ENGLISH NATURE

The significance of secondary effects from roads and road transport on nature conservation

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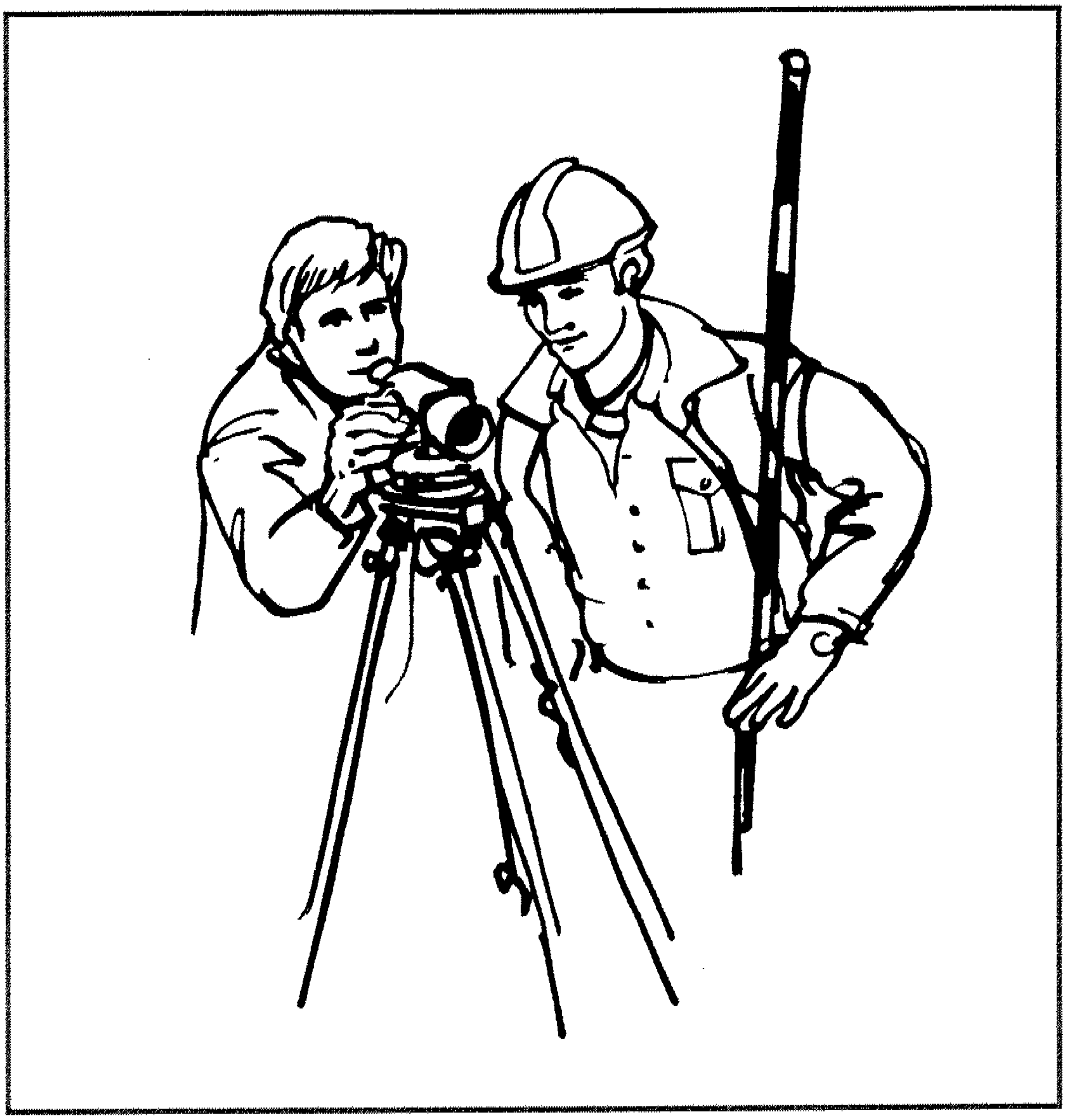

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English Nature Research Report

No. 178

The significance of secondary effects from roads and road transport on nature conservation.

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1 INTRODUCTION

1.1 BACKGROUND

English Nature's current work programme includes a project to ensure full and proper consideration by promoters, and general awareness by others, of the impact of road schemes and road traffic on nature conservation.

In September 1992 English Nature highlighted its concerns over the indirect effects of roads in a *"Position Statement on roads and nature conservation"*. In 1994, English Nature issued a publication entitled *"Roads and Nature Conservation - Guidance on Impacts, Mitigation and Enhancement"*, which explored the issue further. This document will be referred to in this report as English Nature (1994), and is fully referenced in *Section 8*.

In 1992, The Department of Transport (DoT) issued a commitment to the study of the total and cumulative effects of road transport schemes in its response to a report by the Standing Advisory Committee on Trunk Road Assessment (SACTRA) entitled *"Assessing the Environmental Impact of Road Schemes"*, or the *"SACTRA Report"*.

This research report has been prepared to complement and supplement the English Nature 1994 report. The key objective of the 1994 study was to provide guidance on handling nature conservation resources in the context of the planning and design of new road schemes through:

- identification of the range of potential impacts on natural resources;
- establishing high standards of good practice for their mitigation; and
- simultaneously providing scheme enhancement through these positive measures.

The key objectives of this study are:

- to review existing information on the secondary effects of roads and road transport on nature conservation;
- identify current research where possible; and
- identify gaps in the existing information.

1.2 ## Purpose of This Report

This report presents the findings of a research contract into *"The Significance of Secondary Effects of Roads and Road Transport on Nature Conservation"*.

The findings of this study will be used in English Nature's on-going work into the impact of roads on nature conservation.

It is envisaged that this report will contribute to the following:

- any studies into the total and cumulative effects of the Trunk Road Programme;
- responses to statutory consultations regarding individual road improvement schemes and Environmental Assessment (EAs) of such schemes.

It is also envisaged that this report will act as a useful reference guide for use by individuals and organisations other than English Nature with an interest in roads and their impacts on wildlife. It will, for example, provide a useful guide when outlining issues for consideration in the scoping of Environmental Assessments for road schemes.

1.3 ## Definitions Of Direct, Secondary, Indirect, Cumulative Impacts

For the purposes of this report the following definitions have been used:

- *Effects/Impacts* — are physical changes to the environment brought about by particular activities. For the purposes of this report these terms are interchangeable and may be either negative or positive.
- *Direct Impacts* — are those associated with the actual installation of the roadway (*eg* landtake, habitat loss *etc*) and are not part of this study.
- *Secondary Impacts* — impacts arising as a consequence of the direct impacts. An assessment of these forms the focus of this study.
- *Indirect Impacts* — impacts arising from related activities and possible associated development outside the physical extent of the road (see *Section 2.4*).
- *Cumulative Impacts* — resultant impacts from a number of different sources within a particular scheme or the impacts resulting from more than one scheme in one area.

1.4 Sources of Information

Information used in this report has been collated from the following sources:

- consultations with a wide range of organisations with an interest in nature conservation, the environment and roads;
- existing published information and research including a literature search through the British Library;
- representatives of English Nature's Specialist Support Teams and selected local teams;
- ERM's own information database.

1.5 Structure of the Report

The remainder of this report is structured as follows:

- *Section 2* details the consultation process;
- *Section 3* presents a review of the existing relevant information on impact assessment and identifies any information gaps;
- *Section 4* discusses cumulative impacts;
- *Section 5* addresses the measures which are in use or are proposed to mitigate secondary impacts from roads and road transport;
- *Section 6* provides recommendations for future consideration;
- *Section 7* lists the conclusions from the study;
- *Section 8* lists the references which have been consulted in this study.
- *Annex A* List of Consultees.

2 CONSULTATIONS

2.1 SELECTION OF CONSULTEES

Consultations on issues of importance for the study were undertaken with a wide range of organisations including:

- governmental transport departments (*eg* Highways Agency, Department of Transport);
- governmental nature conservation and environmental departments (*eg* Department of the Environment, Scottish Natural Heritage, Countryside Council for Wales);
- non-statutory nature conservation agencies (*eg* RSPB, wildlife trusts *etc*);
- firms of construction engineers in the private sector.

A full list of the organisations which were contacted during the course of the study is contained within *Annex A*.

2.2 INFORMATION REQUESTED

Information was requested from consultees in October 1995, in the form of a questionnaire, organised under the following headings:

- issues relevant to the research contract;
- references and/or further information concerning secondary effects;
- available results of research and monitoring exercises;
- specific issues for concern;
- proposals for mitigation;
- other information or suggestions.

2.3 RELEVANT ISSUES

The range of issues raised by consultees is presented in *Table 2.3a* overleaf. Where these issues have been discussed elsewhere in the report, a relevant section number is also referenced. This report has focused on key issues highlighted by a number of consultees. Some issues raised by consultees have not been reviewed due to information constraints and will require future research and assessment. These are marked by an * in *Table 2.3a*.

