obscured by later, superimposed prints or because they failed to register completely in the medium provided. These were allocated to a category of small mammal (mice, voles or shrews) or 'other' (medium sized mammal including mustelids, squirrel, rats). The number of tracks provides an index of activity, however, they do not indicate the number of individuals actually using the tunnels because multiple sets of tracks may be the result of one individual crossing on several occasions or several individuals crossing just once. This is particularly true for smaller animals. Table 6. gives the results of activity at each of the three tunnels.

When the results of all three tunnels are totalled, badgers were the most frequently recorded species, but it is interesting that there was rarely more than one set of badger tracks at any one tunnel, on any one night. Small mammals were the next most frequently recorded animals. Both were recorded as using all the tunnels during each of the recording sessions. Foxes were recorded occasionally at just two of the tunnels, as were rabbits. Badgers generally travelled the entire length of the tunnel, small mammals occasionally travelled through the tunnel, but generally they moved only around the tunnel entrance. Foxes only rarely travelled the full length of the tunnel. A rat (recorded under 'other') also travelled the entire length of one tunnel on several consecutive nights. Rabbits were never recorded as travelling from one end to the other.

Table 6.6 Frequency of tunnel use by the main species for each of three selected tunnels beneath M40 motorway.

The number of complete passages, i.e.where animals were judged to have *travelled through the tunnel, from one end to another*

	badger	fox	rabbit	sm mamm	other	total
Tunnel 1	9	0	0	3	0	12
Tunnel 2	19	0	0	24	5	48
Tunnel 3	25	3	0	0	0	28
Total	53	3	0	27	5	88
mean	17.67	1.00	0.00	9.00	1.67	
s.d.	8.08	1.73	0.00	13.08	2.89	

The number of incomplete passages i.e.where *animals were judged not to have travelled through the tunnel although tracks may have been found at both ends of the tunnel.*

	badger	fox	rabbit	sm mamm	other	total
Tunnel 1	6	2	5	9	1	23
Tunnel 2	3	0	1	25	2	31
Tunnel 3	4	6	1	11	0	22
Total	13	8	7	45	3	76
mean	4.33	2.67	2.33	15.00	1.00	
s.d.	1.53	3.06	2.31	8.72	1.00	

6.3.2.1 Differences in animals activity at the three study sites

Tunnel 1 was the least used tunnel overall. Rabbits were recorded most often at this tunnel but none were recorded as passing through to the opposite end. A fox was also recorded as entering the tunnel but it was again only recorded at one end of the tunnel. However, a short distance from the tunnel, at the underpass running beneath the motorway, there were numerous muntjac and fallow deer prints, as well as occasional fox prints, indicating frequent and regular use of this wider passageway to access habitat on the other side of the motorway.

Tunnel 2 was the tunnel most frequently visited by small mammals and the one where a rat travelled the entire length on several occasions. One end of this tunnel was in deciduous woodland and connected to arable farmland on the other side of the motorway. Footprints of muntjac were found leading to the entrance of this tunnel, prior to the sandbeds being laid, indicating that it had approached the tunnel, but without the sandbed, there is no way of telling whether it entered the tunnel.

Tunnel 3, which connected arable land and grazing pasture, was found to be the most frequently used by badger. It was also the tunnel most frequently used by foxes. It was into this tunnel that badger(s) twice dragged in large amounts of bedding, presumably to create a summer couche above ground. The tunnel became heavily marked with badger spraint and urine.

6.4 Discussion

6.4.1 Mortality rates

The UK landscape is severely fragmented by a dense network of roads that will affect much of the habitat used by different animals. The barrier effect of roads may prevent some animals from crossing but many species will attempt crossings at some time. Those that do so expose themselves to the risk of traffic accidents more often.

Birds are disturbed by traffic and may avoid nesting or feeding adjacent to roads (Reijnen *et al*. 1997, Mead 1997, Dunthorn and Erington 1963) but rarely will they be deterred from crossing roads. The height at which they fly over the road will influence the risk of them being hit by vehicles, for even when there is sufficient clearance between their flight paths and passing traffic, the down-draught and turbulence created by speeding traffic can drag them into the path of oncoming vehicles. The results provided in this study confirm that large, slow flying birds, such as pheasant, are particularly at risk from this effect.

Rabbits are almost ten times more likely to be killed by passing traffic than the next most frequently killed terrestrial mammal (foxes). They are frequently found grazing in large numbers on the roadside verges, particularly at the edge, where road run-off (Angold 1997b) and the mowing of sightlines contribute to the more vigorous growth and re-growth of grasses and forbs. The high numbers of rabbits and this predisposition to graze in areas close to the road edge, is the most likely explanation of the high-level of mortalities.

The estimated fox population in England is roughly the same as for badgers but there are almost twice as many foxes killed on the road as badgers. Foxes generally have larger home-ranges than badgers, up to 250 ha in lowland farm regions compared to 75 ha for badgers,(Morrison 1994), and they are therefore more likely to encounter and cross roads more frequently. This may reasonably account for much of the higher mortality rate for this species but the number of fatalities is likely to be compounded by the propensity of foxes to use roads to move through their territory (as shown by the CCTV footage recorded in chapter 2). The greater amount of time foxes actually spend on roads the greater will be the risk of road-traffic accidents.

Hedgehog casualties were found at a consistent rate of one or two individuals per month throughout the study period, and were recorded most frequently on class A roads. There was no discernible increase in numbers at locations near to habitation as found in other studies (Doncaster 1994, Doncaster *et al.* 2001, Huijser 1999, Reeve and Huijser, 1994), but the results obtained here may be a reflection of the recording-route travelled, which included few residential areas. As with foxes, hedgehogs were found to utilise roads for foraging and for travel (see chapter 2), and this again will considerably increase their exposure and vulnerability to traffic.

Road-traffic accidents are a major cause of death amongst badgers (Neal and Cheeseman 1996). Traffic fatalities account for more deaths than any other single factor (Davies *et al.* 1987, Harris *et al*. 1992). There were fluctuations across the recording period in the number of badger casualties. These fluctuations agree with the bimodal peaks associated with badger mortalities in spring and late summer found in other studies (Davis *et.al* 1987, Skinner *et al* 1991). Badgers need to access different habitats to find their varied food sources and they wander widely each night as a consequence. They are also creatures of habit and they continue to follow traditional routes irrespective of whether these routes cross roads. The frequency of road crossing and their often slow and ambling gait predisposes them to high casualty rates. In this study, an average of three badgers were killed for every 20 miles of road. When these figures are extrapolated, they are similar to the numbers estimated by Neal and Cheeseman (1996) (approximately 37,500 each year) and Harris *et al.* (1992) (approximately 50,000 per year).

Amphibians move to and from their breeding ponds at particular times of the year, usually at night and often in large numbers. Thus, where roads intersect the terrestrial and aquatic habitat of amphibians, whole breeding populations can be subjected to the risk of road-mortality each year when they move to and from their breeding ponds. Fahrig *et al.* (1995) suggests that a decline in viable populations may be a direct effect of road-kill.

6.4.1.1 Seasonal variation

Although the overall figures show a significant increase in traffic victims during the second part of the year and there are variations between species in the monthly records. Some of the disparity between species can be accounted for by differences in breeding and dispersal times. In March, for instance, amphibians are moving back to their aquatic habitat and, where roads sever their routes, many hundreds may be killed on just one night (Department of Environment, Transport and the Regions 2001a). The high mortality rate of badger in spring has been related to an increase in activity at the commencement of the breeding season (Jefferies 1975, Davies *et. al.* 1987). The increase in fox mortality in November coincides with juvenile dispersal between October and January (Lloyd 1977). The steady rise in rabbit mortality through the recording period is a likely consequence of a general population increase from successive litters through the breeding season. The road-kill pattern for late summer and early autumn of rodents, mainly squirrel, is unclear but it may be a result of young animals dispersing to new areas.

6.4.1.2 Variation according to road class

Traffic and road clearance are both factors in the creation of a barrier effect (Bennett 1991a, Oxley 1974, van der Zee *et al.* 1992, van Langevelde and Jaarsma 1995, Verboom 1995 Yanes *et al.* 1995), but the monitoring of all road classes in this study suggests that many species will venture onto roads irrespective of width and traffic volume, a finding that is consistent with other studies (Clarke *et al*. 1998, Slater 1995). The higher level of deaths on class A and B roads indicates the increased risk for animals when crossing roads with greater clearance and with higher volumes of traffic travelling at greater speeds. The speed of traffic and the inability of individuals to clear wide roads quickly are both important factors in the number of animals killed (van Langevelde 1995, Bennett 1991a); motorways are the exception. There are several explanations for the contrasting results of motorways. These include: traffic volumes that deter animals from venturing onto the road; wider motorway verges that facilitate movements of animals parallel to the road and make it unnecessary for them to move onto the road; a traffic-free hard shoulder that may provide a buffer zone for animals that habitually forage at the roadside, and motorway fencing that may prevent many animals actually reaching the road. All these factors apply to every motorway and distinguish motorways from other trunk roads. The reason for differences in the number of faunal casualties between the M40 and the M42 motorway may be because of the proximity of the roads to habitation; the M42 lies in close proximity to the built environment whereas the M40 travels through large areas of farmland and undeveloped areas which have a greater abundance of animals.

6.4.2 Tunnel usage

The need to monitor the tunnels at both ends to distinguish between complete and incomplete through-passages, was recognised at the inception of this project. What became apparent during the course of the exercise, particularly for small mammals, was the additional need to monitor prints and tracks at the centre of the tunnel. Monitoring at only one end of a tunnel is likely to provide misleading results, especially if the number of animal crossings is used as the measure of success for measures of mitigation. Ideally, therefore, when tunnel dimensions permit access, monitoring should also be carried out at the central point of the tunnel.

The literature contains many examples of animals using passageways of different types (Bekker *et al.* 1995, Becker *et al*. 2001 Clevinger and Waltho 2000, Evink *et al.* 1996, Langton 1986a, Langton 1986b, Nieuwenhuizen and van Appeldoorn 1995, Yanes *et al.* 1995). Tunnel dimensions are considered a crucially important factor in the acceptance and subsequent use of, passageways by vertebrates (Norman *et al.* 1998, Yanes *et al* 1995). However, of the passageways investigated as part of this research, most fail to match the dimensions of the tunnels described in the literature. Those in the UK are considerably smaller than many of those used elsewhere. This may render them less effective as a result.

All three tunnels achieved their primary objective in maintaining traditional badger routes between habitats that are now separated by the motorway. The results obtained here show a considerable improvement on results recorded for 10 badger tunnels monitored on behalf of the Highways Agency in 1994 where only one of the ten was deemed to be ‘almost’ successful (almost is not defined) (British Ecological Consultants 1994). The monthly recording visits in this study detected movement through the tunnels on every recording occasion and it confirms the value of the passageways in maintaining connectivity (for badgers). For small mammals, there were relatively few individuals that travelled the entire length of the tunnel, but by comparison to results obtained from earlier trapping studies (chapters 3-5), there were considerably more crossings than recorded in the earlier trapping studies. For most species however, the recorded use of the tunnels as a passageway is low by comparison with studies elsewhere (Niewenhuizen and van Appeldoorn 1995, Bekker, 1995, Bekker 2001).

As noted by Jackson (1999), the monitoring of animals using these structures provides little information about the animals that fail or refuse to use them. The tunnels clearly seem to be avoided by some species. Hedgehogs were never recorded using or even entering the tunnels, possibly because of the odour of badgers (Doncaster 1999). Deer were never recorded in the tunnels, but they made substantial use of an underpass that was larger and shorter, and where there was a natural substratum. Similarly, foxes made more use of the large underpass than they did of the tunnels. These species-specific results are borne out by other studies elsewhere (Forman and Hersperger 1996). Best practice dictates larger wildlife passages (and wider bridges) than those generally utilised in the UK (see Jackson 1999, Yanes *et al.* 1995).

