The ecological effects of new roads—a literature review

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CONTENTS

Abstract

The brief was as follows:

1. identify and critically assess the impacts (during construction and use) of new roads on the natural environment, habitats and species in protected areas;
2. identify ways of mitigating impacts (such as by way of ecological buffer zones) with reference to specific case studies in New Zealand and in other similar biogeographical regions;
3. identify future research agendas relevant to the topic.

The research is a first step in which information on the topic is assembled.

The methods included searches of journals, library databases, advertisements in journals and on the Worldwide Web and through the generosity of many colleagues.

A few literature databases relevant to the area of research do exist; the largest being that compiled by Wildlands Centre for Preventing Roads (CPR) in the USA. There are also a few literature reviews on the ecological effects of roads (to ensure an independent approach was taken, these were not consulted until this report was completed).

There are many reports on the physical and chemical effects of roads, associated structures and road traffic. These include soil erosion, alteration to surface water hydrology and pollutants in water run-off.

There is a large number of reports on the presence of pollutants in biota inhabiting roadside verges. Most of the literature simply reported surveys in which levels of heavy metals and other pollutants are recorded. Very few reports discuss the effects of pollutants; no generalisation can be made because the effects of biota vary from group to group. Some reports indicate that plants on roadside verges become more susceptible to disease and attacks by pests. There is a need for long-term monitoring studies and research which looks at the fate of pollutants in ecosystems.

The ecological effects of roads include physical disturbance, habitat loss, extinction of populations and species near the road edge, mortality of wildlife on roads, use of road edges has habitats, dispersal of wildlife (including invasive species and alien species) along road networks.

The most important and serious impact of roads on nature is through habitat fragmentation; that is, not only loss of habitats but fragmentation of previously contiguous habitats and subsequent isolation of habitat fragments. Habitat fragmentation is considered by many to be the greatest and most serious threat to nature. Fragmentation of habitats has implications for loss of biological diversity at species, population and genetic levels.

New roads may take traffic, people and introduced species to what were previously undisturbed areas with subsequent impacts on the ecology of the area. Roads facilitate more roads and there is an incremental and long lasting effect.

The detrimental effects of roads on nature by far outweighs any advantages to wildlife; both in the short-term and particularly in the long-term.

Attempts to reduce the ecological effects have been addressed in many ways. Pollutants in surface water from roads can be contained. The barrier effects of roads can be reduced with tunnels and nature overpasses. The road edge can be managed for indigenous wildlife. Loss of habitat can be compensated by establishing similar habitats elsewhere (mitigation banking). However, habitat fragmentation has not and can not been addressed fully; road routes can be changed to reduce fragmentation but the only real answer is not to build the road.

There are several areas in need of further research. The long term effects of pollution on roadside wildlife have not been investigated in depth. The effectiveness of tunnels and other routes for wildlife seems not well quantified. The effects of roads on dispersal of alien species is an area of particular relevance to New Zealand. The methodology and methods for assessment of likely ecological impacts requires much more research and development.

1. Introduction

This is a report of a survey of the literature on the ecological effects of roads on natural areas and wildlife.

The objectives were as follows:

1. identify and critically assess the impacts (during construction and use) of new roads on the natural environment, habitats and species in protected areas;
2. identify ways of mitigating impacts (such as by way of ecological buffer zones) with reference to specific case studies in New Zealand and in other similar biogeographical regions;
3. identify future research agendas relevant to the topic.

The report is a first step by which information on the topic is assembled. This report has been compiled in as objective a fashion as possible. There has been an emphasis on reporting research which can be quantified, rather than material from 'popular articles', reports in magazines and items in newspapers. That is, the emphasis has been to concentrate on reports resulting from empirical investigations rather than reports which deal mainly with generalisations.

The aim of this report is to provide an objective summary of the literature and, where appropriate, comment on the reports or topics of relevance to New Zealand. It was not intended to give interpretations of the literature nor was it intended to comment on any specific proposed road in New Zealand. This report is, therefore, a review of the literature rather than a review of the impacts (positive or negative) of roads on natural areas and wildlife.

The literature references cited in the text form only part of the bibliography included at the end of the report. This is an independent review and it has been written without reading or reference to other reviews. Some aspects of this report and other related research have been published elsewhere (Spellerberg, in press).

2. Methods

Work commenced in July 1996 and the report was completed in July 1997. Most of the survey of the literature was undertaken in 1996.

The search for the literature on the ecological effects of roads was undertaken as follows:

1. A survey of Journals available to the authors. These were obtained privately or in the libraries of Lincoln and Canterbury Universities (see Appendix One for serials checked).
2. A survey of a collection of literature on Linear Features (previously assembled for the UK Nature Conservancy Council; Spellerberg & Gaywood, 1993).
3. Through literature databases such as OPAC, INNZ - New Zealand, SSCI, CAB Abstracts, Current contents, New Zealand Science and Technology, Agricola and Spectrum.
4. On the Internet. A page was put on the Worldwide Web in September 1996 (Appendix Two).
5. By way of correspondence or personal interviews.
6. Through advertisements in journals and bulletins. These were placed in The New Zealand Ecological Society News Letter, The British Ecological Society Bulletin and The Biologist (Journal of Institute of Biology).
7. Reports and existing databases on ecological effects of roads.
8. From references in the literature as reports were obtained.

Reports were therefore obtained first hand, by way of inter-library loans, and through the kindness of colleagues providing material.

3. Results

3.1 PREAMBLE

3.1.1 Ecological effects of secondary activities

This report does not include information on the ecological effects arising from secondary activities such as the mining of aggregates for road building, transportation of materials for road maintenance and the use of fossil fuels for transportation.

3.1.2 Interactions between biota and roads

Whereas this report concerns the ecological effects of roads on biota and ecosystems, there are effects of nature on roads, traffic and products of traffic. For example, trees may prevent land slips onto roads (Haigh *et al.*, 1995). Trees and other plant life forms accumulate heavy metals (Ward *et al.*, 1974) and may help to reduce the amount of airborne pollutants, especially in urban areas (Dochinger, 1980; Greszta, 1982). This aspect is not dealt with in detail.

3.1.3 Roads and landscapes

Roads affect landscapes and although there is an overlap between landscape ecology and large-scale ecology, this topic was considered not to be within the brief of this investigation.

3.1.4 Impacts of traffic and tourism in previously undisturbed areas facilitated by new roads

New roads facilitate travel and opportunities to visit new and possibly undisturbed areas. There are, therefore, implications for impacts of tourism in new areas as a result of new roads. This aspect was not considered within the brief of the present study. However, it may be important to note those studies about human disturbance on plant species richness in 'isolated' conservation areas. For example, Drayton and Primack (1996) studied a 400 ha woodland park in Boston to determine how species composition had changed between 1894 and 1993. The park is isolated by roads and is strongly affected by human activity. They found an increase in exotic species and a decrease in native species (155 out of 422 species had gone). These changes coincide with increased human disturbance.

3.1.5 Effects of roads on the physical environment

Soon after commencing this task it became evident that there was a huge amount of literature about the effects of roads on the physical environment. In particular, the physical and geological effects have been well researched. The effects on water run-off and effects of pollution from roads and traffic have been well documented (see, for example, Watkins (1981) 'Environmental Impact of Roads and Traffic'). The geographical location of roads may have implications in terms of altering the hydrology of an area and also sediment flow. For example, La Cock & Burkinshaw (1996), in a study of the effects of road construction in coastal areas of southern Africa, reported changes in the water and sediment flow.