Table 2.3a ***Relevant Issues Raised by Consultees***

Issue	Comments	Section Number
Air pollution	• as respiratory and gut poisons • effects of sub-lethal doses • impact distances from road • use of pollution barriers • NO_x, O_3, SO_2, CO_2, CO, VOCs, dust, PM_{10} (1) • global warming • lead, benzene *etc* • changes in plant chemistry and herbivore-disease resistance	3.2
Noise	• effects and distance of effect	3.3
Artificial Lighting	• disturbance effects	3.4
Water	• effects on ground and surface waters • pollution impacts on adjacent watercourses • pollution impact distance effects • flooding • accumulation by aquatic organisms of trace elements from exhaust emissions • impact of gulley pots on amphibian populations	3.5
Spillages	• effects on terrestrial habitat	3.5
Fragmentation effects	• barriers to wildlife movement • cutting of wildlife corridors • on Ancient woodland • minimum viable population sizes • effects on dispersal • inbreeding effects of isolated populations • opening up of woodland edges	3.6
Wildlife casualties	• demographic effects • behavioural changes • human injury, loss of life and vehicle damage from deer collisions • injury to deer	3.7
Litter	• effects on fauna	3.8
Road side verges	• use of exotic plant species • tree planting on grassland verges • seeding v natural colonisation • mowing regimes • habitat creation • invasion of exotics • soil stability and erosion	3.9
Salting of roads	• effects on roadside vegetation	3.10
Dispersal	• of seed, spores, invertebrates, pathogens by cars *etc*	*
Engineering design	• effects of hard engineering solutions on riverine physical habitat quality	*

(1) NO_x (Oxides of Nitrogen), O_3 (Ozone), SO_2 (Sulphur Dioxide), CO_2 (Carbon Dioxide), CO (Carbon Monoxide), VOC (Volatile Organic Compounds), PM_{10} (Particle matter sized below 10 µm diameter).

Issue		Comments	Section Number
Fire risk	•	increases in fire risk to terrestrial habitat adjacent to roads	*
Road construction and management	• • •	spoil dumping, vehicles turning *etc* effects of future repair works *etc* use of roads not intended for construction traffic	*
Shading	•	effects from overhanging infrastructure	*
Slipstream effect	• • •	on invertebrate territory holding patterns nectar content of flowers pollination	*
Cumulative effects	•	effects resulting from combinations of the above	4

As general issues, nearly all consultees noted the following:

- the effectiveness of measures used to mitigate the issues raised in *Table 2.3a*; and
- the lack of monitoring of mitigation measures to determine the effectiveness of the above.

2.4 INDIRECT EFFECTS

A number of indirect impacts were raised during consultation which were considered to be outside the scope of this present survey. These included:

- ***the oil industry.*** Extraction, refining, transportation and storage of the fuel used by road traffic is a worldwide industry with wide-ranging environmental implications;
- ***aggregate quarrying to supply road construction.*** The winning of roadstone and aggregates for road construction may have significant impacts on hydrology and nature conservation off-site and the transportation of aggregates to construction sites may increase pollution;
- ***improved access to otherwise remote areas.*** Increased visitor pressure and disturbance created by improved access may have more general implications for nature conservation (Atkinson & Cairns, 1992);
- ***increased development potential of areas adjacent to new roads.*** The construction of new roads may facilitate other development including industrial or commercial development and other road links (junctions, roundabouts *etc*). The implications of such ancillary development pressure on nature conservation interests may be considerable (Nature Conservancy Council 1990);
- ***compensation land managed for nature conservation purposes.*** Opportunities to enhance existing habitats outside the road line in mitigation for impacts of a scheme may provide positive nature conservation benefits.

3 SECONDARY IMPACT ASSESSMENT

3.1 INTRODUCTION

This section reviews the secondary impacts of roads and road transport that have been established to date. Key issues are identified and gaps that exist in current knowledge are highlighted. The coverage of secondary impacts in many environmental statements is considered to have often been poor (Davidson, 1992; Treweek *et al*, 1993).

The information used is drawn from all the information sources listed in *Section 1.6*. It should be noted that The Wildlife Trusts are currently producing documents nationwide, typically entitled *"Head on Collision"* which document the length in km and the number of wildlife sites that would be destroyed for each habitat type, should the programmed road schemes in the area be implemented. For example the Cumbria, Lancashire and Cheshire Wildlife Trusts have produced a combined report which covers Cumbria, Lancashire, Merseyside, Greater Manchester and Cheshire. Some key points from examples considered within this study are contained within the relevant sections of this report.

All the relevant issues highlighted in *Section 2.3* are included in more detail in this section, under the following headings:

- *Section 3.2* Air Pollution
- *Section 3.3* Noise Disturbance
- *Section 3.4* Artificial Lighting
- *Section 3.5* Aquatic Impacts
- *Section 3.6* Fragmentation and Species Movement
- *Section 3.7* Wildlife Casualties
- *Section 3.8* Litter
- *Section 3.9* Roadside Verge Management
- *Section 3.10* Other Effects
- *Section 3.11* Summary of Key Issues

3.2 AIR POLLUTION

3.2.1 General

Vehicle use is a major contributor to air pollution and this may impact at a local and national scale as roadside deposits, or as a major contribution to climatic change, acid deposition and air quality. Vehicles are responsible for emitting 90% of the carbon monoxide, 51% of nitrogen oxides (NO_X), 46% of the black smoke emissions and 33% of volatile organic compounds (VOCs) in Great Britain (English Nature, 1994) and contribute to the formation of ground level ozone.

The Royal Commission's on Environmental Pollution's Eighteenth Report on Transport and the Environment (1994) notes:

> *"emissions from road vehicles are the main influence on air quality over the large areas of the UK in which there are no significant industrial emissions".*

That exhaust fumes contain a number of pollutants is well understood (Spencer *et al*, 1988) although the overall effects are often less clear.

Various experiments by the Forestry Commission have drawn conclusions on the general effects of air pollution on trees although care must be taken in extrapolating these conclusions to potential impacts from road traffic:

- Bambridge *et al* (1993) summarises data collected from experiments using clonal Sitka spruce trees in filtered and unfiltered chambers at the Forestry Commission's Headley site. The experiment found no significant differences in stem length, stem weight or needle dry weight between plants which had been exposed to filtered or ambient air. There was also no difference in root growth between trees exposed to different air qualities. The studies of shoots show that significant effects may take several years to accumulate.

- Field experiments found that some effects of ambient (polluted) air continue to be recorded at Headley in Hampshire, but not at other sites in Derbyshire and Fife. At Headley for the third year running the height growth of Norway spruce and beech was greater in filtered air than in ambient air (Durrant *et al*, undated).

- Redfern *et al* (1994) studied crown density and a variety of other factors for 8808 trees distributed over 367 plots. It was noted that individual trees in hedgerows and on roadsides, particularly beech and oak, may be in much poorer condition than the woodland trees included in the survey (Redfern *et al*, 1994).

- Mather *et al* (undated) concludes that although pollution may be a factor in influencing the health of British trees, with respect to the general condition of trees throughout Britain the role of pollution is probably small and their work could not establish a causal link between pollution and forest condition.

The British Bryological Society (*pers comm*, 1995) has suggested that the general increase of air pollutants associated with car exhausts such as NO_x may be limiting the growth of some sensitive species but further research is required to verify this.

The distance over which pollution is effective appears to be relatively limited and some fieldwork from parts of Europe highlighting this includes the following.

- Experiments in Moscow region near roads with daily traffic flows of between 100 and 92,000 vehicles concluded that in a zone 7-15 m wide either side of the road, where the major concentrations of gaseous pollutants are condensed, visible changes in growth and development of plants are observable (Nikolaeva *et al*, 1995). In the same zone, pollen sterility (up to 100%) was observed as were structural mutant changes in colt's foot and in red clover.

- Reijnen *et al* (1995) also suggests that air pollution from road transport operates over only short distances (*eg* 100 m in woodland and 200 m in open grassland). Further he states that concentrations of exhaust gases can reach background levels within 50 m from a highway with a traffic density of 40-50,000 cars per day.

  The fact that the majority of bird species studied showed maximum effect distances [(1)] of between 100 and 1500 m suggested that pollution by car traffic was not important in causing reduced bird densities. Reijnen *et al* (1995) also reference other theories proposed by Przybylski (1979) and Bolsinger & Flückinger (1989) that insects may be affected by exhaust gases, thereby reducing the food source for breeding birds.

English Nature recognise the potential impacts of atmospheric pollution on plants and animals. They have published guidelines on the necessary components of environmental statements regarding the assessment of air pollution impacts on nature conservation (English Nature, 1993).

Further impacts which have been reported due to individual air pollutants are discussed in the following sections.

3.2.2 *Ozone*

The action of sunlight on a mixture of nitrogen oxides and organic compounds (both found in vehicle emissions) can lead to the formation of ground level ozone.

Annual average concentrations in the UK are in the range of 10-30 ppb and are largest at elevated and coastal sites (UKPORG, 1993). Photochemical episodes occur throughout the UK each year with concentrations typically reaching 60-80 ppb but occasionally exceeding 100 ppb. Such episodes are more common in southern England than northern England and Scotland (UKPORG, 1993).

Exposure to ozone can result in plant damage (UKPORG, 1993; RCEP, 1994; WHO, 1994; Sanders & Benton, 1995; Farmer, 1995). Experimental evidence suggests that existing levels of ozone in the UK, do in certain summers, affect crop yield, tree physiology and growth and the species composition of plant communities (UKPORG, 1993). Typical symptoms (comprising minute bronze or yellow flecks covering most of the leaf surface) and the effects on crop plants are described in Sanders & Benton (1995).

In central and southern Europe, surveys have shown that ozone concentrations can result in injury to sensitive crops during the growing season (Sanders &

(1) The distance between a specified effects factor related to traffic *eg* noise and its effect (impact) on the density of all breeding bird species or the density of a particular species.

Benton, 1995) and the phytotoxicity of ozone has been highlighted as the major cause of crop loss attributable to air pollution (UKPORG, 1993).

UKPORG (1993) noted that preliminary critical levels (based on the seasonal cumulative dose above 40 ppb during daylight hours) for ozone to avoid impacts to the most sensitive plant species were exceeded in rural areas of the UK in most summers. These critical levels have recently been confirmed by the World Health Organisation (WHO, 1994). There is a small north-south gradient in exceedance of the critical level for ozone, however, the relative sensitivity of vegetation may also show substantial spatial variation.