The latest advice note in the Design Manual for Roads and Bridges (Department of Transport, Environment and the Regions, 2001b) provides detailed guidance on the siting, design and supporting arrangements of badger tunnels. It suggests the widening of the tunnel at its entrance, appropriate planting to ‘soften’ the approach to the tunnel, recessed fencing to guide the animals to the structure and fencing erected in a manner to stop them gaining access to the road. The badger tunnels monitored here would benefit from the implementation of these recent guidelines. The absence of some of these peripheral arrangements do not appear to have deterred the use of the tunnels by badgers but it may have inhibited the approach and use by other species. In addition, post-installation checks would ensure the tunnels are ready for use; an absence of any openings in the badger fencing surrounding the badger tunnels revealed by an inspection of the badger tunnels some time after construction (personal communication J. Lewis 1998), prevented use of the tunnels and rendered the mitigation ineffective until the situation was corrected. Also, it is not considered appropriate that the mouth of one of the three inspected tunnels exited onto the unfenced soft estate of the motorway or that the fencing of the enclosing compound failed to prevent badgers accessing the unfenced motorway embankment.

A lack of monitoring is one of the chief complaints made by English Nature in a review of mitigation measures (English Nature 1996a). It is encouraging that the recently updated guidance notes, issued by the Highways Agency, note the requirement for this. Presently, the success or otherwise of many projects, designed to mitigate the damage sustained as a result of development, have yet to be tested.

6.5 Conclusions

Roads take a heavy toll on wildlife, with class A roads exacting the heaviest penalties. Although motorways are wider and have greater volumes of traffic, the greater barrier associated with these highways deters many animals from venturing onto them. Consequently, the fatalities are less than on some other roads. The number of fatalities for larger UK mammals amount to many hundreds of thousands of animals each year. The precise numbers of animals killed each year is unknown but extrapolation of data provides relatively consistent estimates for those species that are most commonly killed on the road. This is an area of conservation concern. It also has implications for human safety. Avoidance of animals on the road by drivers is known to account for the loss of human life (Bekker 2002).

One method of reducing road casualties is to facilitate animal crossings through the provision of safe passageways over or under roads. This has been successful for amphibians (Jackson 1996, Langton 1986b and see Langton 1986a) and the data collected here and elsewhere shows that some vertebrates will adapt readily to tunnels installed beneath motorways. There are benefits for some species, even when usage is limited. Small mammals for instance, did not regularly travel the full length of the tunnels but the number of crossovers to the opposite side of the road is still greater than when the same animals are faced with the prospect of crossing the roads without the facility of a safe passageway. This is an important finding of the study and provides scope for extending the concept of tunnels to other areas where barriers to natural movement exist. Some species however, avoided entering tunnels altogether. Changes to the structural dimensions and their 'supporting arrangements' may improve this, but for the most sensitive species it is unlikely that cosmetic improvements to the exterior of the structures will be sufficient to overcome their natural resistance to enter such small artificial structures. Where it is considered important to maintain connectivity for these species, other types of linking mechanisms need to be considered.

Unfortunately, the difference wildlife tunnels will make to the overall death rate of animals on roads will be negligible. There are too few of these structures to have a significant impact on the number of road-kills and the benefits to be derived from them are likely to accrue almost exclusively to new roads and to a limited number of species. Importantly though, for this limited number of species, these tunnels will moderate the barrier effect of roads, allowing gene-flow across populations and thus reducing the risk of local extinctions for isolated populations.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

The preceding chapters describe a series of investigations into the impacts of roads on wildlife assemblages. Whilst there is an increasing amount of interest in this area, most research has been autecological in its approach and relatively few studies have been conducted in the UK. Autecological work will only elucidate factors applicable to the focal species and may highlight features that have little application to the larger community. Much of the recent research has been undertaken in other European countries and in North America and, whilst general principles apply, the resident faunal communities are quite different from those in the UK. Additionally, the UK road network and traffic-load is generally far more concentrated than in many of these other countries. The importance of this study, therefore, is in its geographical context and the breadth of its approach to wildlife communities. Both large and small terrestrial faunal communities within different habitats and different parts of the landscape matrix have been considered. This chapter synthesises the findings of this research, assesses it in context of findings elsewhere and considers what other information is required and how that may be obtained. It also discusses the prospects for dealing with the adverse impacts that may arise directly or indirectly from roads and highways.

Figure 7.1 shows the manner in which roads affect small and large animals in the UK. Roads directly impact on terrestrial vertebrates by: fragmentation of habitat, fragmentation of populations, isolation of populations and mortality. The indirect effects include alteration in community structure and in the demographic make-up of the population. It is predicted that

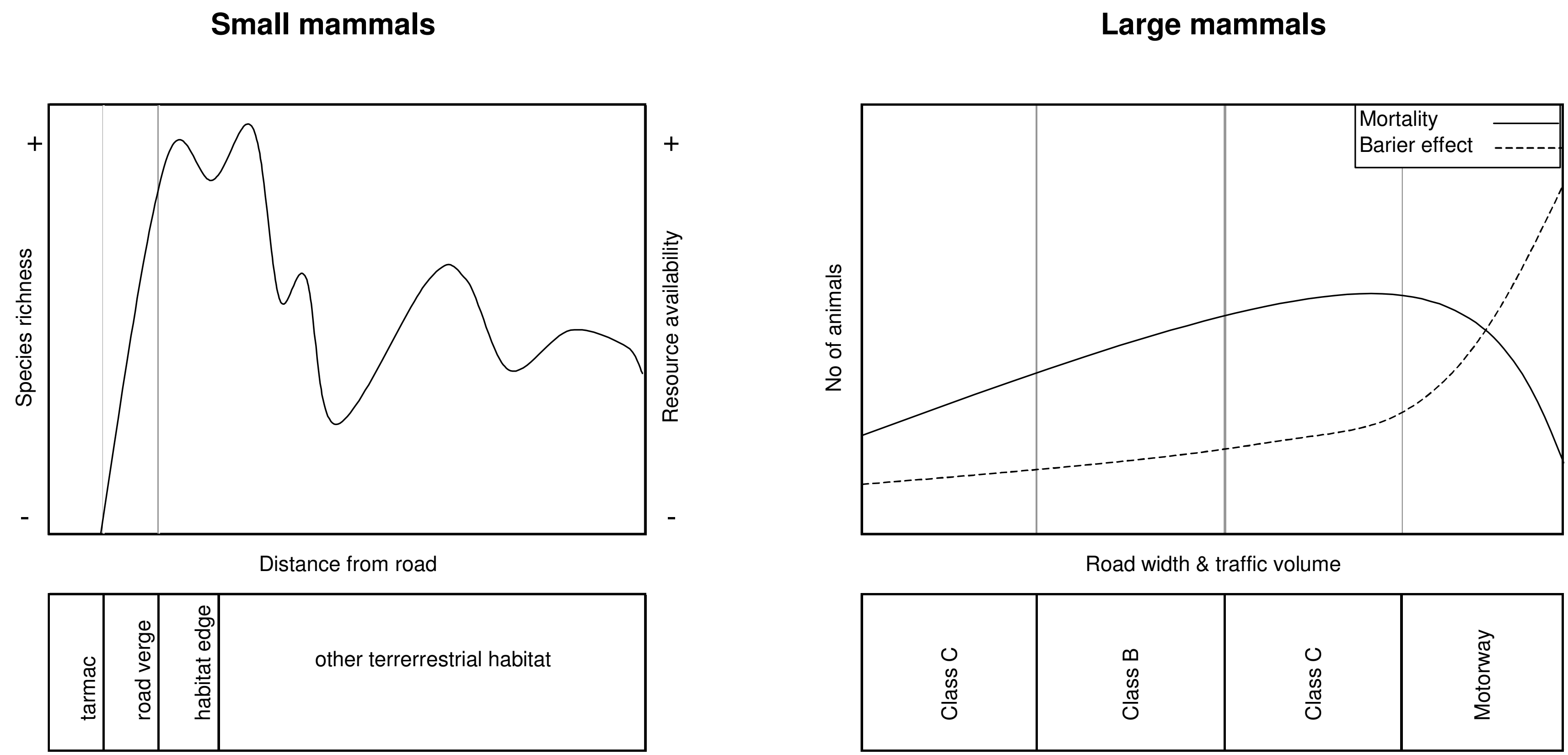


Figure 7.1 Graphical representation of the main effects of roads and their intensity UK mammals

many of the resultant effects of these impacts are not fully realised until many years after the event (Tilman *et al.* 1994). If this is the case, then those responsible for conservation must be alert to the possibility of these consequences and take appropriate action at the earliest opportunity.

7.2 Experimental methods

7.2.1 Larger mammals

The UK has 63 different species of terrestrial wild mammals. Some autecological studies have been undertaken in the UK (Clarke 1998, Philcox 1999, Skinner 1991) and elsewhere, to assess the effects of roads on individual species but there are no known studies in the UK that assess the activity of the range of animals that may be found in habitats adjacent to the road. Various methods have been devised for monitoring of animal activity (see Underhill et al. 1999) but again, the majority of these tend to be appropriate only for a particular focal group (often a single species). Few techniques have been devised and tested as a means of studying faunal communities that comprise a range of species whose size, distribution, behaviour and modes of activity differ. The assortment of larger species commonly found in the UK makes it impossible to devise techniques that fully encapsulate the behaviour and movements of all animals and inevitably, there is an trade-off between the quantity and quality of information that can be acquired from any one method. Pilot studies using two different methods were conducted to find the most effective method for monitoring larger fauna.

In general, roadside sandbeds, which were used to capture the footprints and tracks of animals on the road-verge and in road adjacent habitats, were limited in their application. They provided a guide to presence and absence, as well as information on the levels of activity and the direction of movement of individuals within a finite area. The technique has the advantage of being able to record activity at sites where other methods may be impractical and the comparatively low cost of the method allows a number of sites to be monitored simultaneously. CCTV, on the other hand, provides the same information as sand-bed monitoring for larger mammals, but more importantly, it also captures behavioural detail that significantly enhances the quality of information. It has the disadvantage of requiring an uninterrupted view of the area to be monitored and it is not useful, therefore, for interior locations where the field of view is interrupted. No small mammals were ever recorded by CCTV and accurate identification to species level from video footage would doubtless present difficulties. Finally, the unit cost of the equipment prohibits monitoring several sites at the same time.

7.2.2 Small mammals

Capture-mark-recapture (CMR) and home range estimates, used to monitor the movement and spatial organisation of small mammals have a number of inherent drawbacks (Krebs 1999, Krebs and Boostra 1984, Murray and Fuller 2000, Powell 2000, Southwood and Henderson 2000). Many of the disadvantages of CMR were overcome by careful design of the trapping protocol. Analysis of trappability indicated that a large proportion of animals were captured during the trapping sessions and thus provided satisfactory data on community composition. Between 60% and 80% of wood mice and bank voles made multiple entries at the woodland sites with no significant difference between males and females, or between adults or juveniles, but some species were more trap-prone than others with common shrews being the most likely to enter traps. Generally, the short trapping periods of three to five days, were not capable of providing sufficient data to reliably estimate maximum distances moved or to circumscribe the home ranges of individuals, but the results did allowed comparisons between species during the same trapping sessions. Pre-baiting of traps, which is advised particularly for field voles (Gurnell 1980), reduced latency to first capture for field voles and common shrews but wood mice entered traps freely without pre-baiting. Regulation and localisation of movement arising from CMR techniques was reduced, but not eliminated, by trapping on alternate nights. Overall, the trapping protocols designed for each of the three different small mammal studies, provided results that were satisfactory for statistical analysis of the dominant species, wood mice, bank voles, field voles and common shrews.