3.1.6 Road networks

There are effects of roads on nature and there are effects of road networks on nature. Different road densities and their effects have been investigated (see, for example, Theil's (1985) work on road densities and wolf habitats). The most important implication of road networks is habitat fragmentation. This is discussed in section 3.8.

3.1.7 Structures associated with roads

Structures associated with roads, such as rest areas, telegraph poles and wires, fences, bridges and tunnels, also have effects. Some wildlife use tunnels as habitats and birds may use overhead wires for roosting. The behaviour and movement of wildlife may be affected by such structures. For example, Feldhamer *et al*. (1986) have reported the effects of interstate highway fencing on white-tailed deer activity. Fences reduced the number of deer on the roads but not the road kills.

3.1.8 Geological conservation

Concerns about the effects of roads on the natural environment include those relating to geological conservation (Larwood & Markham, 1995).

3.1.9 Biological diversity

It is noticeable that in more recent publications the term biological diversity starts to replace terms such as wildlife and biota. Biological diversity is defined in the 1992 Convention on Biological Diversity and that definition refers to diversity at different biological levels of organization. It is suggested that whenever the term is used, it should be qualified with respect to which level of organization being referred to. Without qualification, the meaning of the term and the reason why it was introduced may be overlooked.

3.2 LITERATURE DATABASES AND OVERVIEWS ON ECOLOGICAL EFFECTS OF ROADS

There are existing literature databases and overviews, notably from the USA, the U.K. and the Netherlands. English Nature (UK) have commissioned reports on the impacts of roads on nature conservation and guidance on mitigation. The literature databases are as follows:

Transportation Research Board Publications USA.
This is a bibliography (abstracts included) on the ecological and environmental effects of highways and kindly provided by Barbara Post, TRB Library, USA.

ROAD-RIP Roads Bibliographic Database.
This has been compiled by Wildlands Centre for Preventing Roads (CPR) in the USA and includes many citations.

Discs with the CPR files were kindly provided by Bethanie Walder at Wildlands CPR. The ROAD-RIP database contains citations under the following headings (number in brackets is the number of citations under that heading). The citations refer to articles in journals (many local to the USA), books and unpublished reports. A hard copy and set of discs has been provided separately for use by the Department of Conservation (DoC) and are lodged at DoC Head Office library, Wellington. Following the completion of the present report, the citations in the ROAD-RIP database were read and any literature relevant to New Zealand or any literature which could add to the present report was extracted. The ROAD-RIP database has the following numbers of papers on the topics indicated:

Storm run-off (94)
Changing hydrology (16)
Glacial streams (8)
Bank erosion (19)
Toxins (97)

Indiana (12)
Illinois (33)
Mid-west (4)
Ohio (21)

Pollution:
emissions (55)
ground (10)
hydrocarbons (33)
lead (134)
air (180)
water (131)
metals (13)
noise (19)
urban (85)
Pollution control (178)

Reports (not necessarily with bibliographies) with reviews about effects of roads on nature (some with information on mitigation) have been published in several countries. In the Netherlands, in particular, there are Government sponsored promotional publications about ecological effects of roads and also well publicised methods for dealing with habitat fragmentation.

Aanen *et al*. 1991. Nature engineering and civil engineering works. Pudoc, Wageningen.
A collection of papers on the relation between nature engineering and civil engineering works. This book included many examples of mitigation methods.

Edmunds 1995. Head on Collision 1995. The Wildlife and Roads Report. Threats to important wildlife sites from road developments in Cumbria, Lancashire, Merseyside, Greater Manchester and Cheshire.
A report prepared by Janet Edmunds for the Cheshire, Cumbria and Lancashire Wildlife Trusts.

Environmental Resources Management 1996. The significance of secondary effects from roads and road transport on nature conservation. *English Nature Research Reports No. 178*, English Nature, Peterborough.
A very comprehensive report for English Nature by Environmental Resources management.

Noss 1995. The ecological effects of roads or the road to destruction.
Not a very objective report because roads are considered bad from the start.

Ramsay (Ed.) 1994. Roads and nature conservation. Guidance on impacts, mitigation and enhancement. English Nature, Peterborough.
A very comprehensive report by Penny Anderson Associates.

Reviews in book chapters or as journal articles were as follows:

Andrews 1990. Fragmentation of habitat by roads and utility corridors: a review. *Australian Zoologist* 26: 130–141.
Very good review of the literature, particularly with reference to habitat fragmentation.

Bennett 1991. Roads, roadsides and wildlife conservation: a review. Pp. 99–118 in Nature Conservation 2; The role of corridors, Saunders and Hobbs (Eds), Surrey Beatty & Sons.
Very good review of the literature.

Forman 1995. Land mosaics, the ecology of landscapes and regions. Chapter five, Corridor attributes, roads, Cambridge, Cambridge University Press.
Good review of roads as linear landscape features.

Gilbert 1989. The ecology of Urban Habitats. Chapter nine, Roads. Chapman and Hall, London.
Good analysis of the literature.

Leedy 1978. Highways and wildlife: implications for management. Pp. 364–383 in Classification, inventory, and analysis of fish and wildlife habitat. The Proceedings of a National Symposium. Biological Services Programme, Fish and Wildlife Service, U.S. Dept. of the Interior.
An overview of the good and bad aspects of impacts of effects of roads on nature.

Schonewald-Cox & Buechner 1992. Park Protection and public Roads. Pp. 373–395 in Fiedler *et al.*, Conservation Biology, London, Chapmand & Hall.
Good in terms of the role of roads facilitating effects on destinations such as protected areas.

Southerland 1995. Conserving biodiversity in highway development projects.
An excellent overview with reference to the concept of biological diversity, the National Environmental Policy (USA), effects of roads at different stages with emphasis on fragmentation, environmental assessment of the effects, and mitigation.

Watkins 1981. Environmental impact of roads and traffic. Chapter six, roadside pollution. Applied Science Publishers, London.
Excellent review of pollution from roads and traffic.

3.3 RESEARCH ON ECOLOGICAL EFFECTS OF ROADS UNDERTAKEN IN NEW ZEALAND

There were a few reports in the literature which were specific to New Zealand. The nature and extent of effects will be different in different biogeographical regions, therefore it was thought important to identify research on this topic in New Zealand.

3.3.1 Erosion

Impacts of forest road erosion in the Dart valley, Nelson and resulting increasing sediment loads were described in Mosley (1980). Fahey & Coker (1989) have described surface erosion on roads in granite terrain in Nelson and Coker & Fahey (1993) have described sediment yield from erosion in road networks in Golden Downs and Motueka. Similar studies in Marlborough Sounds have been reported by Fahey and Coker (1992) and Coker *et al.* (1993). Most recently, Paterson (1996) has reported on the slope instability in the Arthur's Pass area.

3.3.2 Changes in microclimate with habitat fragmentation

Young & Mitchell (1994) studied the microclimate and edge effects in fragmented podocarp-broadleaf forest (see section 3.8 below).

3.3.3 Emissions

The effects of lead from motor-vehicle on trees and the seasonal variation in the lead of soils has been researched by many people including Ward *et al*. (1974), Ward *et al*. (1975) and by Ward *et al*. (1979). The use of lead-free petrol will have addressed this issue in New Zealand.