Current research by ICP-Crops Coordination Centre is focusing on the establishment of these critical levels of ozone for crop plants. The sensitivity of other vegetation, for example field margin species is also being investigated (Sanders & Benton, 1995).

Secondary effects may also occur through increased drought or frost sensitivity, or increased susceptibility to pests and pathogens (Farmer, 1995).

Combination effects may also result and it is thought that the adverse effects of ozone on vegetation may be greater in areas with higher sulphur dioxide concentrations (UKPORG, 1993).

3.2.3 *Sulphur Dioxide*

The importance of SO_2 as a phytotoxic pollutant in Europe has diminished to some extent since the publication of the World Health Organisation (WHO) Guidelines in 1987. This is partially due to falling emissions but also to a recognition of the greater importance of ozone and nitrogen compounds as being of much greater significance (WHO, 1994).

Recent work has provided information which has been used to updated guidelines for SO_2 with respect to its effect on vegetation (see *Table 3.2a* below).

Table 3.2a ***Gaseous SO_2 Guidelines for Protection of Vegetation***

Vegetation Category	Guideline (µg/m^3)	Time Period
Agricultural Crops	30	Annual and Winter (Oct-Mar) Mean
Forests and Natural Vegetation	20	Annual and Winter (Oct-Mar) Mean
Forests and Natural Vegetation (effective temperature sum <1000° C days > +5° C)	15	Annual and Winter (Oct-Mar) Mean
Lichens	10	Annual Mean

Vegetation Category	Guideline ($\mu g/m^3$)	Time Period
Forests (where ground-level cloud is present >10% of time)	1 sulphate particulate (equivalent to 150 µmol/l non-marine sulphate in mists, when Ca^{2+} and Mg^{2+} concentrations < H^+ and NH_4^+ ion concentrations)	Annual Mean

Acid Deposition

Deposition of acidifying compounds such as SO_2, NO_x and NH_3 leads to soil acidification by oxidation to H_2SO_4 and HNO_3 and leaching of SO_4^{2-} and NO_3^- respectively. Damage to forests in Europe including defoliation, discolouration, growth decrease and tree dieback have been reported over the last decade and have to a large extent been attributed to soil acidification. Acid deposition has also caused acidification of surface waters, fish mortality and other ecological changes in large areas of northern Europe and eastern parts of North America (WHO, 1994)

Mists can contain solute concentrations up to ten times those of rain and thus cause direct impact to vegetation (WHO, 1994). Experiments on young trees (backed up by field observations) show significant effects of acid mists (see *Table 3.2b* below).

Table 3.2b *Acid Mist Effects (Source: WHO, 1994)*

pH and Concentration	Comments
pH 3.5 or 150 µmol/l sulphate	Significant effects on leaf surface structure
pH 3.0 or 500 µmol/l sulphate	Visible lesions (also recorded on sensitive species at pH 3.5
1.0 $\mu g/m^3$ particulate sulphate	Guideline as an annual for trees where the ground level cloud is present 10% or more of the time (1)

Additional information concerning air pollution threats to species, habitats and biomes of conservation interest and acidification threats to protected areas throughout Europe are contained within Tickle, Ferguson & Drucker (1995). As this document considers the combined pollution from a wide range of source including burning of fossil fuels and industrial boilers (as well as motor vehicles) and ammonia from agricultural practices it has not been considered in detail for this report.

3.2.4 *Oxides of Nitrogen*

Emissions of NO_x are dominated by vehicle and power station sources and comprise 846 kt yr^{-1}. Fuel combustion is the major source of NO_x in the UK, however a 20% increase was recorded during the period 1970-90, which has been attributed mainly to vehicle emissions (UKRG, 1994). In 1990 transport

(1) Only applies when calcium and magnesium concentrations in cloud do not exceed hydrogen and ammonium ion concentrations.

sources reportedly comprised 55% of the NO/NO_2 emissions in the UK (Fowler & Sutton, 1992) although the figure is now considered closer to 51% (see *Section 3.2.1*). The introduction of catalyst technology, however, will lead to a general decrease in emissions over the next decade, with cold start emissions becoming relatively more important (UKRG, 1994).

Vehicles with three-way catalysts have been identified as a source of N_2O, however, there is no experimental evidence to suggest that it is deposited onto the landscape (UKRG, 1994). Road transport currently comprises 3 kt N yr^{-1} (N_2O-N) of a total of approximately 100-115 kt N yr^{-1}. The introduction of 3-way catalytic convertors to all petrol fuelled vehicles will lead to a reduction in emissions to atmosphere although the impacts on air quality will to some extent be offset eventually by expected growth in traffic.

Nitrogen Uptake by Plants

The varied impacts of atmospheric nitrogen compounds on plant growth reflects the great variation in requirements of plants (UKRG, 1994). High concentrations of NO_2 are known to retard plant growth and cause visible damage to plants, although low concentrations may promote growth, especially on nitrogen-deficient soil (RCEP, 1994).

Field experiments by Spencer *et al* (1988) found that plants closest to the road attained the highest dry weight and showed a trend towards higher total nitrogen content. The effects were most marked in plants given a low nitrogen treatment, similar to the nutrient status of roadside soils.

Low nutrient plants applied with a salt treatment showed a significant increase in dry weight and soluble nitrogen close to the road suggesting salt may increase the availability of nitrogen from NO_x to plants. The higher nitrogen content of plants close to the road correlated with a more rapid increase of aphid numbers on these plants.

The primary edge effect on an extensive lowland heath area on either side of the A31 in the New Forest was a nitrogen input demonstrated by the increased carbon:nitrogen ratio of the heathland soils. Oxides of nitrogen which reached a flux of 60 ppb/hr near the road were shown to exceed the winter critical level of 20 ppb/hr which may cause damage to vegetation (Angold, 1995). Although all the vascular plant species studied showed a fertilisation effect, with improved performance near the edge of the habitat, more competitive plant species such as *Molinia* and *Bromus* were capable of greater increases in turnover and productivity than other species which maintained a relatively constant nutrient use efficiency.

Nitrogen from vehicle exhausts caused increases in the growth rate of *Molinia,* resulting in a higher rate of decomposition (reflected in the lower carbon content of the soil) and greater nitrogen availability (reflected in the decrease in carbon:nitrogen ratio) in the soil, with further increases in the rate of growth of *Molinia*. This positive feedback resulted in a gradient of change in the heathland vegetation extending from the road at least 200 m into the heathland habitat on either side of the road (Angold, 1995).

A study of the heathland adjacent to minor roads in the New Forest has demonstrated that the extent of this edge effect is closely correlated with the amount of traffic that the road carries and therefore with the amount of atmospheric pollution from vehicle exhausts (Angold, 1995).

Bell *et al* (1992) exposed the moss *Polytrichum formosum* to 122.4 (gr)mg m^{-3} of nitrogen dioxide for 37 weeks to assess pollutant effects on rural roadside vegetation. The results showed a 36% reduction in new shoot production and a 46% reduction in old shoots showing new growth and indicated that specimens growing near roads may be harmed by NO_2.

Woodin (1989) highlights that reports from Europe, including Britain, attribute changes in several vegetation communities to high nitrogen deposition resulting from emissions of nitrogen oxides and ammonia. Habitats affected include heathlands, grasslands, forest ground flora, blanket peatlands and uplands. Whilst not addressing air pollution specifically in relation to roads, Woodin & Farmer (1993) do, however conclude that sulphur and nitrogen pollutants are damaging a wide range of habitats, communities and species throughout Britain.

Secondary effects may also occur with pest insects feeding more vigorously on plants exposed to nitrogen dioxide (Farmer, 1995).

WHO (1994) has recommended guidelines for NO_x and NH_3 as presented in *Table 3.2c* below.

Table 3.2c *Critical Level Guidelines NO_x and NH_3 (Source: WHO, 1994)*

Pollutant	Guideline (μg/m³)	Comment
NO_x (expressed as NO_2 in μg/m³)	30	Annual mean
NH_3	8	Annual mean

Acidic Deposition

In addition to their fertilising action, nitrogen oxides comprise an increasingly important component of acid deposition in some areas (Woodin, 1989) and are considered to be a factor in tree dieback (Edmunds, 1995). Briggs *et al* (1993) state that during the 1980s, transport related emissions of nitrogen oxides increased by 59%.

Farmer (1995) notes impacts from the acidification of fresh waters and its associated aluminium release. Impoverishment of the aquatic invertebrate fauna, declines in certain fish and amphibian species (including those of protected species such as Arctic charr and natterjack toad) and in the species dependent on these such as dipper and otter have all occurred in Britain.

The effect of acid rain on streams is well documented and areas with acid soils such as the northern uplands are most vulnerable (Edmunds, 1995). Acid deposition adversely affects freshwater and terrestrial habitats to the extent that many upland areas (especially heaths) in the UK are now showing signs of acidification as their soils have a low buffering capacity (Thompson & Baddeley, 1991; Briggs *et al*, 1993).

Acidification has effects on bird populations which are sensitive to acidification of watercourses because their invertebrate prey decreases. Dippers on acidic sites have been found to lay later, have smaller clutches and slower nestling growth (Ormerod *et al*, 1991; RSPB, 1995). Females have also been found to be lighter and have lower levels of calcium in their blood compared with birds from non-acidic sites. Evidence also suggests that kingfishers are affected as a result of a decrease in fish populations in acidic streams (Ormerod *et al*, 1988).

Controlled experiments on tree growth following exposure to an artificial acid cloud showed clear effects on seedlings including discolouration of foliage (Leith *et al*, 1989), changes in cell structure (Eamus *et al*, 1989) and significant reductions in frost hardiness in autumn (Fowler *et al*, 1989; Cape *et al*, 1991).