7.3 Barrier effect

7.3.1 Larger mammals

Roads and traffic were found to regulate the movement of both large and small mammals but different species displayed different behaviours and different capabilities in crossing roads. Many of the common large and medium-sized species of British fauna, were recorded on the road-verges as well as moving along and across roads. There was no notable reticence on the part of these animals in moving beyond the confines of the adjacent habitat and onto the open road. Even sensitive woodland species, such as roe and fallow deer, appeared unperturbed by the lack of cover at the road-habitat interface although they responded immediately to the sound of approaching traffic. Badgers foraged along narrow road-verges and they were often observed moving along the road. Hedgehogs were similarly recorded. Foxes demonstrated a high degree of familiarity with roads, making considerable use of the road network to move around their territory. Given the highly adaptable nature of this species and the propensity of the 'new-age' fox to live as much in urban as in rural settings, this is perhaps not surprising.

But, although the ways in which animals variously use roads has been frequently referred to in the literature (see reviews by Bennett 1991, Slater 1995, Spellerberg 1998, Underhill and Angold 2000), there is little documented information about the propensity of particular animals to use the road infrastructure as routeways through their territory, or about the persistence and regularity with which they do so. Indeed, Forman and Alexander (1998) suggest that road usage is limited. They state: 'In general, road surfaces, roadsides and adjacent areas are used little as conduits for animal movement along a road'. It is possible that the greater density of roads in the UK precipitates a different response. Other animals, rabbits, squirrel and muntjac, also spent prolonged periods on the road-verges, although all animals are most active in these areas when traffic volumes are low. It is likely that many animals become habituated to the noise and disturbance of passing traffic, just as rats and mice, when tested, become oblivious to various deterrent noises (Sprock, *et al.* 1967). In this study, all the common larger mammals were found moving freely onto the road surface, although they responded quickly to approaching vehicles.

From observations recorded here, it is clear that neither the road surface itself, nor the lack of cover, deters many of the UK's larger mammals from venturing onto the road. On roads with clearances up to 15 metres, none of the medium or large-size mammals showed any reluctance in venturing onto the road but the sound of traffic invariably provoked a response. This suggests that traffic, rather than other factors, is the key component of the barrier effect for larger mammals. Whether this effect continues to be the primary deterrent when wider roads are encountered was not investigated. It may benefit from further study.

Clarke *et al.* (1998) speculate badgers are reluctant to venture onto roads that carry traffic above a certain threshold. It is likely that this applies to other animals also. The findings of the research undertaken here agree with these conclusions. Larger animals were not deterred from crossing roads with a daily traffic volume up to 15,000 cars a day, but if road-kill is used as an index of cross-over rates, there is a dramatic fall in the number of animals crossing the motorways, the busiest of the UK roads. The suggestion that volume of traffic alone is responsible for this effect however, is somewhat misleading. It is more the persistence and density of traffic, rather than the actual number of vehicles, that prevents crossings of roads, and this is where motorways differ from other classes of road. On class A roads, there is a considerable reduction in traffic during the early hours of the morning. These reductions in traffic-flow, coincide with the peak activity of much of the UK fauna and it is at these times that larger animals were recorded as making the majority of incursions onto the road. An important factor in enabling animal crossing therefore, is not so much the amount of traffic *per se,* but the intensity of traffic, particularly at the times of the day when the focal taxon is most active which, for larger mammals, is often at night.

Presently, tunnels installed as measures of mitigation provide a safe crossing mechanism for some species at a few locations. Most tunnels are installed on the primary trunk-road network, but given that most animals are killed on secondary A and B class roads, reductions in road-killed animals could be achieved more effectively, by targeting not the primary road network but the lower classified roads. However, material consideration for mitigation includes not just animal mortality but also the hazard animals present to drivers when they wander onto roads. Mitigation directed at keeping animals off the highways therefore, will be driven as much, if not more, by human safety concerns, as it is by animal welfare needs. Consequently, motorways and dual carriageways will continue to be the primary focus for these measures despite the fact that they account for fewer fatalities than most other classes of roads.

7.3.2 Small mammals

Results obtained from the small mammal studies show that whilst roads present a barrier to small mammal movement, the barrier is not absolute. This is consistent with other documented work (Kozel and Fleharty 1979, Mader 1984, Merriam *et al.* 1991, Oxley *et al*. 1974, Richardson *et al* 1998, Slater 1974). Nevertheless, roads do produce an *almost* impenetrable obstacle. Although all recorded species travelled distances equal to, or greater than the distance required to cross the two-way roads, only five animals out of a total of 1,818 individuals, captured 4,883 times, were recorded as crossing. Even the narrowest of roads with very low traffic volumes were found to have a strong inhibitory effect on directional movement, and crossings by all species of small mammals were rare events. Inter-specific differences in vagility and habitat requirement will influence the effectiveness of dispersal (see Krohne 1997) and some species are likely therefore, to be more resistant to crossing than others. No field voles or shrews were ever recorded as crossing roads at any of the sites, although they did cross the wide intervening concrete section under bridges which fragmented the road-verges of two dual carriageways. Mice made most crossings of roads and also the most frequent crossings of the concrete section under bridges.

7.3.2.1 <u>The barrier effect and the influence of traffic</u>

It has been suggested that traffic is the primary factor responsible for the barrier effect of roads for small mammals (Korn 1991, Oxley *et al.* 1974, Richardson *et al* 1998) but evidence for this is inconclusive. In the study by Richardson *et al*. (1998), roads carrying different volumes of traffic were selected to test the deterrent effect of traffic on small mammals. The animals were translocated to the opposite side of the road and animals returning to their original side were then recorded. The conclusion of their study, that traffic has a significant influence on road crossings, was based on the number of animals returning to the side of the road from which they had been originally captured, but the fate of 47% of translocated individuals at the road sites with the higher traffic volumes, was unknown. This compares with an unknown outcome for only 26% of individuals at the low traffic sites. So, although the number of returning animals was greatest at the sites with less traffic, there was a significantly greater number of 'unknowns' at the high volume sites ($\chi^2 = 6.745$, df = 1, p = 0.009). It is likely that the conclusions of their study would be different if these 'unknowns' crossed the roads.

If traffic is a major deterrent to small mammal road-crossing, it is reasonable to assume that these animals would generally avoid areas closest to the road, but this is not the case. At the study sites investigated in the course of this work, all species of small animals were found in the trapline nearest to the road edge, often at a high or higher abundance than locations furthest from the road. A significant and positive relationship between abundance and roadside locations confirms that for at least two species (bank vole, common shrews and probably yellow-necked mice) there is a preferential selection for roadside habitats. Additionally, if traffic was a principal deterrent to movement across roads, individuals would be expected to move back and forth across roads when traffic is absent, as is the case for larger mammals, but these studies found no evidence of this. On the smallest of roads studied, where there was virtually no traffic between 11:00 hours and 06:00 hours there was no small mammals movement at all across the road. Although there was greater movement across a traffic-free, concreted area than there was on traffic-carrying road, even here, only 11 out of 445 small mammals were recorded as crossing.

7.3.2.2 The barrier effect and the influence of clearance

Oxley *et al.* (1974) postulated that clearance has the most pronounced inhibitory effect on small mammal movement across roads. The difficulty with this argument is that it implies that small mammals are able to gauge the distance they need to travel to reach favourable habitat on the other side of a road and modify their behaviour accordingly. This assumes that small mammals can detect favourable habitat at considerable distances. Evidence to support this is lacking.

Oxley *et al.* (1994) arrived at their conclusions following a trapping study across eight roads, six of which were two lanes wide and two of which were four lanes wide (actual road surface width is not clearly specified). Results show 21 recorded crossings (14 individuals). All crossings took place on the smaller roads and the four-lane highway was never crossed. However, an examination of the data shows that one of the two-lane roads was also avoided and three of the two-lane roads were crossed only once or twice during the 12 – 16 day trapping period. One road accounted for a disproportionate, 71%, of all crossings. This compromises the conclusions that were drawn from their study.

Findings from the studies undertaken as part of this research agree with those of Oxley *et al.* (1974) insofar as they show that narrower roads were crossed more frequently than wider roads. Indeed, there were no crossings at all of the widest, four-lane roads but importantly, there was also an absence of crossing on roads with smaller dimensions, including the narrowest of all surveyed roads (road surface width was approximately 3 metres). Road crossing therefore, seem to be influenced by more than just the clearance between habitats.

One of the difficulties of monitoring small mammal road-crossings is the small numbers that make up any one data set. Clearly, there are inherent dangers in drawing conclusions from such small data sets. The low number of crossing animals in the study undertaken here, in which only 5 animals crossed the road, and in the study undertaken by Oxley *et al.* in which 14 animals crossed the road, makes it difficult to elucidate the principal factors responsible for inhibiting road crossing by small mammals. However, the case for clearance being the major deterrent is yet to be proven.

7.3.2.3 The barrier effect and the influence of cover

That small mammals avoid crossing roads is indisputable, but if traffic only moderates movement to a minor degree and clearance does not provide a satisfactory explanation, some other factor must also contribute to the lack of crossings. Small mammals instinctively seek cover as protection from predation, and voles and shrews typically avoid open areas. Mice are less averse to open areas although they still favour moving along the base of logs and fallen trees rather than across open ground. The fact that mice will cross open ground far more readily than other small mammals however, is consistent with results showing the greater frequency with which mice crossed the open areas of roads. There is no evidence from the series of studies conducted as part of this research to support either traffic volume or road clearance as the predominant factor influencing small mammal movement across roads. Given what is known about the behaviour of small mammals generally, an absence of cover seems to better explain their reluctance to venture onto roads. The hard edge of the road surface probably intensifies this effect. Other factors such as traffic and clearance, may contribute to the barrier effect but the findings of this research indicates that they are less influential than an absence of cover.

7.4 Habitat fragmentation by roads

7.4.1 Larger mammals

The preponderance of road-kills on the higher classes of road attests to the fact that animals frequently cross roads that have high traffic volumes and that these larger animals cross roads with surprising regularity. The barrier effect for many larger fauna therefore, is far from absolute. The persistence of traffic however, does present a formidable barrier, and on highways where there is little easing of the traffic flow, the number of animals traversing the road decreases substantially. The indirect effects of fragmentation on these larger mammals did not form part of this research, but records were kept of the number of animals killed as a result of road accidents.

There were 260 recorded animal fatalities counted on 52 days over a 10 month period, of which 160 were terrestrial vertebrates. This gives an average of one animal corpse every 12 miles. CCTV recordings indicated that animals freely cross roads (up to 15,000 cars a day). Thus, the greater the number of roads within an animal's home territory, the greater will be the number of road crossings. CCTV also provided evidence of many animals using the road as a means of travelling through their territory, thereby increasing the amount of time they spend on roads. The frequency and duration of road contact will inevitably increase the likelihood of vehicular encounters and, therefore, the risk of an animal being killed, with Class A roads generating the highest animal death-toll; a consequence of wider roads and higher traffic speeds.

An extrapolation of the number of foxes, badgers and hedgehogs killed on roads in the UK is similar to those provided by other autecological studies previously undertaken (Clarke *et al.* 1998, Harris and White 1994, Morris 1994). This is important because it indicates the level of confidence that can be placed in the derived estimates. The ranking of these data show that birds are the most frequently killed animal on the roads. Of the terrestrial animals, rabbits are most commonly killed, followed by foxes, hedgehog and badger. As noted elsewhere (English Nature 1996), data collected from roadside observations undoubtedly underestimate, by an unknown order of magnitude, the actual number of animal fatalities arising from traffic accidents because of the many animals that are not killed outright but die away from the road as a result of the injuries sustained. The high level of road casualties is unpalatable from an ethical viewpoint and there is a growing conviction, reported regularly in the media that the human population has a duty of care to its faunal communities not least because it is as a direct result of anthropogenic effects that such large numbers of animals die prematurely. Nevertheless, there is no evidence yet to show that mortalities have any impact at a population level. Consequently, despite the very large numbers of animals killed, they are not, at this time, of known ecological importance. Long-term, however, the prospects may be less good for some species, particularly when the high mortality levels are coupled with other pressures such as habitat loss. In time, it is likely that the combination of these effects will begin to show at the population level.