3.3.4 Plants on roadside verges

A survey of the distribution of 24 exotic plant species along roadsides in the South Island is reported in Wilson *et al*. (1992). More recently, Ullmann *et al*. (1995) surveyed the roadside verge vegetation with respect to environmental gradients in the South Island.

3.3.5 Alien and invasive species

Williams and Buxton (1995) surveyed vegetation invaded by two species of *Passiflora* in the South Island of New Zealand and drew attention to records from road cuttings. Research on weeds in New Zealand forest and the implications of reserve design for weed control has been reported by Timmins & Williams (1990, 1991). Although not specific to New Zealand, Crawley (1989) from Auckland University has written a review about the chance and timing in biological invasions which is very relevant to the ecology of dispersal of introduced species.

3.3.6 Effects on animals

In a study of stoats inhabiting beech forests, Murphy & Dowding (1994) found that a road through the study area affected the behaviour of stoats. Females avoided the road but males preferred it. More recently, King *et al*. (1996) have reported on studies of small mammals in relation to habitat in Pureora Forest Park, central North Island. They note that roads introduce a linear community of small mammals into forests.

3.3.7 Road mortality

Road mortality studies seem few. Morris and Morris (1988) reported on hedgehog road mortalities.

3.3.8 Road verges as linear habitats

Given (1994) surveyed and reviewed roadsides, railway margins and waterways as habitats for wildlife. They also reviewed and made suggestions for management of these linear habitats.

3.4 PHYSICAL AND CHEMICAL EFFECTS (NOT SPECIFICALLY LINKED TO BIOTA)

The survey of literature revealed a large number of publications dealing with physical and chemical effects. There are studies on road dust (Keller & Lamprecht, 1995), salinity of motorway soils (Thompson *et al*., 1986), sand and salt (Oberts, 1986), roadside litter (Andres and Andres, 1995), character and dispersal of motorway run-off (Bellinger *et al.*, 1982), toxicity of sediments contaminated with road run-off (Boxall & Maltby, 1995), and landslides, erosion and sediments (Haigh, *et al.*, 1993). There are studies specific to pollution detention ponds (e.g., Yousef *et al.*, 1986).

Some researchers have studied the aggregate effects of a variety of impacts generated by motor transport on the environment (Sorokovikova, 1990). Such studies, it is claimed, may provide a basis for policy recommendations on how to reduce pollution.

There have been some very detailed studies on the numerous chemical elements arising from roads, vehicles, fuels and corrosion, wear and tear of vehicle components (see for example Stotz, 1987 and Ward, 1990).

However, the most comprehensive report on highway pollution (including standards, legislation and practice) was Luker and Montague's (1994) report 'Control of pollution from highway drainage discharges' prepared for the Construction Industry Research and Information Association in the U.K. This report also gives a very comprehensive list of the sources and classifications of pollution in highway run-off.

3.5 EFFECTS DURING CONSTRUCTION

Assessment of environmental effects during construction of roads has sometimes been included in environmental impact assessments (see Section 3.10). Reports in the literature which deal only with effects during construction seem to be few. For example, Burke & Sherburne (1982) monitored wildlife populations and activity during and after construction of a road in northern Maine. They reported that movements and densities of birds and mammals did not differ significantly during and after construction. Cramer & Hopkins (1982) examined the effects of a dredged highway construction on water quality in a Louisiana wetland. They reported that any effects tended to be temporary and that increased turbidity and colour gradually returned to the preconstruction conditions.

3.6 POLLUTION EFFECTS ON BIOTA AND ECOSYSTEMS

This section includes physical and chemical effects from existing roads which have been linked to effects on biota and ecosystems.

Pollutants impacting on biota include noise, light, sand, dust and other particulates, metals such as Pb, Cd, Ni and Zn, gases such as CO and NO_x. The range of pollutants in water run-off is large (see for example Gjessing *et al.*, 1984a and 1984b). This great variety may result in less than comprehensive studies for some pollutants.

The extent to which emissions and disturbances extend from a road have been research by some authors. In Table 1 (from Schonewald-Cox & Buechner

TABLE 1. EXAMPLES OF THE DISTANCES THAT ROAD-GENERATED EDGE EFFECTS EXTEND INTO ADJACENT HABITAT.

ROAD EFFECT	DISTANCE	REFERENCE AND LOCATION
High levels of heavy metals:	Upto 48 m	Virginia, USA
In soil near highways	30 m	England
In plants	40 m	Israel
	120 m	Netherlands
In animals	Up to 48 m	Virginia, USA
Sediment reaching areas needing protection	9 m–89 m	USA
Increase in edge-species component of bird community	100 m	Maine, USA
	120 m	USA
Plant damage from de-icing salts	125 m–500 m	Oregon, USA
Decrease in abundance of Roosevelt elk	300 m–600 m	Alaska, USA
Altered activity budget of caribou	400 m	Maine, USA
Altered abundance of some bird species	200 m–1200 m	Netherlands

From Schonewald-Cox & Buechner 1992, Park protection and public roads. Pp. 373–395 in Conservation Biology (Fiedler & Jain, Eds.), The theory and practice of nature conservation preservation and management. London, Chapman & Hall.

(1992)) there is information which shows that effects can be detected some hundreds of metres from a road.

The following section is divided on the basis of types of pollutants but nevertheless there are both secondary effects and synergenistic effects, some of which may be complex in their operation. For example, road pollutants may cause physiological stress in some plants and make them more susceptible to pest attack (see, for example, Braun & Fluckiger's (1984) work on aphid infestations of roadside trees in Switzerland).

In one review of toxic substances in flowing water, Hellawell (1988) described the wide range of potential pollutants and noted that very few generalisations can be made about their effects on biota. Each species tends to respond to different pollutants in different ways and even different stages in the life history may have very different responses.

The literature includes reports and research on effects arising from the following pollutants.

3.6.1 Noise and light

Noise and artificial lighting have been shown to effect some wildlife. For example, Reijnen *et al.* (1995) have researched noise effect distances on wildlife in the Netherlands and found reductions in bird population densities. Some wildlife are attracted to artificial lighting and the timing of behaviour of some birds could be altered. Although there is much research on the effects of noise and light on nature, the effects of road traffic noise and artificial lighting seem not well researched.

3.6.2 Dust and sand

There seem to have been very few studies of the chemical and physical effects of road dust on nature; some of these few studies relate to specific regions or biomes such as the Tundra and Taiga (see for example Forbes, 1995 and also Walker and Everett, 1987). Physical effects may include cell destruction and blocked stomata. Chemical effects may arise from elements such as Al, Cr, Fe and Ni deposited in airborne road dust and affecting biota via soil enrichment (see for example Santelmann & Gorham, 1988). A recent literature review by Farmer (1993) described the effects of dust types on crops, grasslands, heathlands, trees, arctic bryophte and lichen communities. Dust may affect photosynthesis, respiration, transpiration and facilitate affects of gaseous pollutants. Farmer found that Epiphytic lichens, Sphagnum and other mosses were the most sensitive of those studied.