Field experiments in upland areas of Britain recorded that trees which had received the mist treatment, had relative area increments on average 25% smaller than untreated trees and also showed smaller relative height increments. Smaller trees were most severely affected by acid mist treatments (Crossley & Cape, 1992).

Guidelines for nitrogen deposition to specific ecosystems have been determined (WHO, 1994), The most sensitive ecosystems (*eg* soft-water lakes and raised bogs) for which effects thresholds can be estimated show critical loads of 5-10 kg $Nha^{-1}yr^{-1}$. A more average value for the limited range of ecosystems studied is 15-20 kg $Nha^{-1}yr^{-1}$ (*eg* lowland dry-heathland and many forests).

3.2.5 *Dust and Particulates*

Dust may be derived from a variety of sources (traffic and non-traffic related) including road-tyre interactions and debris such as metal fragments from vehicles brake and clutch linings. Dust is especially prevalent under dry conditions when it may be easily mobilised by windy conditions or the air movement created by passing vehicles. Diesel-engined vehicles are the most significant contributors amongst road traffic to particulate emissions. Diesel particulates are carbon granules generally less than 1 micrometre (1 µm) in diameter which carry traces of other pollutants such as polyaromatic hydrocarbons (PAHs) (Holman, 1990).

RCEP (1994) notes with regard to particulates:

> *"The particulates in exhaust gases consist mainly of carbon and unburnt or partially burnt organic compounds........secondary particulates may be formed in the atmosphere; these include nitrates and sulphates formed from nitrogen oxides and sulphur dioxide".*

Farmer (1991 and 1993) summarises previous research work relating to road dust (in particular conditions) and its affect on vegetation. Road dust supplies nutrients to surrounding vegetation and previous studies have found that there is a strong correlation between bryophyte tissue metal content and distance from the road. It also causes an increase in leaf temperature of trees which may affect evaporation and transpiration rates and has also been found to result in a reduction in photosynthesis in certain tree species.

Dusted leaves also allow a greater penetration of road salt which increases water stress. Trees and shrubs are recorded as efficient at filtering road dust and have been planted as screens to prevent dust being transported over large distances.

Colwill *et al* (1982) found that exhaust dust, applied to leaves at a density comparable to that observed on busier motorways, reduced photosynthesis by about 20%. Such an effect would contribute to reduced plant growth, however, the effects of particles generally is likely to be very small.

The most damaging effects of road dust have been found in high arctic communities which are naturally fragile and where there is a higher proportion of unsurfaced roads. In Sweden concentrations of Ca, K, Na and P were all higher close to the road. Other studies found that bryophytes were lost from the ground cover which resulted in an increased thawing rate along roadsides (Farmer, 1991 and 1993).

In a UK study of the physiological effects of dust on *Viburnum tinus* Thompson *et al* (1984) found effects upon photosynthesis only with deposition rates of 5 g m^{-2} d^{-1} and above. The highest dust deposition rates on the M4 motorway were only 1.6 g m^{-2} on leaves which were sampled.

Observations of dust on SSSIs are detailed in Farmer (1991). In many cases, no effects on vegetation were recorded although at Topley Pike and Deep Dale SSSI, dust from limestone quarrying was recorded as having affected plants and invertebrates on calcareous grassland.

3.3 NOISE DISTURBANCE

Noise disturbance to animal populations adjacent to highways is a possible cause of the reductions observed in some population densities and sizes.

For woodland, it has been suggested that noise will be an especially important factor in alterations to breeding bird densities (Reijnen & Thissen, 1987; Reijnen & Foppen, 1994). More recently preliminary studies in the Netherlands have supported this as they indicated that the effects of road traffic on breeding bird density are due to noise emissions rather than visibility or air pollution (Reijnen *et al*, 1995a). However, further research is required to verify this.

Density of breeding birds in the vicinity of roads in woodland and grassland locations in the Netherlands was commonly found to be reduced along roads used by high-speed traffic. The extent of the effect was examined using the dose-effect relationship (1). The effect distance (2) was found to increase with greater traffic intensity and speed and with smaller woodland areas along the road (Reijnen *et al*, 1995a). *Table 3.3a* presents some details of traffic noise effect distances from a motorway in the Netherlands (Reijnen *et al*, 1995a). Disturbance distances for nesting species of meadow birds in the Netherlands have been recorded by van der Zande *et al* (1980) (see *Table 3.3b*).

***Table 3.3a* Traffic Noise Effect Distances From a Motorway in the Netherlands with 75,000 Vehicles per day (Source: Reijnen et al, 1995a)**

	75% Woodland	Open Grassland
Effect distances (3)	Smallest:81 m (woodcock) Largest:990 m (cuckoo)	Smallest:100 m (coot) Largest:1130 m (black-tailed godwit)
Density reduction in affected zones	37% - 99%	36% - 82%
All species:		
• effect distances	460 m	710 m
• density reduction	34%	39%

***Table 3.3b* Disturbance to Nesting Meadow Birds in the Netherlands (Source: van der Zande, 1980)**

Road Type	Disturbance Distance
Quiet Rural Road	500-600 m
Busy Highway	>1 km

(1) The relationship between a specified effects factor related to traffic *eg* noise and its effect (impact) on the density of all breeding bird species or the density of a particular species.

(2) The distance between the edge of the road to a location where the noise threshold is reached. The noise threshold is the noise level above which density is reduced.

(3) The uncertainties in the effect distances vary greatly between species.

Reijnen & Foppen (1995b) recorded lower densities close to roads as compared with populations remote from roads, in more than half of 43 songbirds species which were surveyed. The effects were measured for up to 1 km and included a range of common species. Effects on willow warbler were particularly marked. Females did not appear to be able to hear males' song, within a zone of up to 200 m from the road.

Although it was not the aim of the study, Reijnen *et al* (1995a) suggested that there were indications that noise level was the main causal factor in the reduction of bird density adjacent to roads. Further they suggested that in woodland only noise pollution was considered relevant (and not visual effects) at greater distances from the road (eg >200m). In open areas, however, the reduction in density was more likely to be a combination of noise and visual impacts, although statistical analysis showed that the relationship between the traffic load and density was more readily associated with noise impact than with visual impact or with the combined effect.

It was also concluded that the effects of traffic on breeding bird populations would probably be greater than recorded in the study due to the relationship between density and habitat quality. Where population density has been used as the effect variable, the width of the zone along the road where the quality of the habitat was reduced would be underestimated.

Road traffic noise has also been found to interfere with the breeding of wading birds such as lapwing and redshank (SNH, 1994).

In Finland, Hirvonen (1995) noted a decrease in the conservation value of a wetland bird community from construction of the E18 (see *Table 3.3c*).

Table 3.3c *E18 Construction in Finland (Source: Hirvonen, 1995)*

Location and Disturbance Type	Impacts on Conservation Value
Construction Area	Decreased by 26%
Habitat change and disturbance especially through traffic noise	Included loss of several endangered and threatened species *eg* bittern, marsh harrier, crane, ruff and little gull
Control Area	Increased by 4%

Conservation value is based on species specific indices of population size and endangerment

Hirvonen (1995) also noted that the number of pairs of waders breeding in the shore meadows near the traffic dropped by 80% after the road was opened. This decline in wader populations decreased with distance from the road and the number of pairs even tended to increase at distances over 800 m. Three responses were noted:

- waders avoided areas where traffic noise exceeded 56 dB;
- the mating calls of male bitterns were disturbed by noise and birds left the area;
- passerines were less vulnerable to habitat changes than waders and did not show any clear effect due to disturbance.

The results indicate that habitat fragmentation and disturbance caused by infrastructure had considerable effects on breeding populations of waders and wildfowl, while passerine populations showed minor responses. The endangered and threatened wetland bird species proved to be most vulnerable to habitat changes and disturbance especially from traffic noise.

Hill (1992) addresses the likely impact of disturbance on birds caused during and after the construction of roads. The study was undertaken for the assessment of the Second Severn Crossing. Hill's study found that little of the searched literature dealt specifically with waterfowl, noise and road construction. The literature was also found to be biased towards detecting negative effects since studies are more often undertaken when a problem is perceived.

Table 3.3d presents the possible effects of disturbance and the potential responses by birds to primarily noise-related disturbances during and after road construction.

Table 3.3d *Effects of Disturbance (Source: Hill, 1992)*

Effect	Potential Response
Reduction of feeding time	Harassment, birds move elsewhere
Interference with breeding	Birds move elsewhere
Reduced feeding area	Risk of predation/mortality by proximity of humans or proximity to a structure causes birds to move elsewhere

Hill also found evidence of noise disturbance impacts in geese, divers and three species of waders. However, he considered it difficult to assess the impacts of disturbance as it was likely to be species specific.

3.4 ARTIFICIAL LIGHTING

Work by Campbell (1990) suggests that the potential implications for plants of artificial lighting are considerable and harmful effects of sodium vapour lighting on plants through disruption of photoperiodic regulation of growth and development have been shown by several workers (*eg* Sinnadurai, 1981; Cathey & Campbell, 1975 and Shropshire, 1977). However, Andresen (1978) suggests that such effects are apparently greater under greenhouse conditions than outdoors.

Rawson (1923) demonstrated a close correlation between commencement of dawn singing in thrushes in Hertfordshire and critical light intensity at sunrise, suggesting that artificial lighting could conceivably modify the timing of natural behaviour patterns.

Farner (1964) has demonstrated the photoperiodic control of reproduction in birds and that artificially increasing day length will induce hormonal, physiological and behavioural changes initiating breeding. Lofts & Merton

(1968) report that about 60 species of wild birds have now been brought into breeding condition prematurely by exposure to artificially long days in winter. None failed to respond although the effects are more pronounced in males.