A commissioned piece of research by the Highways Agency to confirm the impacts of road-kill on various species is presently awaited. Meanwhile, other research is required to determine the most effective methods of reducing the scale of this phenomenon for the range of animals most at risk in the UK.

7.4.2 Small mammals

A different approach was taken in studying the effects of fragmentation on small mammal communities. For small mammals, roads effectively sever habitats and they also fragment populations. The proficiency of roads at filtering dispersal and migration is such that it changes the population make-up, reduces species richness and isolates sub-populations. It can do this to the extent that there is a detectable level of genetic sub-structuring within a population (Gerlach and Musolf 2000, Kozakiewicz 1993, and see Saunders and Hobbs 1991). Fragmentation alters the ecological dynamic and the ecological integrity of a site (Andren 1994, Bolger *et al*. 1997, Wilcox and Murphy 1984). Severed habitats show greater heterogeneity than connected ones and the more isolated a site is, the more dissimilar habitats are likely to become over time (MacArthur and Wilson 1967, Saunders *et al.* 1990). Change to remnant habitats continues to evolve over time and this modifies faunal communities accordingly (see Krohne 1997); more immediate changes are prompted in faunal communities through the fracturing of existing populations and through the loss of connectivity between extant populations. These processes were confirmed by the research undertaken here.

There were highly significant differences in small mammal community structure and species diversity between remote woodland study areas, but equally, there were significant differences in the study sites that were separated just by several metres of road. Differences were also detectable in species richness and species diversity in the study sites either side of the road although these differences were generally not statistically significant. The considerable variability between sites and between remnant populations in the fragmented study areas indicates that roads have an effect on small mammal communities that is disproportionate to the degree of separation.

It is not just roads that create this effect. On the road-verges of the dual carriageway there were differences in small mammal communities where habitat had been interrupted by a concreted section under a road bridge. The vegetation on road-verges of two dual-carriageways which had been created at the same time, planted in the same manner with the same array of species, and had been subjected to the same management regimes, had still developed differently and the small mammal communities responded accordingly. Lack of movement by animals between the severed road-verge sections compounded these differences.

7.5 Corridors and connectivity

7.5.1 Larger mammals

Installation of connecting links between habitats in the building phase of new highways is an indication of the regulating authority's desire to offset some of the worst, and potentially most damaging, effects of roads on wildlife. Badgers are particularly vulnerable to habitat fragmentation because of their faithfulness to traditional routes, regardless of new constructions. The maintenance of their traditional pathways is therefore, considered of particular importance and connections have been retained by artificial means to mitigate the effects of new roads.

The study of badger-tunnels in this research indicates that measures of mitigation for badgers have been effective in maintaining connectivity, but few other species appear to benefit to the same degree; small mammals are possibly the exception. Whilst small mammals did not frequently travel the entire length of the tunnels, they travelled to the other side of the road more frequently when tunnels were available than they did without the benefit of such structures. This is an important finding of the study because highways present an almost impenetrable barrier to small mammals. Use of tunnels to traverse the road network by other species, was noticeable, largely through its absence. Where larger underpasses were available however, a wide range of species, including fallow and muntjac deer, utilised the crossing points. Clearly, structures installed for badgers are useful but they are limited, whereas passageways of larger dimensions facilitate a much broader range of animals. Badger tunnels with smaller dimensions than those monitored here, have been widely installed as a less costly option under many new roads. None of these smaller tunnels were monitored as part of this work, but casual inspections for tracks leading to them suggest they are not utilised to the same degree as the larger tunnels.

7.5.2 Small mammals

There are many empirical studies investigating the effects of habitat fragmentation on small mammal populations and their use as corridors to access different habitats (Bolger *et al.* 1997, Bolger *et al.* 2001, Coffman *et al.*2001, Getz *et al.* 1978, Perault and Lomolin 2000, Szacki 1987, Szacki *et al.* 1993 and others) but the effects have been explored less often in the context of roads (but see Getz et al 1978, Bennett 1990, Downes *et al.* 1997). There have been no UK studies. Fragmentation by linear structures such as roads is arguably more severe because of their indefinite length and the intensity of the barrier effect. Conversely, roads may provide benefits through the provision of the little-disturbed habitat of road-verges, which have the potential to act as a connecting route-way through other unfavourable landscapes.

Seven different species were trapped on just 200m of road-verge in this study. Only two of the British small mammal species, harvest mouse (*Micromys minutus*) and bank vole (*Clethrionomys glareolus*) were absent from the survey data. The diversity of small mammal species captured on the road-verges demonstrates the value of this marginal habitat. Not only are road-verges providing habitat for an array of ubiquitous small mammal species they also provide alternative habitat for less common species. Yellow-necked mice and water shrews are both species of conservation interest whose distribution is patchy and whose present population status is uncertain. Both were captured on the road-verges in studies conducted here.

The value of undisturbed habitat becomes increasingly important in an environment where large tracts of green space are lost to the built-environment and where changes in the manner and the intensity of agricultural practices renders large areas of previously important wildlife habitat, barren. Where local extinctions have occurred through stochastic events, connectivity can be particularly important for the re-establishment of populations through colonisation (Anderson 1970, Burkey 1988, Fahrig and Merriam 1994, Gilbert *et al.* 1998, Brown and Kodric-Brown 1977, Merriam 1991).

Of the five small mammal species that were regularly trapped at woodland sites over a twelve-month period, four of them were absent from at least one of the study sites at some time during the study period. Not surprisingly, absences occurred for species with small populations and they occurred most often in the spring trapping session when populations are generally low. These sub-populations may have gone extinct or may have been reduced to such small numbers that the few remaining individuals escaped capture during these sessions. In every case where one or more species went absent from a site, they were subsequently recorded at a later trapping session. Where species are absent because of localised extinction, re-establishment, can only occur if there is inter-patch connectivity. As sites become more fragmented and more isolated, there is an increasing risk that the populations will fail to recover and extinctions will become more widespread and permanent (Fahrig and Merriam 1985). At the study areas investigated in this work, there was sufficient connectivity for re-establishment but the continuing expansion of the road network makes rescue and recovery less likely, and isolation and local extinction more probable. If local extinctions become more widespread there are then there are implications for the wider population.

Where a small mammal corridor is functioning as a means of dispersal only, it follows that the habitat will often be sub-optimal and it is important therefore, that progress of the dispersing animal is unimpeded. If the progress of individuals along the road-verge is severely hindered, it is possible that they will not survive to reach their new habitat and the corridor will then function as a mortality sink (Pulliam 1988). Several water shrews were found on the road-verges during different parts of this research. Given that aquatic areas are the preferred habitat for this species, their presence at these locations suggests that road-verges are being used as routeways for dispersal through the landscape. For animals, such as the water shrew in Britain, whose present status is uncertain, (Harris *et al* 1995) and for other taxa with limited vagility, it is especially important to facilitate movement along corridors and reduce limitations to successful dispersion.

The potential of road-verges as movement corridors has been long recognised and their value in this respect is often promoted (Bennett 1988, Forman and Godron, 1986, Getz *et al*. 1978, Spellerberg and Gaywood 1993, van Apeldoorn 1995). Interruptions to the continuity of road-verges impair this potential. On the 10,000 kilometres of primary road network in the UK there are over 16,000 bridges and gantries (Highways Agency 2002a); beneath most of the bridges there is a concreted expanse that severs the road-verge. Results from the investigations on dual carriageway road-verges confirm that such areas hinder movement of small mammals. Monitoring of the verge either side of the concreted expanse indicates that the barrier effect imposed on small mammals by these road-verge interruptions is almost equal to that of roads.

Experimental treatments directed at de-fragmenting roadside habitat indicates that the establishment of even narrow linkages might facilitate small mammal movement and preserve road-verge continuity. Other research, where connecting corridors have been created, indicate that an increase in movement can be expected when habitat patches are linked (Bekker *et al.* 1995, Boudjemadi *et al* 1999, Coffman 2001, Ims and Andeassen 1999). There were insufficient data from which to draw reliable conclusions about the success and utility of experimental treatments tried out here, but given the rarity of recorded crossings by small mammals on these untreated areas beneath bridge, the rationale for connecting the fragmented habitat is evident. Whether the treatment itself was wholly appropriate and adequate in terms of material and dimensions, needs to be tested.

Many of the adverse effects of roads are well documented (Bennett 1991, Forman and Alexander 1998, Spellerberg 1998) but there is no recognition in the literature of the deleterious effects that certain highway structures may have on populations residing on the highway verges or on dispersing organisms. Only in Holland, where a very long underpass was built to carry a motorway over a main road, has any similar research been undertaken (Bekker *et al.* 1995). The experimental study carried out on the dual carriageway verges here is the first study of its kind in the UK

7.6 The distribution of animals in relation to the road

Only the distribution of small mammals was investigated as part of this research.

Distribution across a site is rarely homogenous and tends to be governed by the availability and distribution of resources (see for instance, Marsh *et al.* 2001, Wolton and Flowerdew a 1985) but it has been suggested that the disturbance arising from roads can also affect the spatial distribution of individuals in habitats adjacent to roads (Adams and Geis 1983). In this study, no consistent statistically significant patterns of distribution were detected across the sites as a whole, but were there was localised effect at trapline one, the trapline nearest to the road. Bank voles, common shrews and yellow-necked mice all positively selected for this location at the woodland sites. Wood mice, on the other hand, tended to avoid trapline one. The attraction of animals to trapline one suggests there is an edge-effect at the woodland-edge ecotone, displayed by the increased species richness at this boundary zone (see Leopold, 1935, Wiens 1976, Kellerman 1996, Humphrey and Kitchner 1982 for discussion and studies relating the effects of 'edge'). The avoidance of trapline one by wood mice may be a response to the higher levels of competition at the edge, or there may be other resource requirements that are better served by woodland rather than edge habitat. Yellow-necked mice are considered specialist species of interior woodland (Marsh and Harris 2001). Their frequency at trapline one was unexpected and prompts further investigation.

The greater abundance of animals at trapline one was most pronounced on roads with higher volumes of traffic. This is explained by these roads having wider road-verges. It is this increase in habitat type and the corresponding increase in resources that is considered the predominant factor influencing small mammal abundance at this location. Small and large roads therefore, each have respective merits as well as drawbacks. Smaller roads may have fewer interruptions of the road verge and may therefore be more appropriate for dispersing animals, but larger roads offer wider road-verges that can act as habitat as well as having the potential to act as a route of connectivity.

7.7 Summary and recommendations for future work

The research conducted as part of this study has detected some interesting patterns of mammalian behaviour induced by roads. The research deliberately took a broad perspective in an attempt to elucidate some of the critical factors affecting a wide group of species. From this information, more focused work can be undertaken to obtain a detailed understanding of the effects on single species. Research invariably throws up new lines of enquiry and leaves some issues unresolved. To gain a more complete understanding of some of the complexities of road-induced impacts on the behaviour and spatial dynamics of fauna in the UK consideration should be given to further research that extends some of the initial work undertaken as part of this study. Recommendations for further research are as follows:

- There is a need to establish how effectively verges fulfil their potential as connecting habitat and dispersal corridors for small mammals. This can be established by a more intense trapping programme, preferably in late summer/early autumn when small mammals are dispersing from their natal habitat.

- The investigation into the barrier effect of highway-related structures on small mammal movement and dispersal was inconclusive and needs to be pursued. Alongside this, is the need to consider methods for defragmentating road-verges on the existing highways and for appropriate modifications to the design of new constructions that might impinge on small mammal movements. The cost and effectiveness of different treatments should be included in such a study.

- Further investigation is required into the abundance of yellow-necked mice at the woodland / road verge ecotone. Yellow-necked mice have received less attention than most other small mammals in the UK and such work will contribute to our understanding about the behaviour and habitat requirements of this species.