3.6.3 Heavy metals (trace metals)

Elements such as Pb, Ni, Cd, and Zn arise from petroleum products and car tires and find their way into roadside biota. These elements are known to accumulate in roadside plants, animals and other organisms. In one study in Germany, the highest levels of heavy metal accumulation occurred in mosses on the ground (Lötschert & Köhm, 1978). This seems to be a very well researched area with regard to levels and rate of accumulation with respect to traffic volumes (for example Motto & Daines, 1970). However, there seems to be less research on the effects of accumulation of heavy metals in biota.

Some authors report only the levels of accumulation of the elements (and, in many cases, that accumulations caused no apparent harm). For some plants there may be enhanced root growth as a result of soil contamination from roadside dust carrying trace metals (Wong *et al*. 1984). Amongst invertebrates, the effects may or may not be detrimental. For example, Przybylski (1979) found that whereas combustion gases may cause reductions in species richness in arthropods, some groups flourish in the environment polluted by combustion gases. In an earlier study, Muskett and Jones (1980) found no obvious decline in either numbers of invertebrates caught in pitfall traps or in species diversity (alpha diversity index) with increasing metal pollution load.

Some reports draw attention to the limited research on the effects of animals feeding on biota near roads. There has been concern about bio-accumulation of metals from one trophic level to another (see, for example, Scanlon 1987). There were also warnings about possible effects on humans who may consume roadside plants and fruits (Rodriguez-Flores & Rodriguez-Castellon, 1982). Some studies show that the levels in animal predators are too low to be toxic (Wade *et al*., 1980). In one study it was suggested that contamination of roadside habitats by lead does not pose a serious threat to highway nesting birds that are aerial feeders, such as swallows (Grue *et al*. 1984).

3.6.4 gases

The direct effects of road traffic gases (SO_2, CO_2, CO, NO_X and Hydrocarbons) on biota other than humans seems not to have been widely researched. Effects on plant growth have been observed; for example Sarkar *et al*. (1986) recorded stunted growth in plants near highways. Kammerbauer *et al*. (1986) drew attention to the apparent lack of experimental work on the effects of exhaust emissions on forest trees (noting much controversy about reasons for die-back in forest trees near roads). In their work, they give evidence for injuries of Norway spruce by exhaust emissions CO and NO_X). They also demonstrated drastic reductions in these effects when catalytic converters are used.

Spencer and Port (1988) found that *Lolium perenne* grows more vigorously in soil taken from near roads and that NO_X and de-icing salt are considered as possible causes. In Angold's (1992) detailed study of the ecological effects of road pollutants on heathland communities in southern England, it was found that nitrogen caused increase growth in plant species. This appeared to have resulted in changes in the plant species composition (effects were measured up to two hundred metres into the heathland communities).

3.6.5 Deicer agents

Much concern has been expressed about the effects of deicing agents on roadside vegetation. Surveys and experimental work has been undertaken on the effects of deicing agents since at least the late 1960s and early 1970s (see for example Westing, 1969 and Davison, 1971). The effects on roadside verge vegetation may extend up to several metres from the road (Westing, 1969). Water run-off from the road could result in more distant effects in water courses but little research has been done on this aspect (Good & Grenier, 1994). Sodium chloride has been very widely used as a deicing agent and there are effects in terms of changes in species composition (Davison, 1971) and in facilitating dispersal of halophytic species (Scott & Davison, 1985). Salt in roadside soils may also increase the available nitrogen and some minerals (Spencer *et al*., 1988; Townsend, 1984).

Calcium magnesium acetate (CMA) is being used as an alternative to NaCl for deicing highways and reports in the USA from the 1980s suggest that CMA may have beneficial effects on trace metal mobility (Amrhein & Strong, 1990).

Some research has been undertaken on the selection of tree species and varieties, as part of roadside landscaping. In one study, trees sensitive to $CaCl_2$ were identified and in addition it was found that deicing agents increased sensitivity of *Platanus* to infection by fungus *Gnomonia venata.*

3.6.6 Effects on aquatic systems and biota

Effects from both road construction and operational roads have been investigated. Serious river pollution has occurred in some instances during road construction (McNeill, 1996), and in another report, Extence (1978) observed that discharges arising from road construction can be serious enough to warrant implementation of control measures.

The effects of pollutants in water run-off from roads and urban areas on aquatic biota and ecosystems may be both immediate and long-term (the former seems well researched but not the latter). Water run-off may alter hydrology, increase sediment load, increase nutrients and may also result in accumulation of many kinds of pollutants.

Increases in sediment load and changes in stream flows resulting from logging activities have long caused concern. In 1972, Burns (1992) noted sustained logging prolonged adverse conditions in streams for fish. Increased sediment in streams resulting from logging operations has been found to effect fish populations (Eaglin & Hubert 1993).

Effects of roads and run-off on aquatic biota and aquatic ecosystems have attracted much attention in terms of their impacts. The role of wetlands as sinks for metals and macronutrients from roads has also been much researched (see for example Yousef *et al*. 1983, Yousef *et al*. 1996). There is an area of conflict here; on one hand there are attempts to avoid pollution of wetlands and on the other hand there are wetlands being used as pollution sinks.

One particularly detailed study on the effects of motorway run-off on freshwater ecosystems has been undertaken by Maltby *et al*. (1995). They reported changes in species diversity and in species composition of macro-invertebrate assemblages but found no changes in either diversity or abundance of epilithic algae.

The most damaging agent in aquatic habitats has been said to be siltation and increasing nutrient loads rather than by the many chemicals (Dickson, 1986).

3.7 EFFECTS OF ROADS ON BIOTA AND HABITATS

A general review of the effects is provided in this section and specific literature is listed in Box 1.

Southerland (1995) has drawn attention to the incremental effects of road developments and argues strongly that roads are an important case of the loss of biological diversity. The effects of roads on biota and habitats are often described as being either negative or positive. For example, road kills are seen as negative and an increase in edge habitat is seen as positive. This dichotomy is simplistic because it does not analyse the effects in the wider context of community ecology. For example, although there are many reports in the literature on road kills, the longer term effects on the population dynamics of the species concerned may not have been researched. In general road kills do not seem to have detrimental effects on animal populations except in those cases of species with small or diminishing populations. A good overview on road kills is given by Bennett (1991).

The secondary effects on other species is often not researched. One example of a secondary effect has been the transportation of fungal spores in mud and debris attached to vehicles which in turn may have facilitated the spread of the pathogenic fungus *Phytopthora cinnamomi* in forests in southern Australia (Weste, 1977; cited in Bennett, 1991).

The effects of roads on biota and habitats vary with biogeography and vary from species to species. The greatest effects of roads occur in previously undisturbed areas. It is not possible therefore to generalise. Even within some genera it may not be possible to make generalisations because some species may benefit and some may not. However, the following subject areas indicate the range of effects (but not the extent or magnitude) and can be used as a guide for design of environmental impact assessments for new road projects.

Roads causing loss of habitat or deterioration in habitat

Reijnen & Foppen 1994. Birds, *Phylloscopus trochilus*, Netherlands.
Sherburne 1985. Several species of birds and mammals, Northern Maine, USA.

Road edges providing linear habitats

Adams & Geis 1983. Small mammals, USA.
King *et al.* 1996. Small mammals in forests, New Zealand.
Reijnen & Foppen 1995. Birds, Netherlands.
Warner 1992. Birds, Illinois
Lamont *et al.* 1994. Plants, *Banksia hookeriana*, Australia.
Munguira & Thomas 1992. Butterflies, UK.