The attraction of birds to lights has been known for a long time. Ceilometer lights at airports caused heavy mortality until they were modified by shifting their spectra into the ultraviolet and turning them on briefly. It has also been estimated that as many as one million migrants die at illuminated TV towers annually (Aldrich *et al*, 1966).

Verheijen (1980; 1981) studied bird kills at lighthouses and other tall structures and demonstrated that the greatest number of mortalities occurred around new moon nights. Artificial light in moonless conditions impaired the orientational ability of birds - but birds were not disorientated by such light sources in the presence of moonlight.

Street lights can cause local problems to seabirds on cloudy nights (Hill, 1992). Elkins (1983) recorded that dense fog or cloud, especially where accompanied by rain, appears to render nocturnal migrants susceptible to attraction to isolated artificial light sources.

Nocturnal animals and birds such as barn owls are likely to be disturbed by the presence of bright illumination. As many of these species are already under threat this may be a significant pressure on remaining populations (Outen, undated). It is possible that badgers may become accustomed under some circumstances to artificial lighting (see *Section 5.6*).

Artificial lighting has the potential to provide more feeding time for birds by enabling nocturnal feeding (Hill, 1992; Outen, undated). Whilst this could represent a positive impact by increasing feeding time for birds it could also have a detrimental effect on prey populations leading ultimately to food shortage for the birds. Imber (1975) suggested that petrels were attracted to artificial light sources to feed as it allowed them to exploit bio-luminescent prey. A good example of such nocturnal feeding is at the Slimbridge headquarters of the Wildfowl and Wetlands Trust.

Hill (1992) noted that increased night feeding (visually rather than tactilely) was recorded on estuaries in north-east England due to street lights and that redshank and oystercatcher have been recorded on the Forth Estuary feeding within 50 m of street lighting.

Hill (1992) noted that birds (predominantly dunlin) had been observed roosting next to a large roundabout in Cornwall which was lit by artificial light.

Rydell & Racey (1993) report on the beneficial effects for fast-flying bat species (*Nyctalus, Vespertillio, Eptesicus, Pipistrellus*) feeding on insects attracted to street lamps though such locations are apparently not exploited by the slower-flying species (*Myotis, Plecotus* and *Rhinolophus*) which include most of those considered particularly vulnerable in Europe.

Some observers suggest that continuous lighting along roads creates barriers which bats will not cross. In the Netherlands, Sweden and Switzerland stretches of road have been left unlit to avoid isolation of bats.

Moths and other night-flying insects are attracted to lights and concern has been expressed that street lighting may have affected their populations in some way.

Robinson & Robinson (1950) showed that a high general level of illumination may cause night-flying insects to cease flying and settle. A light seen at a great distance (for example the sun or the moon) enables an insect to fly in a straight line and thus maintain a constant angle with the direction of the light. Artificial lights mislead an insect and in its attempts to try and maintain the constant angle to the light source the consequence is that it approaches the light in an ever steepening spiral.

There is a perception among some entomologists that in Britain urban locations support a far lower diversity of moth species than they did 30-40 years ago even when there has been little change in the composition of their vegetation and hence food availability. Increased street lighting since that time may have been a significant factor in this apparent deterioration in the moth fauna.

Frank (1988) cites evidence of decrease in moths at urban lamps but considers many factors may contribute to this including decline in moth populations, dilution of moths among the multitude of urban light sources and suppression of the flight to light response as a result of overall increase in background illumination. However, other sources suggest no downward trends in moth populations are apparent and that moth populations in areas undergoing urban changes can substantially recover despite electric lighting (Taylor *et al* 1978).

The same urban changes that increase outdoor lighting also lead to a fragmentation of habitats and the result is the creation of small isolated insect colonies exposed to illumination. Urbanisation increases both vulnerability and exposure of such insect populations to artificial lighting.

Outdoor lighting may also act selectively on particular individuals within a population, perhaps selecting against those most strongly attracted to light. Frank (1988) suggests that the fact that some species of moth are not attracted to light sources might indicate that behavioural modification of the flight to light response has already occurred.

Outen (undated) reports that the greatest likelihood of problems arising is close to sites of high conservation value or to known populations of rare species.

3.5 AQUATIC IMPACTS

The hydrological impacts associated with road schemes were discussed in some detail in English Nature (1994) including details on secondary issues such as drainage and runoff.

Ellis & Revitt (1991) was amongst the source references used in the compilation of that report and the following principal impacts to water quality draws not only on this reference but also on Luker & Montague (1994):

- Highway runoff does degrade receiving water quality. Discharges from highway drainage are intermittent and can be either:
    - routine discharges due to rainfall washing off pollutants that have built up over a long period from everyday use of the road; and
    - accidental discharges.
- More than 30 different substances have been identified in routine discharges, the two main sources of pollutants being pollutants from the regular passage of traffic and those from winter maintenance activities.

The major pollutants in routine discharges are presented in *Table 3.5a* below.

Table 3.5a ***Major Pollutants in Routine Discharges (Source: Ellis & Revitt, 1991; Luker & Montague, 1994)***

Pollutant	Comment
Sediments	Can cause an impact on receiving water, but also act as a transport mechanism for many pollutants. Up to 85% of pollutants are to be found as, or adsorbed on, or adsorbed by, sedimentary particles.
Hydrocarbons	Generally immiscible with water (*eg* oil).
Metals	Highway runoff does contain cadmium and lead, which are very toxic metals, although at small and reducing levels. A greater problem is from the more common metals such as copper, iron and zinc that are present in larger quantities.

Pollution from routine discharges, although generally of a low level, has been observed to have a number of effects on receiving waters (see *Text Box 3.5a*) below.

- **Increased turbidity and blanketing of stream beds. Highway outfalls may cause turbulence and sediment resuspension.**
- **Depletion of dissolved oxygen.**
- **Two week chronic algal assays have demonstrated a reduced algal growth in the presence of undiluted highway runoff and a low mutagenic effect, though acute tests have shown little negative effect on either growth or behaviour.**
- **Toxicity studies on stream flora and fauna indicate that major ecological impacts are restricted to runoff from trunk roads and motorways carrying high traffic volumes and principally result from long term chronic exposure and bioaccumulation.**
- **The impact on water quality and associated habitat and biota downstream of major highway outfalls is exacerbated if discharges take place into a standing-water lake body.**
- **Smell, tainting and visual effects.**

- The potential impact of discharges on receiving waters will vary, but groundwaters are particularly vulnerable because of the great difficulty of cleaning up pollution once it has entered the ground.

- Special measures need to be taken to avoid problems from discharges to static surface waters. In particular, sediment should be removed from the discharge so as to avoid the subsequent need to dredge polluted sediment.

- Accidental discharges are an environmental threat because of the range of potential pollutants involved. The only satisfactory solution to the problem is containment of the spill to prevent it reaching the receiving water. This must use a method that is simple, robust and quick to operate and accessible to emergency services and disposal vehicles.

A study of river and flood plain crossings, river diversions, channel modifications and flood plain incursions by Kings Environmental Services (undated) on the Rivers Avon, Itchen (all high quality chalk rivers in the South of England subject to major road developments on their floodplains within the last 20 years) concluded that river siltation, high water turbidity, and oil pollution are clear risks associated with major engineering works within or adjacent to river channels. Assuming appropriate precautions are taken, however, the risk of pollution incidents can be minimised.

Where pollution incidents occurred this was due to poor construction site management (*eg* unbunded storage of diesel oil, no collection of site runoff) and could have been avoided. The effects of such incidents are though essentially short term. If undertaken properly, river diversions do not have severe or lasting impacts and full naturalisation of the channel can be achieved within a few years.

Oil and other pollutants from vehicles on roads and carparks enter the freshwater system through drains as a result of runoff during heavy rains. This can lead to sporadic pollution events in the water body and such pollution can lead to decreased biodiversity in waterbodies which are close to heavily used roads (SNH, 1994).

Hydrogeological impacts due to road schemes are possible when aquifers are present in the vicinity of road schemes or when deep cuttings or tunnels are proposed. A key issue is the pollution of the groundwater which can be difficult and in some cases impossible to rehabilitate. The importance of protecting groundwaters is due to:

- difficulty in rehabilitating the resource;
- its use as a potable supply for which a high quality standard must be maintained;
- it providing a storage for large quantities of high quality water that requires little treatment prior to use;
- it providing the baseflow of many surface water systems.

Strategies for the protection of groundwaters have been determined and further details are available from the NRA (1992) and the Association of Directors and River Inspectors of Scotland (ADRIS) (1995) (see *Section 5.2.5*).

3.6 FRAGMENTATION AND SPECIES MOVEMENT

Road construction may result in fragmentation of remaining habitats and populations. Research suggests that fragmentation may have a greater impact than isolation, but the barrier and disturbance effects of roads, as well as the high death rates incurred for some species, increases isolation effects (English Nature, 1994).

Future road widening may further increase the width of the barrier and thus the fragmentation impacts. In the Veluwe district of the Netherlands (the largest natural area in the country) motorways are regarded as the most effective fragmentors and isolators (Berris, 1995). Here, the construction of the A1 motorway from 1990 to 1992 resulted in fragmentation, damage and loss of natural and landscape features and various mitigation measures were implemented (Stegehuis, 1995) (see *Section 5.2.7*). Elsewhere in the Netherlands, the A2 motorway (and a canal and railway) forms a large barrier between two important wetland areas which have become totally fragmented (Lichtendahl & Stam, 1995).

Despite being a feature of forests before man became a predominant influence *eg* through treefall gaps, grazing areas and regeneration (Warren & Key, 1991), fragmentation (and loss of contiguous habitat) is now considered one of the most important factors worldwide in accelerating reduction in biodiversity (Wilson, 1992).