- It was not feasible as part of this study to conduct research on the effects of disturbance from roads on larger mammals. However, it is important to establish this because it will reveal minimum viable areas required for the local persistence of different species.

- A more comprehensive review of the effectiveness of existing connecting structures, such as badger tunnels, is recommended. This should incorporate a larger sample of connecting passageways to validate the pilot study undertaken here. Any new study should include comparisons of the different sized passageways to assess their effectiveness and to establish best practice. These sites are currently being listed (pers. comm. A Sangwine, Highways Agency 2001). When the exercise has been completed, it is recommended that a monitoring and inspection programme of the sites is established to ensure structures are correctly maintained.

A balance between the need for an effective transport network and a sustainable environment is difficult to achieve. The predicted growth of traffic and the expansion of the transport infrastructure can only contribute further to the degradation of conservation interest in the remaining landscape and exert even greater pressures on wildlife. Transport 2010, the 10 Year Plan (Department of Transport, Environment and the Regions 2000), sets out the road-building programme for the UK over the next 10 years. It proposes 100 new bypasses and 360 miles of trunk road and motorway widening at a cost of £21bn.

Currently, there are still relatively few schemes that address the adverse effects of the highway infrastructure on wildlife and even fewer projects that have specifically addressed the particular problems imposed by habitat fragmentation. A number of accounts suggest that the measures of mitigation that have been designed to offset these effects in the UK, have been successful (Penny Anderson Associates 1994,, Highways Agency 2002b), but there are similarly, several accounts that point to the failure of some of these the schemes and to inconsistencies in the consideration of ecological impacts and the applications of relevant guidelines (Byron *et al.* 1999, Chinn *et. al.* 1999, English Nature 1996a, Glendinning and Jain 1997).

In 1996, English Nature (English Nature 1996) reported that the effectiveness of many of the then existing schemes of mitigation had not been assessed, this still seems to be the case. To provide effective mitigation, it is crucial to determine whether measures already implemented have fulfilled expectations; best practice cannot otherwise be determined. A further shortfall of the existing system of habitat linkage is that schemes already in place are only suitable for the limited number of wildlife species that are afforded protection by statute, and mitigation is almost exclusively applied to new or improved roads. Even if effective mitigation is applied to all the new roads specified in the 10-year plan, the number of new constructions will constitute only a minor proportion of the road network in 2010. This leaves animals in fragmented habitats and vulnerable to road-kill, and increasingly so, in most of the UK.

The constraints on wildlife mitigation are financial and suffer from being low in an order of priorities that is driven by the economic imperative of keeping Britain moving. It is hoped that collaborative working, with assemblies such as Infra Eco Network Europe (IENE), will assist in the creation of new and imaginative schemes that will provide holistic and cost-effective approaches to help resolve some of most serious impacts of the highway infrastructure. Presently the UK lags behind a number of its European neighbours who have already established a number of major civil engineering works aimed at 'defragmentation' of the landscape, but the recently published Highway's Agency Biodiversity Action Plan (HABAP) (Highways Agency 2002b) may be the precursor to change. This document recognises both the negative impacts of the road network and the potential the network has as a contributor to the achievement of the UK's biodiversity targets. Specific targets have been set to improve the current situation, including the need for surveys to record the ecological status of the soft estate. Crossing links to maintain connectivity are also recommended where new roads fragment the known habitat of susceptible designated species (water vole habitat is curiously not included for this treatment). The aim of identifying ‘mortality’ hotspots as a first step towards retrofitting existing roads is also a positive step towards ameliorating some of adverse impacts of the existing network. HABAP could be instrumental in reducing some of the worst effects of habitat fragmentation but implementation will require a large financial commitment from Government that has been notably absent in the past. A balance between the need for an effective transport network and a sustainable environment is difficult to achieve. The financial resources made available to develop, install and monitor measures that can effectively mitigate the impacts of the highways infrastructure will be a true test of the Government’s commitment to sustainability.

APPENDIX

Appendix A. The status of common terrestrial animals in the UK

Appendix A The status of common terrestrial animals in the UK and the perceived threats to their populations. (from Harris *et al*, 1995). Particularly note has been made where these threats are derived from roads and traffic. Small mammals (mice, field and bank vole and shrews) are not included.

Generic name	Scientific name	UK status	Threats
Badger	Meles meles	Generally increasing but some local decline	Road kill, habitat fragmentation, fragmentation of populations due to developments incl. roads
Brown hare	Lepus europaeus	Declining	Habitat loss and habitat change. Changes in agricultural ecosystem
Fallow deer	Dama daa	Stable	Road kill,
Grey squirrel	Sciurus carlinesisi	Increasing	None
Common dormouse	Muscardinus avellanarius	Continuing decline	Habitat loss and habitat fragmentation
Hedgehog	Erinaceus europaeus	Widespread Declining?	Road kill. Habitat loss and habitat change. Change to arable farming, hedgerow removal
Mink	Mustela vison	Increasing	Disease
Muntjac	Muntiacus reevesi	Increasing rapidly	Road kill. Juvenile mortality and predation
Otter	Lutra lutra	Local Recovering	Road kill, pollution, reduced fish stocks
Polecat	Mustela putorius	Locally common Increasing	Road kill. Habitat fragmentation and habitat loss, agricultural improvements and changes.
Rabbit	Oryctolagus cuniculus	increasing	Introduced disease
Red fox	Vulpes vulpes	Widespread Increasing	Road kill. Culling
Red Squirrel	Sciurus vulgaris	Steady decline	Habitat change and habitat loss. Competitive exclusion
Roe deer	Capreolus capreolus	Increasing Common	None known
Stoat	Mustela erminea	Continuing decline	Unknown, possible loss prey species which could be linked to habitat loss and fragmentation
Water vole	Arvicola terestris	Declining	Habitat loss. Habitat and population fragmentation.
Weasel	Mustela nivalis	Widespread Continued decline	Unknown, possible loss of prey species which could be linked to habitat loss and fragmentation

Appendix B. Attributes of the Warwickshire woodland sites

<u>Appendix B</u>. The attributes of the eight Warwickshire woodlands where sandbed monitoring sites were located

	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	2.3m	4.3m	8.3m	4.0m	1.7m	5.0m	4.0m	7.0m
Distance between woodland edges either side of the road (clearance)	7.8m	10.2m	41.1m	36.8m	7.0m	19.4m	11.4m	14.4m
Woodland dominants plant species	*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 plant species	*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* *Anthrycus sylvestris* *Chamerion angustifolium* *Valerian*	*Dactylis glomerata* *Heracleum sphondylium* *Festuca rubra* *Geum urbanum*	*Heracleum sphondylium* *Athryscus sylvestris* *Urtica dioica* *Rannunaculus repens* *Rumex obtusifolius*
Ave number of vehicles per 24 hours.	3300	3000	125,000	125,000	1500	1480	13600	8500

Appendix C. CCTV recording dates

Appendix C **CCTV recording dates showing period of simultaneous recording at different sites**

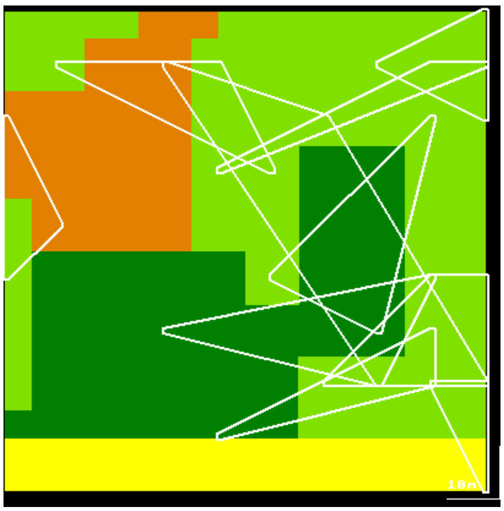
Period	Date	Loxley	Wellesborne	Oakley	Wiggerland
	17-Mar			■	
17-31 Mar	18-Mar			■	
	19-Mar			■	
	20-Mar			■	
	21-Mar			■	
	22-Mar			■	
	23-Mar			■	
	24-Mar			■	
	25-Mar			■	
	26-Mar				
	27-Mar				
	28-Mar				
	29-Mar				
	30-Mar			■	
	31-Mar			■	
	01-Apr			■	
1-15 April	02-Apr				■
	03-Apr				
	04-Apr			■	
	05-Apr				
	06-Apr				
	07-Apr			■	■
	08-Apr			■	
	09-Apr			■	
	10-Apr			■	■
	11-Apr			■	■
	12-Apr			■	
	13-Apr				■
	14-Apr			■	
	07-May				
	08-May				■
8-31 May	09-May				■
	10-May				■
	11-May				
	12-May				■
	13-May				■
	14-May				■
	15-May				■
	16-May				■
	17-May				■
	18-May				■
	19-May				■
	20-May				
	21-May				■
	22-May				■
	23-May				■
	24-May		■		
	25-May				
	26-May		■		
	27-May		■		
	28-May				
	29-May		■		
	30-May	■			
	31-May				
	01-Jun	■			
1-29 June	02-Jun		■		
	03-Jun	■			
	04-Jun	■			
	05-Jun	■			
	06-Jun	■			
	07-Jun	■			
	08-Jun	■			
	09-Jun		■		
	10-Jun	■	■		
	11-Jun	■	■		
	12-Jun	■	■		
	13-Jun	■	■		
	14-Jun	■			
	15-Jun	■			
	16-Jun	■			
	17-Jun				
	18-Jun	■			
	19-Jun	■	■		
	20-Jun		■		
	21-Jun		■		
	22-Jun	■			
	23-Jun	■	■		
Total days		**20**	**14**	**20**	**20**

Appendix D. Home range boundaries at Chaddesley Wood.

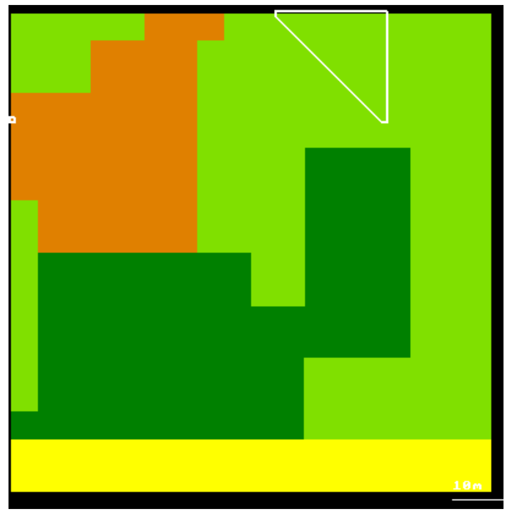
Appendix D1 Home range boundaries at Chaddesley A for wood mice as defined by minimum convex polygons. Separate figures are given for males and females and adults and juveniles.