Roads affecting behaviour (including dispersal) of mammals

Adams & Geis 1983. Small mammals, USA.
Backowski & Kozakiewicz 1988. Small mammals, Poland.
Brody & Pelton 1989. Bears, North Carolina.
Burnett 1992. Small mammals, Australia.
Garland & Bradley 1984. Desert rodents, Mojave Desert, Nevada.
Korn 1991. Small mammals, Germany.
Mader 1984. Wood mice, Germany.
Merriam *et al.* 1989. Mice, Ottawa.
Murphy & Curatolo 1987. Caribou, Canada.
Murphy & Dowding 1994. Stoats, New Zealand Beech forest.
Oxley *et al.* 1974. Small mammals, Canada.
Verboom 1995. General review of roads as barriers, Netherlands.

Roads and traffic affecting birds

Canaday 1996. Several species, Ecuador.
Clark & Karr 1979. Several species, Illinois.
Ferris 1979 Several species, Maine, USA.
Johnson 1990. Bald eagles, Southern Alaska.
Reijnen *et al.* 1995. Several species, Netherlands.
Zande *et al.* 1980. Several species, Netherlands and re-analysis of a previous study.

Roads and traffic affecting biota other than birds and mammals

Baur & Baur 1990. Snails (*Arianta*), canada.
Mader 1984. Carabid beetles, Germany.
Mader *et al.* 1990. Arthropods, Germany.
Majer & Beeston 1996. Alpha diversity of ants and comparison of effects of roads with effects of other land uses in Western Australia.

Road mortalities

Adams & Geis 1983. Small mammals, USA.
Bennett 1991. Good review for all taxa.
Bernardino & Dalrymple 1992. Snakes, Florida.
Bruinderink & Hazebroek 1996. Ungulates, Europe.
Case 1978. Various animal taxa, Nebraska.
Dhindsa *et al.* 1988. Birds, India.
Dowler & Swanson 1982. Cedar Waxwings (*Bombycilla cedrorum*), Texas.
Fahrig *et al.* 1995. Amphibians, Ottawa, Canada.
Illner 1992a. Grey Partridge (*Perdix perdix*), Germany.
Illner 1992b. Owls, Germany.
Madsen 1996. Otters (*Lutra lutra*), Denmark.
Morris & Morris 1988. Hedgehogs, New Zealand.
Romin & Bissonette 1996. Deer, USA.

Vestjens 1973. Various taxa, New South Wales.

BOX 1. EFFECTS OF ROADS AND TRAFFIC ON NATURE: EXAMPLES OF THE RANGE OF LITERATURE.

Effects during construction

- During road construction there is loss of habitat (usually not quantified in terms of the area) and biota.
- Additional effects result from the supporting activities for construction.
- There are impacts which occur beyond the immediate vicinity of the road such as changes in hydrology. Mining for aggregates for the road may take place in a different area. It is important therefore to agree on the geographical boundary for environmental impact assessments.

Short term effects

- The new linear gap created by the road introduces a new microclimate and a change in physical conditions extends to varying distances from the road edge.
- In the short term there is plant mortality along the road edge and such mortalities may extend from the road edge for varying distances.
- The mortality of plants has direct and secondary effects on other organisms.
- Some fauna will move from the area of the road as a result of habitat loss and physical disturbance.
- Animals may be killed on the road.

Long term effects

- Effect of road kill on populations of species killed.
- Road kills have secondary effects as a source of food.
- The loss of habitat and change in habitat extends beyond the edge of the road.
- There is a change in the biological communities which extends for varying distances from the road edge.
- There is fragmentation of habitat and this in turn has implications for habitat damage and loss, for dispersal and mobility of organisms, and for isolation of populations.
- The newly created edge provides habitat for edge species.
- The edge habitat or ecotone and traffic on the road may facilitate dispersal of some taxa, including pest species.
- Dispersal of pest species via ecotones or traffic may have secondary effects on biological communities.
- Associated structures such as bridges and tunnels may provide habitats for some taxa.
- Run-off from the roads may affect aquatic communities.
- Emissions, litter, noise and other physical disturbances may extend into the roadside vegetation for varying distances and results in changes in species composition.
- For some taxa, roads may act as barriers limiting dispersal and mobility. There may be secondary effects caused by changes in dispersal of some predators.

- Roads provide an infrastructure for more developments and incremental effects. Road facilitate more roads.
- Roads bring people and further impacts to undisturbed areas.

3.8 HABITAT FRAGMENTATION BY ROADS

3.8.1 General comments

In addition to the ecological effects of roads described in part seven, every road contributes to habitat fragmentation and every road facilitates more habitat fragmentation.

Habitat fragmentation (sometimes referred to as landscape fragmentation) has become a major focus of research in conservation biology. This is because it is believed by many to be having, by far, the greatest detrimental impact on nature. Wilcox and Murphy (1985), for example, have claimed that it is 'the most serious threat to biological diversity, and the primary cause of the present extinction crisis'. Andrews (1990) has provided a good overview of the effects of habitat fragmentation by roads. She refers to literature on the following effects:

- habitat loss and modification;
- edge effects and penetration into biological communities;
- isolation of populations;
- roads facilitating disturbance;
- increased road kills;
- increased human access.

3.8.2 Analysis of fragmentation

There are many ways of quantifying habitat fragmentation. In addition to rate of reduction of total habitat area and increase in the number of fragments, the studies on habitat fragmentation have included the measurement of the extent of isolation of habitats, area of edge (and edge related indices), shape of fragments and degree of heterogeneity. The research on forest edges has also prompted discussion about methods of analysis. In Australia, for example, Salisbury (1993, 1996) has prepared a report 'A Design for Studying Edge effects in Forests'.

In one study of forest fragmentation in the Rocky Mountains, Reed *et al*. (1996) assessed the extent of fragmentation caused by roads and by clearcut forestry. They found that roads contributed more to fragmentation than did clearcuts. Edge habitat created by roads was 1.54–1.98 times the edge habitat created by clearcuts.

3.8.3 The general effects

The ecology of habitat fragmentation is becoming a very well researched area. Not all habitat fragmentation is caused by roads but nevertheless the general research on the effects of habitat fragmentation is pertinent to any appraisal of the ecological effects of roads. Reviews of the literature on habitat fragmentation can be found in literature listed in Box 2 and a summary of the effects of habitat fragmentation is given in Box 3 (from Schonewald-Cox &

Buechner (1992)). Agriculture, forestry, urbanization, roads and other linear human made features can all cause fragmentation.

Robinson, G.R., Quinn, J.F. 1992. Habitat fragmentation, species diversity, extinction, and design of nature reserves. Pp. 223–248 in Jain, S.K., Botsford, L.W. (Eds) 1992 Applied Population Biology, *Monographiae Biologicae Vol. 67*, Kluwer Academic Publishers, Dordrecht.

Spellerberg, I.F. 1991. Biogeographical basis of conservation. Pp. 293–322 in Spellerberg, I.F. *et al.* (Eds) 1991, The Scientific Management of Temperate Communities for Conservation, Blackwell Science, Oxford.

Usher, M.B. 1987. Effects of fragmentation on communities and populations; a review with applications to wildlife conservation. Pp. 103–121 in Saunders, D.A. *et al.* (Eds) Nature conservation: the role of remnants of native vegetation, Surrey Beatty & Sons, Australia.