Fragmentation of Habitats

English Nature (1994) lists the principal effects of habitat fragmentation as follows:

- A *decline in species number* as the habitat patch is reduced in size. This is most likely to be seen in animals which exist as metapopulations in the surrounding habitat mosaic, and in specialist species for which the reduced patch area can no longer support a viable population.

- A *loss of core or characteristic species* and concomitant invasion of edge and more widespread species - this has been found for plants and invertebrates on heathland, and birds and mammals in woodland, and might be expected in principle in any habitat.

- *changes in community composition* as a product of the loss of species which were part of an inter-related web of life. Parasitic, symbiotic, commensal predator-prey relationships and inter-specific competition can be altered, which can lead to secondary extinctions.

Habitat (or biotope) patches are often clustered and in considering species mobility three levels of movement can be distinguished - within patch, within clusters and between clusters. The impact of infrastructure fragmentation differs from that caused by agricultural or forestry practices in that the isolation created in distance terms may be small, often less than 100m, *ie* at the "within cluster" scale. The barrier effect may be greater per unit width however, because of the nature of road or rail surfaces (Kirby, 1995).

Previous studies of breeding birds in the highly fragmented woodlands of East Anglia indicated that more species were recorded in larger woods and that factors such as length of available hedgerow within 0.5 km of the wood and the composition of the woodland area were significant contributors to the variation in numbers of breeding species (Hinsley *et al*, 1992). Local species extinctions and colonisations were more pronounced in small woods than larger woods and the relative turnover rate (RTR) [(1)] was higher for smaller woods and increased rapidly as woods decreased below 2 ha. The results of this research therefore have significant implications for woodlands affected by future road development.

Indeed, English Nature (1994) report that fragmentation is most significant in habitats which were formerly more widespread and are now reduced to variable sized patches within a landscape of other uses. The habitats most affected are woodland, heathland and species-rich grasslands. Plant and animal populations affected most severely by fragmentation are those species which maintain genetic diversity and avoid interbreeding by moving between habitats. Many of these species have been found to exist in metapopulations in a fragmented landscape - where sub-populations form nuclei in the habitat patches, or a larger population in a 'mainland' habitat, but where there is

(1) Changes in species composition in which both extinctions and colonisations are accounted for.

regular interchange of animals between patches. Where sub-populations die out in small populations, they are regularly replaced by immigration but this process is hindered or prevented where roads are introduced. This reduction in connectiveness of the patches may cause loss of sub-populations, and if this takes place in several places within a short time period, metapopulations without a mainland habitat can become extinct.

As well as the reduction in total extent of different habitats by fragmentation, the size of the surviving patches may be less and the intervening land may present problems or dangers to species movement (Dawson 1994; Bennett, 1995; Forman, 1995; Langevelde & Jaarsma, 1995; Opdam, 1995; Van Apeldoorn, 1995).

Present decline of capercaillie in Scotland and elsewhere in Europe has been linked to habitat fragmentation and degradation of its pine (*Pinus*) forest habitat (Rolstad & Wegge, 1989). Fragmentation of montane heath habitat has resulted in declines in dotterel populations (RSPB, 1995), a species which is protected under the *EC Wild Birds Directive (79/409/EEC)*. In considering fragmentation and isolation effects on birds, the minimum area requirements and dispersal ability of bird species should also be considered.

Some species (*eg* great spotted woodpecker) readily cross gaps and may meet their area requirements by using groups of small woods (Hinsley *et al*, 1994). The ability to cross gaps, however, varies with species and those less able become isolated more readily by fragmentation. The rarity of nuthatches even in larger woods, their short dispersal abilities and their absence from suitable habitats, suggests that they were sufficiently isolated to prevent recolonisation (Verboom *et al*, 1991). The probability of woodland specialists breeding did not approach 100% until woodland size was approximately 10 ha or greater suggesting that such specialists have a low probability of breeding in small woods (Hinsley *et al*, 1994).

Further details of the area requirements of woodland birds studied in Cambridgeshire and South Lincolnshire are presented in *Text Box 3.6a*.

Box 3.6a *Woodland Bird Area Requirements (Source: Hinsley et al, 1994)*

A study in Cambridgeshire and south Lincolnshire between 1990-92 recorded 151 bird species in broad-leaved woodlands ranging from 0.02 - 30 ha, with 78% of 2 ha or less. 31 species were examined:

- **there was little evidence for a general strict minimum area requirement;**
- **8 bred in woods down to 0.02 ha;**
- **20 in woods down to 0.5 ha;**
- **2 (chiffchaff and marsh tit) in woods 0.5-1 ha; and**
- **1 (nightingale) failed to breed in woods of less than 1 ha.**

Habitat fragmentation is also a major threat to the survival of many mammal populations and road building in Britain is likely to affect mammal populations (Bright, 1993). Species that are rare or vulnerable to local extinction are also likely to be influenced by habitat fragmentation (see *Text Box 3.6b* (Bright, 1993).

Box 3.6b *Rare and Vulnerable Species and Fragmentation (Source: Bright, 1993)*

Such species exhibit certain characteristics including:

- **low population density;**
- **low dispersal rates or short dispersal distances;**
- **habitat specialisation;**
- **stochastic population dynamics and low rates of increase; and**
- **vulnerability to extrinsic factors.**

Populations of these species show three responses to habitat fragmentation:

- **a gradual decrease in population size followed by rapid extinction when a threshold level of fragmentation is reached - the rapid extinction occurs when the interfragmented distances become too great to permit dispersal between fragments, which may occur in species of semi-natural habitat;**
- **an initial small population increase followed by a gradual decrease then extinction, typical of edge species;**
- **a marked increase in population size followed by a gradual decline, typical of species which can utilise different habitats.**

In the Netherlands, a classification of ground mammals according to their vulnerability to fragmentation by infrastructure has been made, based on three criteria: habitat characteristics, dispersal behaviour and home-range size (Langeveld & Jaarsma, 1995). It appears that mammal species of closed (*eg* forest) and half-open landscape types (*eg* forest matrix, hedgerow and wide agricultural parcels) with a large home range and well dispersing behaviour are sensitive to fragmentation, however, the comparative width of roads in these landscapes is small and they do not appear to present a barrier.

Research is currently ongoing on the effects of fragmentation and also noise, air pollution and accessibility on The Inner Thames Marshes SSSI from the construction of the A13. A report is expected in March 1996 (*pers comm EN, 1995).*

Barrier Effects to Movement

The busier and wider the road, the more it is effective as a barrier to movements. Some species cannot, or rarely, cross such obstacles whilst others venturing onto the road risk vehicle collision. Other species will not settle even within several hundred metres of a road (English Nature, 1994).

Narrow roads may pose few problems as barriers to some small mammals (Slater, 1994). Other evidence, however, suggests that roads can be a barrier to small mammals (Mader, 1984). Edmunds (1995) notes that roads inhibit many small mammals from crossing and in Europe, bank vole, yellow necked mice and doormice are particularly vulnerable. Barrier effects are also felt by a wide variety of invertebrates such as beetles.

The viability problem caused by fragmentation effects is particularly apparent in low flying species of butterfly and has also been observed in carabid beetles and woodmice (SNH, 1994). In West Germany Mader (1984) reported that highly mobile forest-dwelling animal species such as woodmice and stenotopic woodland carabid beetles avoided road verges and never or only rarely crossed the road even forest roads not open to public traffic. He suggested that woodmice may adjust the edges of their territories to such man made linear constructions. A study of the effect of main roads in Dorset and Hampshire on butterfly and burnet populations by Munguira & Thomas (1992) concluded that wide busy roads were no barrier to species of butterfly and burnet moth living in open populations, but slightly impeded those in closed populations. Roads were not considered a barrier to gene flow in any of the species studied.

Further studies by Adams (1984) recorded no difference in small mammal density in unmown habitat along the side of the central reserve or in similar habitat along the outside edge of the highway. Highest density was recorded in unmown roadside habitat bordered by woods towards the centre of the road. Within the wooded strip density was similar to that within wooded habitat adjacent to the highway.

Reptiles and amphibians may be particularly affected by fragmentation of their habitats particularly where a road divides the breeding and terrestrial habitat of amphibians. The impact on reptiles is less clear as there are rarely large seasonal migrations (English Nature, *pers comm*, 1995).

Extrapolation of the survival probability of crossing toads to the car density of the Dutch road network, concluded that highways and most secondary roads must be regarded as absolute barriers (Vos, 1995).

Major losses of insect species have occurred, especially during the last 50 years (Warren & Key, 1991). Woodland insects with limited powers of disposal within fragmented patterns of woodlands are particularly threatened with isolated races evolving reduced powers of dispersal. Beech trees (*Fagus sylvatica*) in smaller secluded woods support fewer insect species notably micro moths and gall midges suggesting that insect populations in woodlands less than 2 ha may not be as viable as those in larger woodland (Dennis, 1992).

Oggier (1995) examined the effect of road width on dispersal of the endangered land snail *Helicella itala*. Typically it was confined to roadside verges but several snails crossed smaller roads or pathways (more often than wider ones). Regularly used roads with no vegetation cover acted as a barrier separating populations.

Vermeulen (1994) studied the corridor function of a poor sandy roadside verge adjacent to an open area of drift sand for ground-dwelling beetles. Sites with trees and narrow areas at the verge edge had a barrier effect on beetle movement. Vermeulen suggested that it might be more practical to create verges supporting habitat types which would benefit rarer species but also support more common species as well.

In landscapes where road densities are already very high (eg southern England), most of the species sensitive to habitat fragmentation are likely to have already disappeared, but any that are left may well be pushed beyond their viability thresholds if further fragmentation occurs. If fragmentation does occur the potential benefits from habitat creation or other mitigation works are likely to be relatively high because of the generally low wildlife interest of much of the land.

Where road densities are currently low and the extent of semi-natural habitat is high (eg Scandinavia), the disturbance from infrastructure development may be relatively small and only the most sensitive species are likely to be affected.