Side A

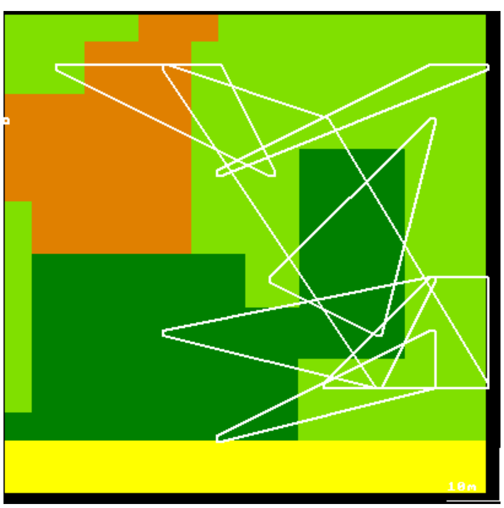
wood mouse - adults



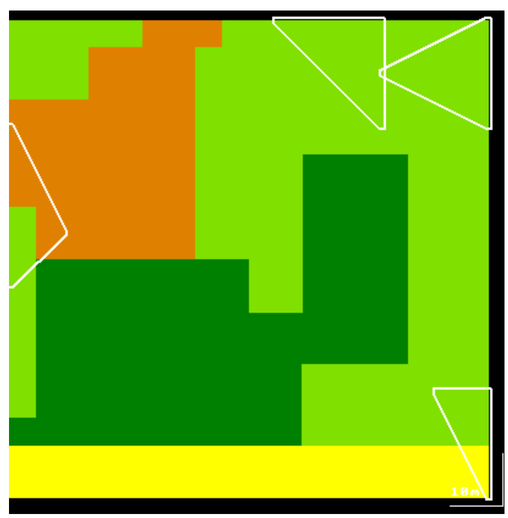
wood mouse – juvenile



wood mouse - male



wood mouse - female



Key:

Roadside, edge habitat

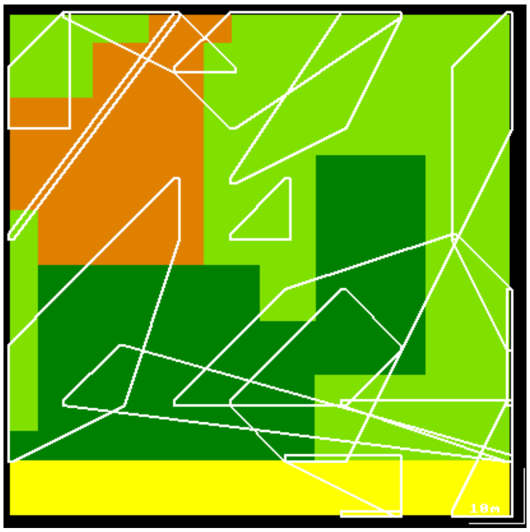
Dense ground cover

Sparse ground cover

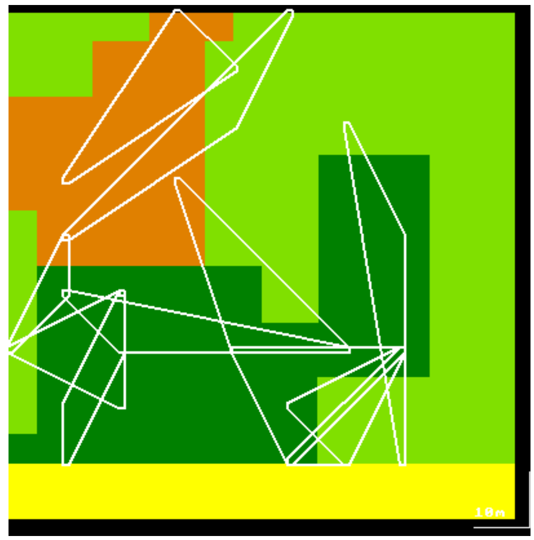
Bare ground, beneath coppice

<u>Appendix D2</u> Home range boundaries at Chaddesley A for bank voles as defined by minimum convex polygons. Separate figures are given for males and females and adults and juveniles.

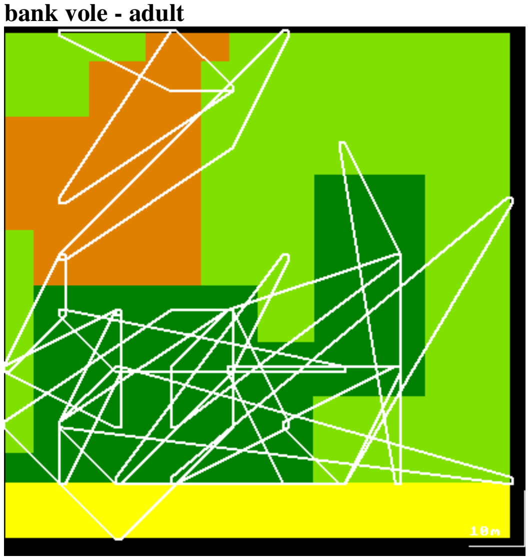
Side A



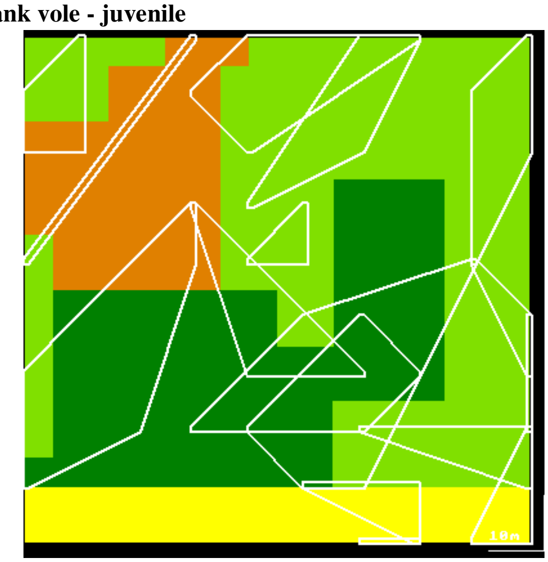
bank vole - adult



bank vole - juvenile



bank vole - male



bank vole - female

Key:

Roadside, edge habitat

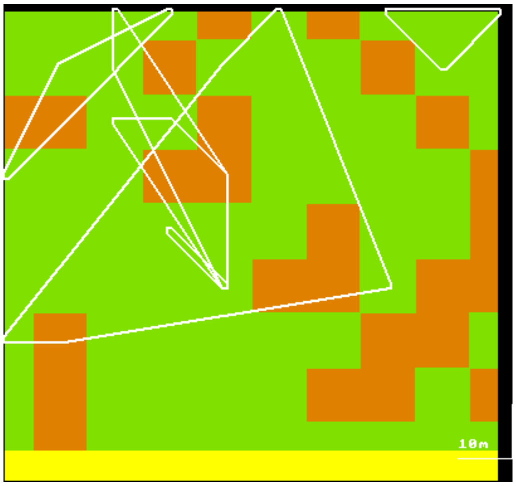
Dense ground cover

Sparse ground cover

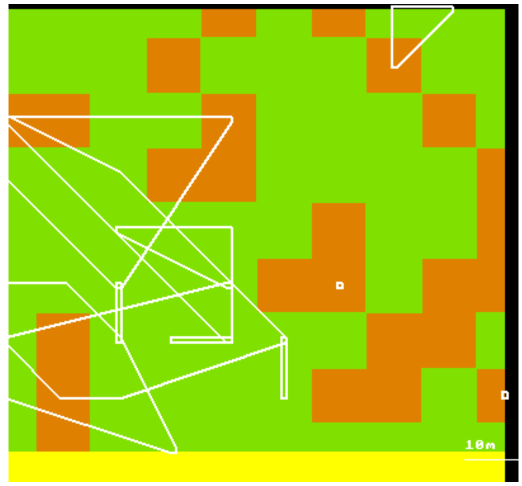
Bare ground, beneath coppice

Appendix D3 Home range boundaries at Chaddesley B for wood mice as defined by minimum convex polygons. Separate figures are given for males and females and adults and juveniles.

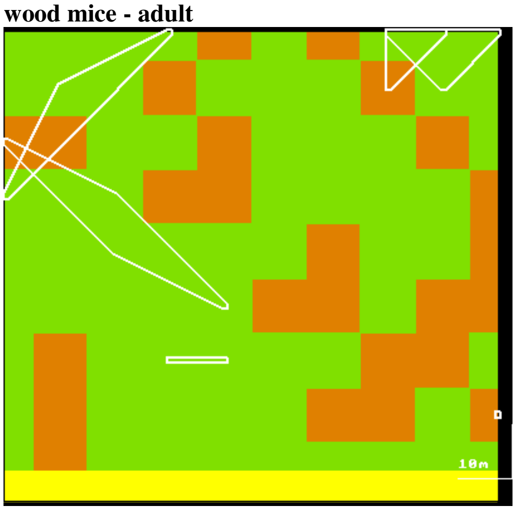
Side B



wood mice - adult



wood mice - juvenile



wood mice – male

wood mouse - female

Key:

Roadside, edge habitat

Dense ground cover

Sparse ground cover

Bare ground, beneath coppice

(There were insufficient bank voles for the ranges to be calculated)

Appendix E. Capture details of the Redditch and Alvechurch study sites.

<u>Appendix E1</u> The number of individuals (common species) captured at the Redditch and Alvechurch dual carriageway study sites

		field voles								wood mice								common shrew							
Month	Trap Grid Night	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4
June	1	1	1	3	3	0	2	1	1	2	0	1	0	3	2	0	2	0	0	1	2	1	1	0	2
	2	2	1	2	2	2	1	3	0	0	0	1	1	0	0	1	0	3	2	4	1	0	1	0	1
	3	4	2	0	2	2	0	1	1	1	2	0	1	0	0	0	2	0	2	2	1	0	1	0	0
	4	2	0	0	1	3	0	4	1	1	0	1	2	0	0	0	0	0	1	2	2	0	1	0	0
	5	1	3	2	0	1	1	0	0	0	0	0	0	0	0	0	2	1	1	3	2	0	0	1	0
	Total	10	7	7	8	8	4	9	3	4	2	3	4	3	2	1	6	4	6	12	8	1	4	1	3
	% Site	31	22	22	25	25	13	28	9	13	6	9	13	9	6	3	19	13	19	38	25	3	13	3	9
Month	Trap Grid Night	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4
July	1	4	2	0	2	5	2	3	5	2	0	0	1	0	1	1	2	4	8	3	5	0	4	2	2
	2	2	5	1	1	0	2	1	2	0	0	1	4	1	1	1	2	3	2	1	3	0	4	0	1
	3	0	0	1	1	0	0	1	0	1	0	0	1	0	1	1	0	2	1	3	0	0	0	2	1
	4	0	1	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	2	0	0	0	0	0
	5	2	1	1	0	3	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0
	Total	8	9	4	4	8	4	6	7	3	0	1	6	2	4	3	4	11	11	9	9	0	8	4	4
	% Site	32	36	16	16	32	16	24	28	12	0	4	24	8	16	12	16	44	44	36	36	0	32	16	16
Month	Trap Grid Night	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4
August	1	19	8	0	12	0	4	6	10	4	1	2	2	1	1	3	2	6	7	2	5	0	3	2	1
	2	3	2	0	1	0	1	1	5	0	1	1	2	0	2	0	4	2	0	0	0	0	2	1	1
	3	0	0	0	0	1	2	0	0	0	0	1	1	1	0	0	2	0	0	0	0	0	0	0	0
	4	1	0	0	2	0	0	1	0	0	0	2	0	0	0	0	1	0	0	0	1	0	1	0	0
	5	0	0	0	0	4	0	0	0	0	0	1	2	0	0	0	0	0	1	1	1	1	0	0	0
	Total	23	10	0	15	5	7	8	15	4	2	7	7	2	3	3	9	8	8	3	7	1	6	3	2
	% Site	48	21	0	31	10	15	17	31	8	4	15	15	4	6	6	19	17	17	6	15	2	13	6	4

<u>Appendix E2</u> The total number of captures (captures and recaptures) for the three common species at the Alvechurch and Redditch study sites

		field voles								wood mice								common shrew							
Month	Trap Grid Night	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4
June	1	2	2	3	6	0	9	1	7	7	0	4	0	8	11	0	10	0	0	3	17	1	8	0	10
	2	2	4	8	8	8	1	6	0	0	0	4	2	0	0	5	0	9	12	19	1	0	1	0	2
	3	7	2	0	6	5	0	4	2	3	5	0	2	0	0	0	4	0	6	7	1	0	4	0	0
	4	4	0	0	2	4	0	7	3	1	0	1	3	0	0	0	0	0	3	6	2	0	1	0	0
	5	1	3	2	0	1	1	0	0	0	0	0	0	0	0	0	2	1	1	3	3	0	0	1	0
	Total	16	11	13	22	18	11	18	12	11	5	9	7	8	11	5	16	10	22	38	24	1	14	1	12
	% Site	50	34	41	69	56	34	56	38	34	16	28	22	25	34	16	50	31	69	119	75	3	44	3	38