Wilcove, D.S. *et al.* 1986. Habitat fragmentation in the temperate zone. Pp. 237–256 in Soule, M.E. (Ed.) 1986, Conservation Biology: The science of scarcity and diversity, Sinauer Associates, Massachusetts.

Wilcox, B.A., Murphy, D.D. (Eds) 1985. Conservation strategy: the effects of fragmentation on extinction, *American Naturalist* 125, 879–887.

BOX 2. LITERATURE REVIEWS OF HABITAT FRAGMENTATION.

Habitat fragmentation results in loss of habitat, an increase in the number of habitat fragments and the isolation of populations (which has implications for loss of biological diversity at the population and genetic level). For some taxa, the area of habitat becomes too small to support the resources needed for survival. Populations are reduced in size, which has implications for biological diversity at the population level of organization. For example, forest fragmentation may lead to reduced levels of standing dead wood which then impacts on tree cavity nesting birds. In highly fragmented forests, some bird species are attracted to nest near forest edges, where predation rates are highest (referred to as an 'ecological trap' by Gates & Gysel, 1978).

Reduction in area of biotic communities also has implications for ecological processes and resilience of communities to recover from perturbations. This is because as the area becomes smaller, there is less flexibility. In some biotic communities, natural disturbance such as gaps or cleared areas (ranging in scale from mole hills to land-slips) and perturbations such as flooding and fire have important functions, but the scale is important. Some communities become so small and isolated that they are at risk of total destruction by fires or other perturbations. In a review paper on protection of natural areas in fragmented landscapes, Noss (1987) has drawn attention to the need for conservation networks to be developed to help overcome the effects of habitat fragmentation.

3.8.4 Microclimate and edge effects in forests

In a study of woodlands in Ohio, Kupfer (1996) looked at patterns and determinants of edge vegetation and concluded that the stand microclimate dictates edge successional processes. Williams-Linera (1990), working on forest edges in tropical pre-montane wet forests of Panama, found changes in microclimate conditions penetrating as much as 15 m into the forests.

I. MODIFICATION OF HABITAT
   A. Changes in the size and shape of landscape elements
      1. Decreased size of continuous habitat in remnant patches
      2. Altered shape of continuous areas of patch interior habitat
      3. Altered geometry of edges
      4. Increased perimeter:area ratios of remnant patches
   B. Changes in the connectivity and isolation of landscape elements
      1. Increased degree of isolation of remnant patches for species, materials, or effects restricted to patch interior habitats
      2. Increased connectivity of remnant patches for species, materials, or effects following edge or modified habitat
      3. Increased access for logging, mining, hunting, and other resource-extraction activities
      4. Increased access for poachers and other illegal activities
   C. Changes in habitat types
      1. Increased amount of edge and modified habitats
      2. Decreased amount of patch interior habitats
      3. Changes in the composition and geometry of edge habitats
      4. Loss of sensitive species from small remnant patches
      5. Altered balance of exotic and native species
      6. Altered balance of weedy or edge and patch interior species
      7. Increased spatial and temporal variation in habitat quality for patch interior species
      8. Increased habitat homogeneity within small remnant patches
      9. Changes in the capacity of the reserve for populations of sensitive species

II. MODIFICATION OF THE QUALITY OF PROTECTION PROVIDED
   A. Changes in balance of patch interior versus edge species and native versus exotic species
   B. Increased exposure of internal areas and further subdivision of landscape
      1. Direct removal of habitat
      2. Increased amount of edge in landscape
      3. Incresed exposure to edge effects
      4. Increasing fluctuation of microclimate and related processes
      5. Influx of foreign materials (pollen, insects, toxins, garbage etc.)
      6. Disturbance of habitat (soil compaction, direct destruction of vegetation or substrate, etc.)
   C. Declines of populations of species that
      1. occur naturally at low densities
      2. have large area requirements
      3. do not do well in edge habitats
      4. are sensitive to human contact
      5. are unlikely or unable to cross roads
      6. are frequently killed on roads (e.g., seek out roads for heat or food)
      7. are otherwise sensitive to extinction resulting from habitat fragmentation or disturbance

III. MAJOR OBSERVED CHANGES
   A. Peninsula effects and some island effects
   B. Altered population dynamics of many species
   C. Possible increased probability of further fragmentation
   D. Increase in absolute amount of edge in the landscape
   E. Decrease in the amount of edge that can support sensitive species
   F. Subdivision of protected habitats and forced metapopulation structure of patch interior species
   G. Altered patch dynamics; for example, loss of species for which patch colonisation rates are lower than local patch extinction rates
   H. Increased instability of ecological processes and increased frequency of fluctuation in habitat quality
   I. Predisposition of local extinction of some species

BOX 4. SUMMARY OF SOME MAJOR EFFECTS OF LANDSCAPE FRAGMENTATION ON SENSITIVE SPECIES OR SYSTEMS, PARTICULARLY AS DETERMINED BY ROADS WITHIN PARKS. FROM SCHONEWALD-COX & BUECHNER (1992).

Young and Mitchell (1994) have researched the microclimate and vegetation edge effects of forest margins created 100–130 years ago. Their research was in fragmented podocarp-broadleaf forest in the North Island. Penetration of edge effects was approximately 50 m, regardless of forest size. Some species-specific edge/interior differences could be related to timing of critical life history stages (e.g., germination and early establishment). They conclude that these edge processes are now probably a major feature of the overall forest dynamics.

3.85 Effects of fragmentation on forest birds

Rich *et al*. (1994) reported that extensive fragmentation of what was formerly contiguous forest in eastern North America (and loss of habitats) is viewed as the primary contributor to decline in forest bird species. They report that even narrow forest-dividing corridors do affect the distribution and abundance of birds in ways that are associated typically with the effects of forest fragmentation.

3.8.6 Effects on small mammals

In Kansas, small road clearances less than 3 m have been shown to effect small mammals such as voles and rats (Swihart & Slade, 1984).

In Australia, Mansergh & Scotts (1989) have shown that the social organization and survival rates of the mountain pigmy-possum (*Burramys parvus*) has been disrupted because its habitat has become fragmented by roads and other developments within a ski resort. They go on to suggest under-road corridors to aid dispersal.

3.8.7 Consequences for feral predators

Fragmentation of habitats may have implications for dispersal by feral predators, but little research seems to have been done in this area. May and Norton (1996) in Australia have noted that the extent to which roads influence the distribution and abundance of species such as foxes, cats and dingoes, and the consequences for native fauna, are poorly known.

3.8.8 Roads, fragmentation and invasive species

Roads can act as barriers for some taxa, while aiding the dispersal of others. Concern has been expressed about the spread of alien and invasive species, particularly with regard to invasions of nature reserves. For example, Bothers & Spingarn (1992) working in Central Indiana, USA, have drawn attention to the possibility of forest fragmentation encouraging alien invasions for at least two reasons. First, fragmentation increases the ratio of non-forest to forest and of forest edge to interior. Second, micro-environmental changes at forest edges may provide points of entry for alien species. In New Zealand, Timmins & Williams (1991) have noted that the most important factors influencing the number of problem weeds in reserves are, amongst other things, distance from roads and railway lines. Other literature about the spread of weeds and about the ecology of invasive species is given below.