The effects of road (and rail) bridges as barriers to bird movement were examined by Bryant & Logie (1994) on estuarine bridge crossings in Scotland.

Movement of birds across the line of the bridge was not hindered by the presence of bridge crossings. It was also noted that estuarine bridges did not appear to comprise a sufficient source of disturbance to reduce usage of nearby intertidal areas by shore birds or waterfowl, although a low bridge is likely to reduce usage of mudflats within the limited area beneath its span.

Edge Effects

The effects from roads and road vehicles favour edge, generalist and exotic species over specialist species (Forman, 1995). Increased predation by edge or invasive species can occur along edges, with effects recorded up to 600 m into woodlands (English Nature, 1994).

However, roadsides can also provide positive benefits to fauna and flora. Way (1977) reports that British roadsides support a number of plant and animal species (see *Table 3.6a*) below.

Table 3.6a ***Plants and Animals Recorded in British Roadside Verges (Source: Way, 1977)***

Animal	Numbers
Plants	870 (mostly native) of 2000 British species
Nationally rare plants	35 of 257 British species
Mammals	20 of 50 British species
Birds	40 of 200 British species
Reptiles	All 6 British species
Amphibians	5 of 6 British species
Butterflies	25 of the 60 British species
Bumble bees	8 of the 17 British species

The importance of a buffer zone to absorb edge effects from land use adjacent to protected habitats is widely recognised (Angold, 1995). Edge habitat is often of great value for conservation but it is not "core area" and should not be included in calculations of the size of a given habitat fragment for nature conservation purposes.

Conclusions

The greatest impacts on nature conservation interests resulting from habitat fragmentation by roads are thus likely to be in the intermediate situation: in landscapes where sufficient natural and semi-natural habitat exists that all routes are likely to involve some damage to sites; where fragmentation has already put many species close to their limits; but where the relative benefits from mitigation are likely to be small.

Quantitative indications using computer models of the extent of habitat loss, disturbance and collisions are being advanced (Canters & Cuperus, 1995), however, the extent of the effects of barrier action cannot yet be determined.

3.7 WILDLIFE CASUALTIES

3.7.1 *General*

As a result of fragmentation and the barrier effects of roads (see *Section 3.6*), some animals attempt to cross roads. "*Because our roads are so heavily used, almost anything which ventures onto, across or over the road is vulnerable*" (Slater 1994). These may include rare or protected species such as badgers, red squirrels, otters, owls and amphibians trying to reach their breeding ponds (Edmunds, 1995) and many animals are killed whilst scavenging on road kills. Such effects are noted worldwide and include animals of all sizes from insects to large mammals such as moose (Slater, 1994).

Estimates of kills are reviewed in several documents including English Nature (1994) and Slater (1994), both for individual species and total annual kill estimates for countries. Examples of the latter are reproduced in *Table 3.7a* below.

Table 3.7a ***Estimates of Total Animal Kills (Source: Slater, 1994)***

Country	Kill Estimate
Netherlands	653,000 (birds) 159,000 (mammals)
Bulgaria	7 million (birds)
Australia	5 million (frogs and reptiles)
USA	1 million **per day** (vertebrates)
Spain	10 million (mammals)
UK	1 million (animals)

Table 3.7b summarises annual wild animal deaths recorded at a local level on the stretch of the A370 between Weston-super-Mare and Bristol (the St Georges Interchange of the M5 and the stretch of road to the east of the railway line near Barrow hospital) between 1990 and 1994 and *Table 3.7c* notes casual records of wildlife casualties recorded from a car by ERM on the A895/A9 from Thurso to Inverness and on the A9/M90/A90 from Inverness to Edinburgh on 24 October 1995.

Table 3.7b ***Road Deaths on the A370 1990-4 (Source: Green (undated))***

Animal	1990 - June 1991	1992	1993	1994
Fox	27	13	14	4
Hedgehog	15	5	9	7
Rabbit	35	11	8	9
Badger	9	8	9	7
Pheasant	-	-	-	1
Squirrel	2	1	3	
Total	**88**	**38**	**43**	**28**

Table 3.7c ***Casualties Noted on Road Between Thurso - Edinburgh***

Section	Animal	Number
Thurso - Inverness A895/A9	Rabbit / Hare	14
	Pheasant	2
	Hedgehog	2
	Cat	1
	Corvid	1
	Unidentified [1]	3
	Total	**23**
Inverness - Edinburgh A9/M90/A90	Rabbit / Hare	9
	Pheasant	2
	Corvid	3
	Deer	1
	Unidentified	8
	Total	**8**

Slater (1994) notes that a single day census probably underestimates daytime death rates by a factor which depends upon the duration time [2] and the hours of daylight. Other census influences noted are the mode of transport selected from which to conduct the survey, size of casualty, season and day of the week and casualties which die off the road and therefore, remain unobserved.

Wildlife mortality affects the birth/death ratio of (local) populations and a reduction in this ratio increases the likelihood of extinction of populations.

Whilst *Tables 3.7a - c* note that apparently large numbers of animals casualties are recorded on British roads, the significance of these losses is still undetermined in all but exceptional cases (English Nature, 1994).

A high mortality reduces exchange and increases isolation illustrating that mortality and barrier effect caused by fragmentation are interlinked and are road and species specific (Van Apeldoorn, 1995).

More specific comments relating to individual species or groups of species are provided in the following sections.

3.7.2 *Badgers*

It is estimated that there are about 250,000 adult badgers with 175,000 cubs born each year (RSPCA, 1994) and that a minimum of 50,000 badgers are killed on the roads each year Harris *et al* (1992). Whilst there is no evidence that such mortality is having a major impact on the total badger population, roads can reduce local populations or eliminate social groups.

(1) Either too mutilated or too old to allow identification.

(2) Depends upon the density and activity of scavengers.

In the 1970s and 1980s in the Netherlands there was a continual decline of badgers and populated badger setts. The high number of total victims (annually approximately 20-25% of the total population) reduced the species to an extremely vulnerable position (Bekker, 1995; Janssen *et al*, 1995). Preliminary planning for road construction in the Heuman/A73 area in the Netherlands identified that the motorway would cross the foraging grounds of three of the six badger setts in the area. Given the high mortality rate of badgers due to road traffic, building the motorway without provisions for badgers would have resulted in the extinction of this population (Douwel, 1995). Mitigation measures were, therefore required in the scheme design (see *Section 5.2.6*).

There is a widespread and relatively dense population of badgers in the south west of England and a large proportion are killed on the region's roads. *Table 3.7d* summarises badger road deaths in Avon notified to Bristol Regional Environmental Records Centre (BRERC) between 1989 and 1991.

Table 3.7d ***Badger Road Deaths in Avon Notified to BRERC***

Month	**1989**	**1990**	**1991**
January	1	8(5)	2
February	9 (5)[(1)]	10 (5)	3 (1)
March	6 (5)	7 (3)	1
April	3 (2)	5 (3)	3
May	4 (3)	2	4 (3)
June	2 (2)	5	1
July	2 (1)	7	
August	3 (3)	10	
September	3	8	
October	1	2	
November	6 (1)	2	
December	2 (2)	2	
Total	**42 (24)** **(= 8 at Limeburn Hill)**	**68 (16)**	**14 (4)**

(1) The figures in brackets refer to badgers killed between Junctions 19-21 of the M5 in Avon.

Many badgers involved in road accidents will die out of sight of the road after being seriously injured and it is therefore likely that the total is under-recorded, possibly by more than a factor of ten according to staff at the records centre.

The role of minor rural roads (MRRs) in habitat fragmentation and for wildlife casualties is substantial and in the Netherlands 46% of badger kills and 23% of barn owl kills annually have been attributed to MRRs (Langevelde & Jaarsma, 1995).

3.7.3 *Otters*

No published estimate of otter populations is yet available, as most distribution surveys have been based on the presence of spraints and there is no established relationship between otter evidence and otter numbers (Morris, 1993). The results of the latest Otter Survey of Britain will not be published until 1996 (*pers comm*, Vincent Wildlife Trust, 1995).

Roads are now thought to be one of the major causes of otter deaths, although in many instances the actual numbers of road casualties have not been collated, though the data to do so are often available (*pers comm* Otter Trust, 1995). Some data, however, are available for example records of otter casualties in parts of East Anglia (see *Table 3.7e* below) and casualties reported to the NRA (South West) (see *Table 3.7f* below).

Table 3.7e ***Otter Deaths in Road Accidents 1984 - 1995 (Source: Otter Trust, 1995)***

Area	Total Numbers	Yearly Counts
North Norfolk Broads	4	1 (1988) 1 (1992) 1 (1994) 1 (1995)
North Thames Tributaries	2	1 (1991) 1 (1992)
Ouse Basin	10	1 (1992) 3 (1993) 2 (1994) 4 (1995)
Rivers Reaching the Sea in Suffolk and Essex	8	1 (1986) 1 (1987) 2 (1989) 1 (1990) 3 (1995)
Welland and Nene Basins	1	1 (1994)

Table 3.7f ***Otter Casualties Reported to NRA (South West) (Source: NRA, 1995)***

Year	Numbers	Months
1986	1	Nov
1987	1	Nov
1988	6	Jan (1) Feb (1) Mar (2) Apr (1) Dec (1)
1989	None reported	-
1990	5	Feb (2) Jun (1) Sep (1) Dec (1)
1991	6	Jan (2) Feb (1) Mar (1) Nov (2)
1992	12	Mar (2) Apr (3) May (1) Oct (2) Nov (2) Dec (2)

Year	Numbers	Months
1993	15	Feb (1) Mar (3) Apr (2) Jul (1) Sep (1) Oct (2) Nov (1) Dec (4)
1994	24	Feb (2) Mar (2) Apr (1) Jun (1) Jul (1) Aug (2) Sep (4) Oct (3) Nov (3) Dec (5)
1995 (up to 27.11.95)	15	Jan (1) Feb (2) Mar (2) May (1) Sep (1) Oct (3) Nov (5)

Elsewhere 4 otter deaths had been recorded in Northumberland since August 1995 as compared with only a similar number over the previous 3-4 years (*pers comm* NWT, 1995).