Month	Trap Grid Night	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4
July	1	14	5	0	4	12	2	9	10	6	0	0	2	0	5	1	2	27	45	15	19	0	27	9	13
	2	4	7	5	1	0	2	3	13	0	0	1	10	1	1	5	5	9	5	1	7	0	6	0	1
	3	0	0	1	2	0	0	2	0	1	0	0	5	0	2	3	0	3	1	4	0	0	0	5	2
	4	0	1	2	0	0	0	2	0	0	0	0	0	1	3	0	0	0	0	5	0	0	0	0	0
	5	2	1	2	0	4	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0
	Total	20	14	10	7	16	4	16	23	7	0	1	17	2	11	9	7	41	51	25	27	0	33	14	16
	% Site	80	56	40	28	64	16	64	92	28	0	4	68	8	44	36	28	164	204	100	108	0	132	56	64

Month	Trap Grid Night	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4
August	1	57	39	0	41	0	12	15	22	10	5	13	7	1	2	9	6	28	44	13	17	0	18	5	7
	2	6	3	0	1	0	3	1	17	0	2	2	7	0	2	0	8	8	0	0	0	0	3	2	5
	3	0	0	0	0	3	3	0	0	0	0	2	1	2	0	0	3	0	0	0	0	0	0	0	0
	4	2	0	0	2	0	0	2	0	0	0	2	0	0	0	0	1	0	0	0	1	0	1	0	0
	5	0	0	0	0	4	0	0	0	0	0	1	2	0	0	0	0	0	1	1	2	1	0	0	0
	Total	65	42	0	44	7	18	18	39	10	7	20	17	3	4	9	18	36	45	14	20	1	22	7	12
	% Site	135	88	0	92	15	38	38	81	21	15	42	35	6	8	19	38	75	94	29	42	2	46	15	25

<u>Appendix E3</u> The number of individuals (uncommon species) captured at the Redditch and Alvechurch dual carriageway study sites

Month	Trap Grid Night	pigmy shrew A1	A2	A3	A4	R1	R2	R3	R4	yellow-necked mouse A1	A2	A3	A4	R1	R2	R3	R4	water shrew A1	A2	A3	A4	R1	R2	R3	R4
June	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
	2	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	1	0	2	3	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
	% Site	17	0	33	50	0	0	0	0	0	0	0	0	67	0	0	0	0	0	0	0	0	0	0	0

Month	Trap Grid Night	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4
July	1	1	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	1	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Total	2	0	5	7	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	% Site	14	0	36	50	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0

Month	Trap Grid Night	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4
August	1	0	0	4	1	1	1	1	4	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0
	2	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	0	0	6	3	0	0	1	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0
	% Site	0	0	67	33	0	0	11	0	0	0	0	0	0	0	0	0	0	11	22	0	0	0	0	0

.

Appendix E4 **The total number of captures (captures and recaptures) for the three uncommon species at the Alvechurch and Redditch study sites**

		pigmy shrew								yellow-necked mouse								water shrew							
Month	Trap Grid Night	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4
June	1	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0
	2	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	2	0	2	5	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0
	% Site	22	0	22	56	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0

Month	Trap Grid Night	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4
July	1	5	0	11	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	3	0	6	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Total	8	0	17	21	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	% Site	17	0	37	46	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0

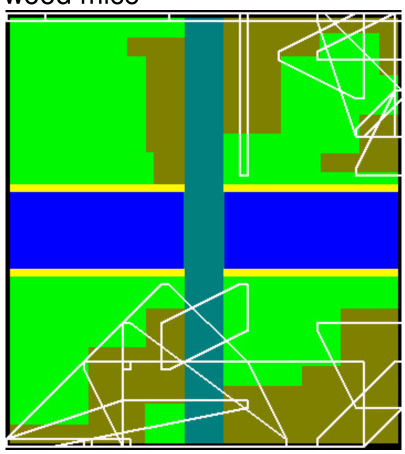
Month	Trap Grid Night	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4	A1	A2	A3	A4	R1	R2	R3	R4
August	1	0	0	5	3	0	0	1	0	0	0	0	0	0	0	0	0	0	1	5	0	0	0	0	0
	2	0	0	5	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Total	0	0	7	3	0	0	0	0	0	0	0	0	1	0	0	0	0	1	5	0	0	0	0	0
	% Site	0	0	70	30	0	0	0	0	0	0	0	0	100	0	0	0	0	17	83	0	0	0	0	0

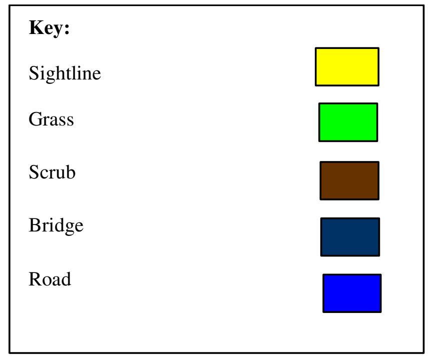
Appendix F. Home range boundaries at Alvechurch and Redditch study sites.

Appendix F1 Home range boundaries for wood mice at Alvechurch study sites as defined by minimum convex polygons. Separate figures are given for males and females and adults and juveniles

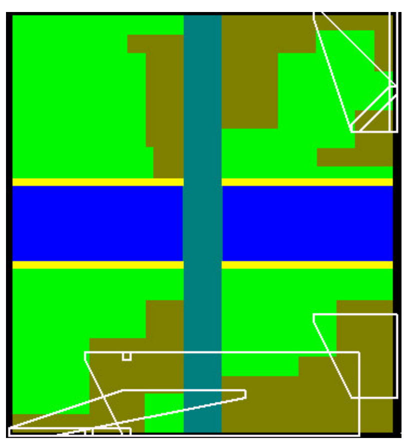
Alvechurch Wood mice

All wood mice

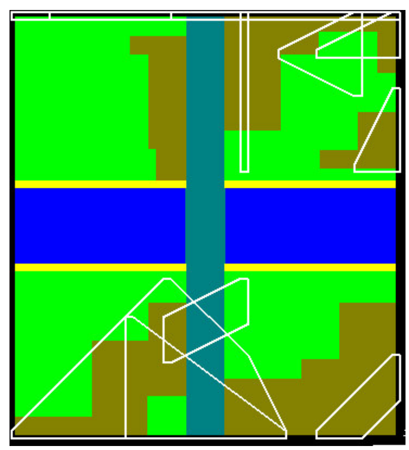




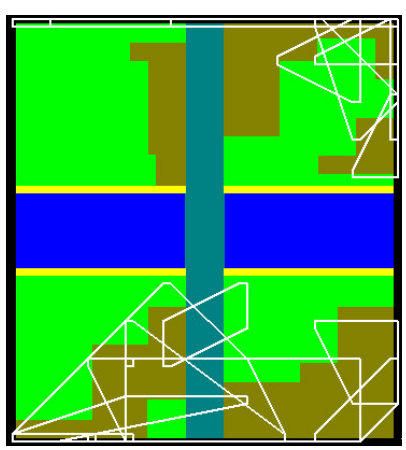
Male wood mice



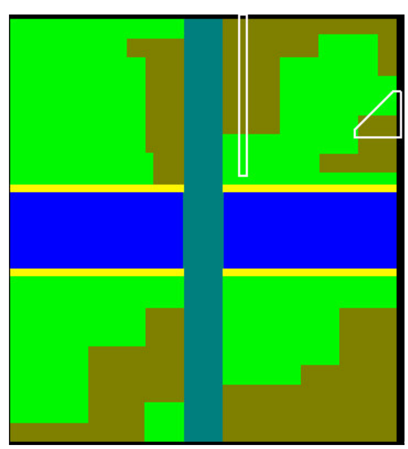
Female wood mice



Adult wood mice

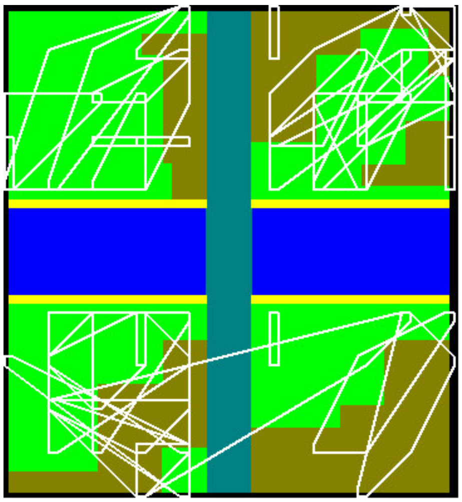


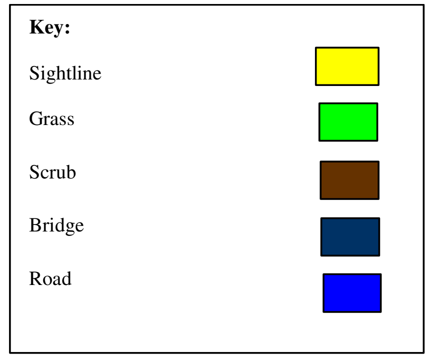
Juvenile wood mice



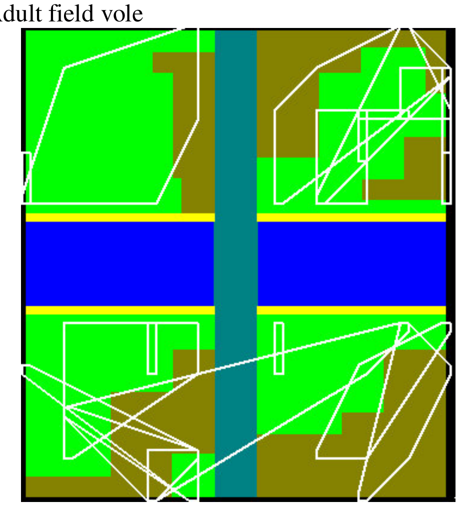
Apendix F2 Home range boundaries for field voles at Alvechurch study sites as defined by minimum convex polygons. Separate figures are given for males and females and adults and juveniles