3.9 ROADS AND ROADSIDE VERGES AS LINEAR LANDSCAPE FEATURES

Much has been made of the fact that roads can benefit nature. Birds may feed on the grit on roads, power lines provide perches for birds and roadside verges may provide wildlife habitats. The total area of road verges in some countries has been documented (but not along with estimates of the total area of habitat lost as a result of road construction). In modified and cultural landscapes, these verges could contribute, or add, to the area of nature reserves. In some countries, there is much interest in linear habitats (such as those provided by road verges). For example, Roach & Kirkpatrick (1985) reviewed the wildlife use of roadside woody plantings in Indiana, USA, and suggest planting regimes. Also in America, Smith & Hellmund (Eds) (1993) have reviewed what they call 'Greenways' and provide an overview of greenway ecology and habitats management. In the UK, there has been considerable interest in the contribution of roadside verges to conservation. Way (1977) has reviewed roadside verges and conservation in Britain. A detailed analysis of one County's roadside verges has been undertaken for Cheshire (Cheshire Ecological Services). This report details survey methods, analyses roadside verge habitats and makes recommendations for management and monitoring. Examples of the literature are given in Box 4 and include material on:

- roadside verge as habitats;
- management of roadside verges for wildlife;
- dispersal of wildlife along verges; possible corridor functions;
- dispersal of alien and pest species.

The third—the possible 'corridor function'—has become very popularised and the term wildlife corridor is widely used. Whereas many linear landscape features such as roadside verges may provide linear habitats, there is only a small amount of evidence to show that roadside verges are actually used by wildlife as conduits for dispersal (Spellerberg and Gaywood, 1993). There is now a rapidly growing interest in this topic.

Dispersal of plant species via roads and road traffic has been addressed in some surveys and an excellent analysis of the mechanism is given in Wace (1977) 'Assessment of dispersal of plant species—the car borne flora in Canberra'.

Pathogenic fungi may be spread by traffic and it seems possible that such pathogens may have affected forests in southern Australia (Weste, 1977).

Dispersal of weeds and alien flora via roads and road traffic (and by vehicles and humans during road construction) has received attention in New Zealand, Australia and in the USA. For example, Timmins and Williams (1990, 1991) have looked at the accidental spread of weeds through reserves and have noted that reduced roading could address this problem. The role of roads and traffic in the spread of weeds in Australia has been addressed by Amor & Stevens (1975), Cowie & Werner (1993) and Lonsdale & Lane (1994). Rather than trying to attempt to prevent this form of seed movement, it was suggested by Lonsdale and Lane (1976) resources are best spent on detecting and eradicating weed infestations. Such a conclusion is based on the acceptance that the road has been built and is operational. Furthermore, there are implications for ongoing costs.

Road verge surveys

Adams 1984. Small mammals, North carolina, USA.
Cowie & Werner 1993. Alien plant species, Northern Australia.
Hansen & Jensen 1972. Plant communities, Denmark.
Havlin 1987. Birds, Czech Republic.
Lane 1976. Plants, Australia.
Michael 1986. Songbirds, West Virginia, USA.
Munguira & Thomas 1992. Butterflies, UK.
Newbey & Newbey 1987. Birds, Western Australia.
Roach & Kirkpatrick 1985. Wildlife, Indiana, USA.
Reznicek 1980. Halophytes, Michigan, USA.
Samways 1989. Bush crickets, Southern France.
Tyser & Worley 1992. Alien flora, Montana, USA.
Wester & Juvik 1983. Plant communities, Hawaii.
Wells *et al.* 1996. Reptiles, UK.
Wilson *et al.* 1992. Plant communities, New Zealand. Road verge management for wildlife.
Williams & Buxton 1995. *Passiflora* species, New Zealand.

Road verge management

Laursen 1981. Mowing frequency and birds, Denmark.
Munguira & Thomas 1992. Buterflies, UK.
Parr & Way 1988. Long-term effects of mowing, UK.
Pedevillano & Wright 1987. Visitor management and mountain goats, Montana, USA.
Roach & Kirkpatrick 1985. Wildlife, Indiana, USA.
Sangwine 1992. Landscape planting, UK.
Thompson & Rutter 1986. British native plants tolerant of salinity UK.
Watson *et al.* 1989. Herbicide for weed control, northern Rockies, USA.

Dispersal studies (via traffic and along and from road verges)

Amor & Stevens 1975. Weeds into forest, Dartmouth, Australia.
Clifford 1959. Seed dispersal via traffic, Nigeria.
Getz *et al.* 1978. Small mammals, Illinois, USA.
Lonsdale & Lane 1994. Weed seeds, Northern Australia.
Schmidt 1989. Plant dispersal by traffic, Germany.
Seabrook & Dettmann 1996. Cane toads, NSW, Australia.
Timmins & Williams 1991. Weeds in New Zealand forest reserves.
Travis & Tilsworth 1986. Fish in culverts, Alaska.
Vermeulen 1994. Ground beetles, Netherlands.
Wace 1977. Plant species via cars, Canberra, Australia.
Warner 1985. Free range domestic cats, Illinois, USA.
Wilcox 1989. Purple Loosetrife (*Lythrum salicaria*), New York State, USA.

BOX 4. EXAMPLES OF LITERATURE ABOUT ROADS AND ROADSIDE VERGES AS LINEAR HABITATS AND ROADS AND TRAFFIC AS CORRIDORS (FACILITATING DISPERSAL) FOR WILDLIFE.

In Illinois, Warner (1985) studied the movements of free-ranging domestic cats and found that they made disproportionately high use of farmsteads, roadsides and field boundaries.

That roads and road traffic can facilitate the dispersal of species, including pest species, is without doubt. The ecology of dispersal of alien species and the ecology of invasions has become a huge research area and is of considerable importance to New Zealand. In Britain, Usher (1988) has written a review about biological invasions and notes that tourism poses dangers for reserves since there is a positive correlation between visitation rate and the number of introduced species. Studies and reviews of invasions of nature reserves by introduced species include Macdonald & Frame (1988) and Macdonald *et al.* (1989).

3.10 ASSESSING THE LIKELY IMPACTS

There are opportunities to address some of the problems of environmental effects of roads before construction (during the planning stages), during construction and after construction. For example, impact assessments and inventories could help to assess the location and route of the road and thus avoid or reduce impacts on areas of conservation importance. The effects of the types of materials used, including the possible chemical effects of aggregates used for road building, can be assessed before construction. Pollution prevention, habitat enhancement and management and also mitigation can all be considered at the planning stage.

Environmental impact assessments (EIAs) are not new and there are many examples from around the World which deal with road projects in different environments. International organizations such as the IUCN (IUCN, 1996) have published documents such as ‘Tourism, ecotourism and protected areas’ in which the question of assessments of new roads with respect to environmental impacts is outlined. The theory of EIA with regards to roads has been explored in a 1989 FAO Conservation Guide (‘Watershed Management Field manual. Road design and construction in sensitive watersheds’). Hodgen & Ford (1985) have described the planning and design of roads in UK areas of outstanding natural beauty (AONB). For the State of Washington, Horner and Mar (1985) have reported a protocol for assessing the impacts of road operations on aquatic ecosystems. The protocol offers opportunities to forecast potential aquatic impacts at an early stage of development. In the UK, the Department of Transport (1992) has published a review ‘Assessing the Environmental Impact of Road Schemes’ which includes effects on wildlife.