The fact that more otter deaths on roads are recorded now may in part be due to the increase in the number of otters in many areas, resulting in more frequent contact with roads. Numbers in the south-west and parts of Wales are considered to be at "healthy saturation levels" and animals are spreading east (*pers comm* Otter Trust, 1995).

This would appear to be true in East Anglia, where a reintroduction programme commenced in the late 1980s. Otter casualties have increased since the programme commenced to a level where most premature deaths are now caused by road accidents (*pers comm* Otter Trust, 1996). Recent numbers are presented in *Table 3.7g* below.

Table 3.7g *Recent Otter Deaths in East Anglia Following the Reintroduction Programme (Source: pers comm Otter Trust, 1996)*

Year	Number of Deaths
1995	9
1994	5
1993	3

3.7.4 *Red Squirrel*

Of the 70 red squirrel corpses handed in to the National Trust at their red squirrel reserve at Formby Point, Merseyside between April 1992 and December 1994, 29 were directly identified as road casualties (Edmunds, 1995).

3.7.5 *Barn Owl*

More roads and increased traffic have been highlighted as a major component in the decline of barn owls both in the UK and in parts of the Netherlands (Shawyer, 1987; de Bruin, 1994; RSPB, 1995; *pers comm* Hawk and Owl Trust, 1995). In the UK road casualties comprise an annual estimate of 5,000 individuals (*pers comm* Hawk and Owl Trust, 1995). Twice as many barn owls are now killed by road traffic compared with the 1950s and in some areas even suitable habitat no longer supports barn owls.

The barn owl survey of 1982-85 noted that mortality is high over the first 5-10 years following the opening of new motorways and then falls off (Shawyer, 1987). Further it recorded 0.5% of the breeding population of barn owls in Britain within 1 km of any major trunk road and only 2% within 3 km. This suggests that populations are already depleted probably due to the effects of habitat fragmentation and road mortality (*pers comm* Hawk and Owl Trust, 1995).

A possible reason for the occurrence of barn owls near roads (especially trunk roads) is the availability of small mammal prey on roadside verges, although it is suggested that in such areas this indicates poor surrounding habitat. In addition, these rough-grassland corridors appear to provide the main routes of dispersal for juveniles between September and November. A second peak of mortality occurs between January and March and this peak is likely to include more adult birds as they extend their foraging range in the winter (*pers comm* Hawk and Owl Trust, 1995; RSPB, 1995; Shawyer, 1995).

A new study by the Hawk and Owl Trust has been commissioned by the Highways Agency and is currently being undertaken along a 50 km section of the A303 between Broadway and Wincanton in Somerset. The study will be conducted over a three year period and has the following aims:

- to investigate levels and seasonal occurrence of road mortality and their significance to barn owl populations;
- to determine if particular habitat features alongside roads predispose to mortality; and

- to determine whether measures could be taken to mitigate these effects, and advise on how these measures might be implemented.

This work is expected to be completed by mid 1997.

3.7.6 *Deer*

Due to their size, deer casualties are more noticeable, however, it is concluded that reports are likely to be underestimates due to carcasses being "removed" following accidents (*pers comm* British Deer Society, 1995).

National statistics are not available in UK but in some areas such as the New Forest, Cannock Chase and Thetford Forest, over 60 accidents per year have been reported every year since 1980. In Cannock Chase a total of approximately 180 accidents involving deer are reported every year (*pers comm*, British Deer Society, 1995).

Even in more urban areas such as London, road traffic accidents are noted with an average of 30 animals killed per year in Richmond Park over the last 10 years comprising some 4% of the population (*pers comm*, British Deer Society).

More generally, throughout England a study showed that road accidents were found to be the most frequent cause of death of fallow deer (of all the animals examined) accounting for between 50-80% of all carcasses found (*pers comm* British Deer Society, 1995).

In 1982 40% (10,000) of all road accidents occurring in Sweden were due to collisions with elk, red and roe deer (*pers comm* British Deer Society, 1995). Rotar & Adamic (1995), however, noted that despite high local densities of red deer and wild boar populations in the forests along a motorway in Slovenia, as well as their abilities to cross the fence, few casualties were recorded.

3.7.7 *Fox*

Green (undated) found that roads sever traditional territories and result in road deaths. A study of a sample of 1636 foxes collected in Bristol recorded 61.7% of adults and 64.3% of cubs killed in road accidents [(1)]. Statistically most foxes can expect to die on a Friday or Saturday night, when late night traffic is at its heaviest.

3.7.8 *Hedgehog*

The numbers of hedgehogs killed on British roads is very high. Reeve (1994) records a figure of 100,000. Road kills would appear to be the most important causes of death in hedgehogs. From a sample of 5552 hedgehogs recorded during survey work for the Mammal Atlas, Arnold (1993) records 3234 (58.2%) as road casualties. As the survey included live specimens, the proportion of road casualties of the overall death total could be much greater.

Date records for 1688 of the 3234 road casualties showed peaks from late April to mid May and then a fluctuation around this peak until September. Several studies have noted similar effects and the spring peak has been previously attributable to the increase activity on emergence from hibernation (Brockie,

[(1)] Data from Harris and Smith 1987 - Courtesy of Bristol Naturalists Trust

1960). It is also possible that the high mortality rates simply reflects the presence of a substantial and thriving populations (Slater, 1994).

Elsewhere, in 1994 56 hedgehogs were captured, marked and released in a 150 ha study area near Elburg in the Netherlands. In 1995, 34 of these animals were still alive and present in the study area. Of the other 22 animals, 12 emigrated, 3 died (of which 1 was a traffic victim) and the fate of the remaining 7 is unknown. Whether or not this has affected the population survival is uncertain (Huijser & Bergers, 1995).

3.7.9 *Small Mammals*

In the UK, narrow roads seem to present no barrier to small mammals with yellow necked mice in mid-Wales being retrapped 400 m from their release site having crossed two country lanes (Slater, 1994).

Arnold (1993) records bank voles, field voles and woodmice as road casualties during survey work for the Mammal Atlas.

3.7.10 *Other Mammals*

From a sample of 10,045 detailed records of moles, Arnold (1993) recorded only 68 (0.7%) as road casualties.

Bats are also recorded as road casualties. Arnold (1993) noted 5 (1.0%) lesser horseshoe bats, 1 (1.1%) Brandt's, 10 (1.7%) Natterer's, 4 (0.8%) Daubenton's, 3 (1.2%) Noctule, 35 (1.2%) pipistrelle and 4 (3.9%) Barbastelle.

Arnold (1993) also records rabbit and brown hare deaths and low proportions of mink, weasel, stoat and pine marten as road casualties with much larger proportion of brown rat and polecat. Records of the latter peak strongly in September/October which supports the theory of higher mortality in emerging young (Oxley *et al*, 1973).

3.7.11 *Other Birds*

Amongst birds there is again considerable variation. Nests of Dartford warblers close to roads are reportedly less successful as the adults can be killed during the breeding season (Catchpole & Phillips, 1992). Slater (1994) also reports on deaths of house sparrows, linnet, song thrush and blackbird on roads.

Reijnen *et al* (1995) reports that the proximity of a road does not appear to have any effect on the overall annual mortality of willow warbler populations, suggesting that traffic-related deaths do not significantly affect this species.

Some bird species typically benefit from wildlife casualties, notably carrion crow, rooks and magpies which scavenge on the carcases (Slater, 1994).

The BTO has recently reported that finches die by the thousand after eating beech nuts contaminated by de-icing salt. Mute swans can also be injured when they land on tarmac mistaken for water (Ballard & Hacker, 1996).

3.7.12 *Amphibians and Reptiles*

In Britain 20 - 40% of breeding amphibians are killed every spring as road casualties. However, there has been little research to determine whether such mortalities have an overall impact on the populations of these species (SNH, 1994).

Crittins (1983) suggested that in mid-Wales, the annual mortality of common toads was 50-60%, however, only 4% was road related.

In contrast, studies by Galet (1995) on the A71 crossing the Sologne, noted that the construction of a motorway between the habitat and spawning grounds of amphibians has serious implications for the population since amphibians always follow the same route. Traffic flows of as little as 60 vehicles per hour can eliminate about 90% of frogs in migration. Full populations can be destroyed in several years.

The Herpetological Conservation Trust suggested that some snakes may be killed on roads after using the tarmac to warm up (*pers comm*, 1995).

Lizards may be more reluctant to cross roads than snakes since the ranges they travel are smaller (English Nature, *per comm*, 1995).

3.7.13 *Insects*

Vehicles killed 0.6 - 1.9% of sedentary species such as meadow brown and approximately 7% of more wandering species such as small white. These figures were, however, insignificant when compared to those caused by natural factors (Munguira *et al*, 1992)

3.8 LITTER

Litter has not been raised as a major issue through the consultation process. From the review of published information, Luker & Montague (1994) note that litter and vegetation deposits constitute the major component of street refuse and that litter control, especially in highly impervious areas can be an effective measure to combat the pollution of road runoff.

The Mammal Society has recently distributed a survey form to members requesting information concerning small mammals which have become trapped within discarded bottles and cans. The form refers to a press article which suggested that millions of small mammals die in such litter and the form notes that up to 28 small mammals have been recorded in one bottle. The survey is to run from the beginning of February until the beginning of May 1996.