All field voles

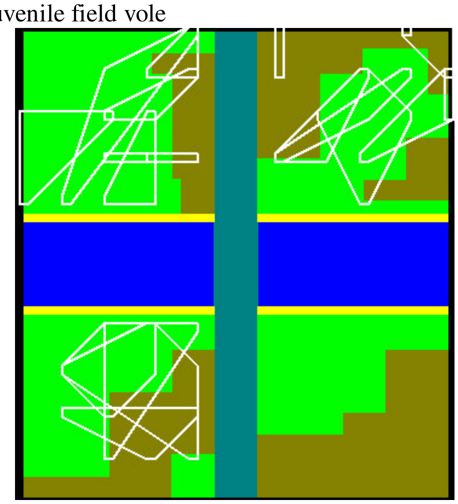




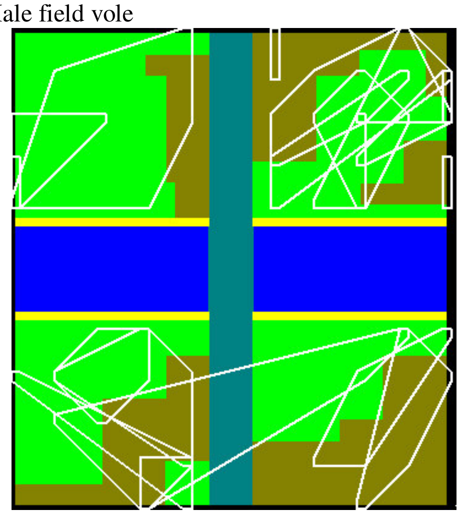
Adult field vole



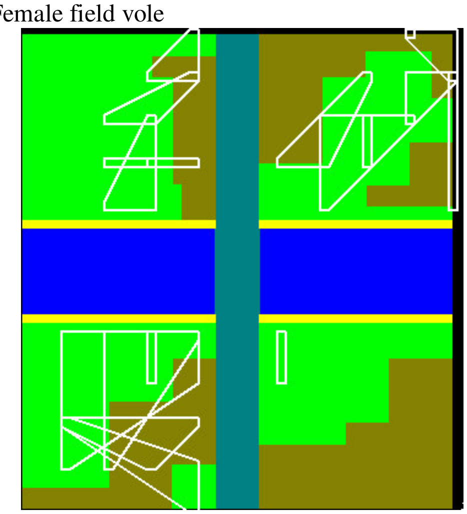
Juvenile field vole



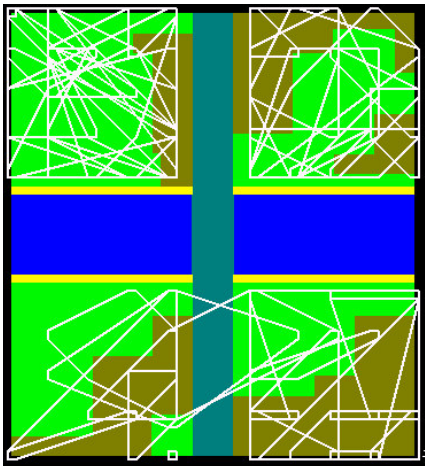
Male field vole

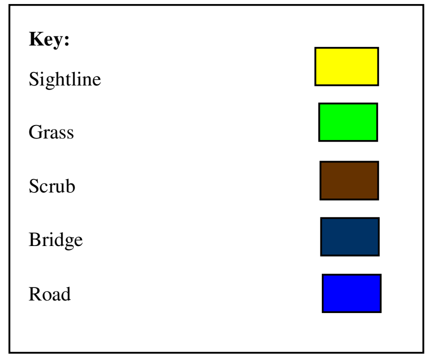


Female field vole

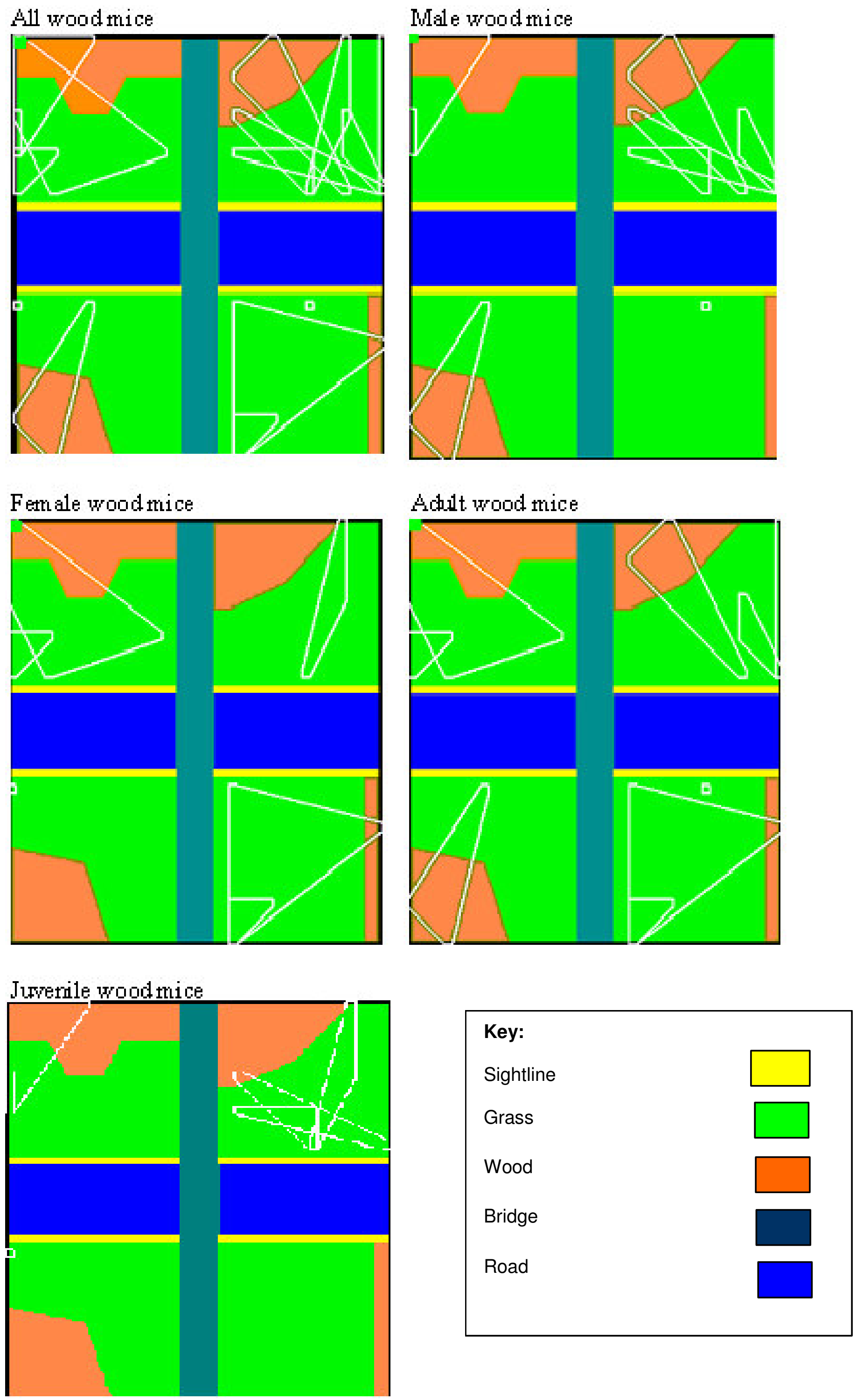


<u>Apendix F3</u>. Home range boundaries for common shrews at Alvechurch study sites as defined by minimum convex polygons. Separate figures are given for males and females and adults and juveniles Alvechurch Common shrews





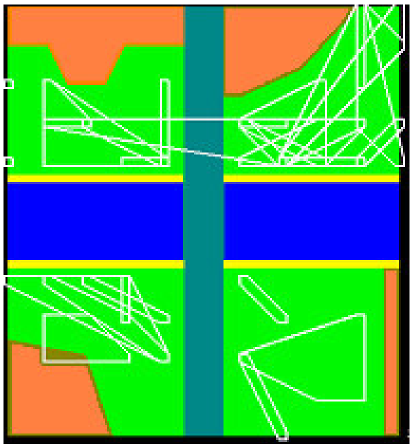
<u>Appendix F4</u> Home range boundaries for wood mice at Redditch study sites as defined by minimum convex polygons. Separate figures are given for males and females and adults and juveniles

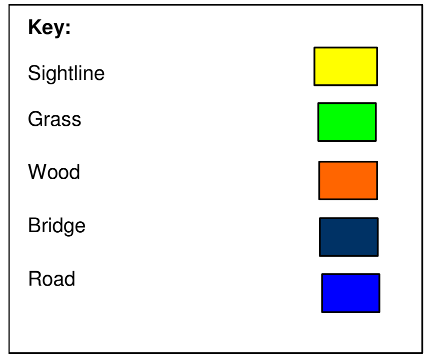


<u>Appendix F5</u>. Home range boundaries for field voles at Redditch study sites as defined by minimum convex polygons. Separate figures are given for males and females and adults and juveniles

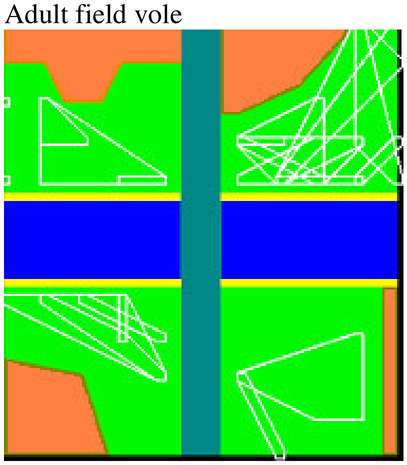
.

All field voles

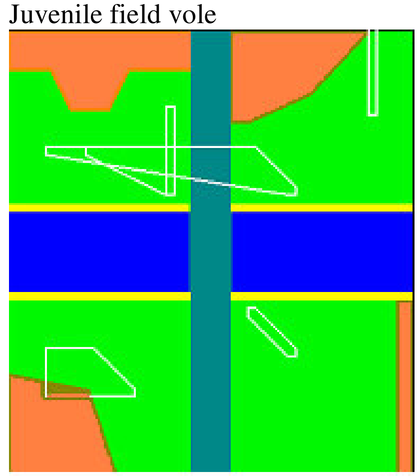




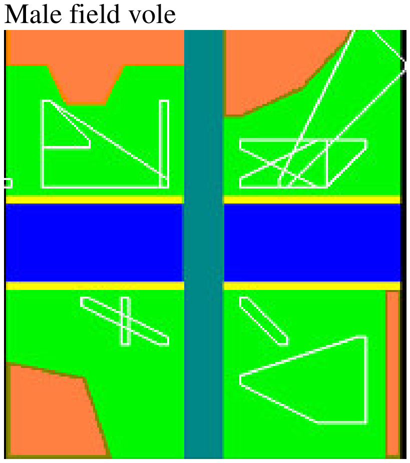
Adult field vole



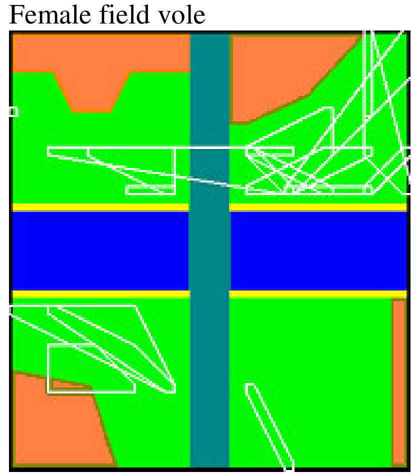
Juvenile field vole



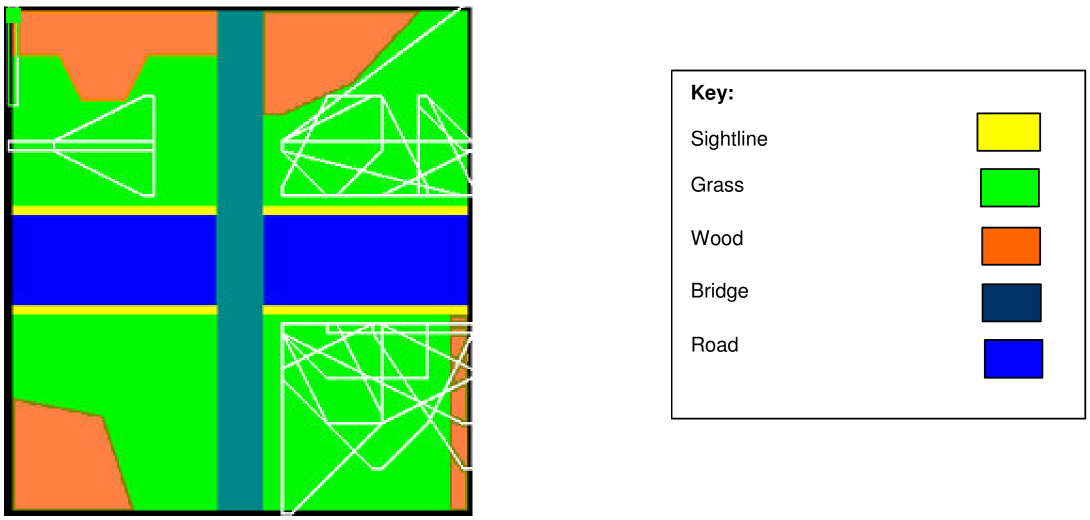
Male field vole



Female field vole



Appendix F6 **Home range boundaries for common shrews at Redditch study sites as defined by minimum convex polygons**



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