In the USA, the National Environmental Policy Act (NEPA) provides a framework for assessing the effects of road projects and environmental impact assessments. Southerland (1995) has examined the conservation of biological diversity in road projects and has suggested an interesting hypothetical comparison of effects of road development alternatives on biological diversity objectives (Table 2).

In New Zealand, the requirements for environmental impact assessments are described in the Resource Management Act 1991 and the contents of an impact assessment are outlined in the Fourth Schedule of the Act. In an article in ‘Local Authority Engineering’, Brown (1993) described how the Resource Management Act had major impacts for roading projects, including that of environmental impact assessments. As is the case in other countries, there are many examples of EIAs for road projects in New Zealand. The ecological content and depth of these reports varies a great deal. An appraisal would be timely and it is suggested that these be the topic for another investigation.

TABLE 2. CONSERVING BIODIVERSITY IN HIGHWAY DEVELOPMENT. FROM SOUTHERLAND 1995, CONSERVING BIODIVERSITY IN HIGHWAY DEVELOPMENT PROJECTS. *THE ENVIRONMENTAL PROFESSIONAL* 17, 226–242.

HYPOTHETICAL COMPARISON OF EFFECTS OF HIGHWAY DEVELOPMENT ALTERNATIVES ON BIODIVERSITY ENDPOINTS			
	ALTERNATIVES		
BIODIVERSITY ENDPOINTS	NO ACTION ALTERNATIVE	ALTERNATIVE 1	ALTERNATIVE 2
Consistency with regional plans	Does not provide transportation level of service	Opens planned agricultural area to urbanisation	No conflicts with local growth plan or state highway plan
Functional integrity of regional ecosystem	No change	Loss of forested area in core natural area degrades water quality at headwaters of watershed	No effect on core area, and increase in impervious surface has only minor effects on water quality
Composition of habitat types in region	No change	Reduces the proportion of old-growth forest in region	Does not significantly change proportion of natural habitats in region
Area of sensitive communities	No change	Loss of 100 acres of old-growth forest and 10 acres of wetland	Loss of 50 acres of second growth forest along agricultural fields
Status of sensitive communities	No change	Open edge habitat created along 50 miles of old-growth forest	No change
Native species diversity	Existing exotic weed problem in second-growth forest	Possible invasion of exotic shrubs into forest edge	Incliudes exotic plant management program
Native structural habitat diversity	No change	Loss of old-growth forest removes snags and down wood	Loss of second-growth forest removes hedgerows along fields
Status of hydrology, nutrient and energy cycling, fire regime, and keystone species interactions	No change	Reduction of subsurface flow to adjacent wetlands	No significant change in hydrology or other processes
Number of sensitive species	No change	Local extinction of wetland species	No change
Status of sensitive species populations	No change	Nest parasites reduce reproductive success of forest interior birds	Loss of foraging area for some forest species
Habitat connectivity	No change	Severs 5 parcels of old-growth forest	Eliminates hedgerows connecting second-growth forest
Habitat patch distribution	No change	Fewer large forest patches	No change in proportion of patch sizes
Number of contiguous habitat areas affected	No change	Disturbance radius (10 miles) intersects 2 wilderness areas	No change

Within the context of EIAs, many methods have been proposed for identifying impacts (primary, secondary and tertiary) and some have been developed specifically for roads. For example Lelievre & Serodes (1995) have suggested a cause-effect network. This type of identification is based on three components: actions undertaken, environmental characteristics and the stages of the project (Fig. 1).

FIGURE 1. INTERCONNECTED ELEMENTS IN A NETWORK. FROM LELIEVRE & SERODES, 1995, A NEW APPROACH FOR THE IDENTIFICATION OF ENVIRONMENTAL ISSUES AT STAKE IN A ROAD PROJECT. *JOURNAL OF ENVIRONMENTAL MANAGEMENT* 44, 221–231.

EIAs with particular reference to assessment of sediment load and water run-off from potential roads have been examined by several authors (for example Younkin & Connelly (1981), Horner & Mar (1983), Kerri *et al*. (1985), Lord (1987), Shelly *et al*. (1987), Smith & Lord (1990)).

Ecological considerations have been included within EIAs of some roads, for example Box & Forbes (1992) have suggested a conceptual framework for an ecological input into road projects. However, ecological impact assessments seem much less well researched than EIAs. The Institute of Environmental Assessment (IEA, 1995) has produced 'Guidelines for baseline ecological assessment'. In a recent book edited by Schmitt & Osenberg (1996), there are many ideas about detecting ecological impacts in coastal habitats. In another book (Reijnen *et al*., 1995), the authors describe methods for predicting the effects of motorway traffic on breeding bird populations. This is a particularly extensive book from the Netherlands and one in which there is very detailed theory and clear practical applications.

Environmental monitoring and ecological monitoring should follow on from EIAs or at least be included in EIAs. There seem to be very few reports which deal with this aspect, especially ecological monitoring. Two papers (Pratt & Coler (1976), Davis & George (1987)) describe monitoring of urban and road run-off.

3.11 ADDRESSING THE DETRIMENTAL ECOLOGICAL EFFECTS

Much has been written about ways of addressing the environmental effects of roads and road traffic. Appropriate choice of route may help to lessen the ecological effects. Reflecting lights at the side of roads may deter mammals from attempting to cross a road. There are many regulations with respect to pollution. Perhaps not surprisingly, there has also been some concern expressed about the increasing number of regulations regarding impacts and maintenance of roads and also the costs of compliance (see for example Tarrer *et al*. 1995). There are regulations specific to environmental effects of roads and there are also regulations which are noteworthy with respect to identifying and dealing with impacts of construction.

Many of the regulations deal specifically with effects on environmental quality (e.g., air quality). In one report (Kammerbauer *et al*., 1986), the reduction of toxic exhaust emissions by use of catalytic converters is advocated to reduce the effects of pollution on spruce and other conifers.

The need to address both the environmental and ecological effects of roads is clearly expressed in some general reviews of mitigation and enhancement; for example Thrasher (1983) and De Santo & Smith (1993). Most significant, in terms of both research on development of policy (Bohemen, 1995) and in terms of several publications written for the wider community, is the literature from the Netherlands and Denmark. Some of these publications include detailed methods for addressing the problems (for example the book 'Nature across motorways', published in 1995 by Rijkswaterstaat (RWS), Dienst Weg- en Waterbouwkunde (DWW), Delft.

Agencies such as Wallace, McHarg, Roberts and Todd (WMRT) in the USA have produced structured guidelines for including buffer zones in roading projects. An example is given in Table 3. In New Zealand, Transit New Zealand have produced a manual for cost benefit analysis of road projects; that manual includes a section on ecology with some information on mitigation. There have been some specific mitigation proposals such as that contained in the Audit of the Future State Highway Number One Route environmental impact report (Parliamentary Commissioner for the Environment, 1990). These mitigation measures included reference to roadside design, drainage and buffers for waterways and habitat disruption.

The literature dealing with ways of addressing environmental and ecological effects has included the following topics (examples of the literature in Box 5.):

- reducing pollution;
- road mortality and barrier effects;
- mitigation banking;
- landscaping roadside verges and use of native species;
- buffers and filter strips.

The literature on pollution seems mainly concerned with avoiding contamination of wetlands (see for example Kober & Kehler, 1987) and containing surface run-off from roads. By way of contrast there has been research on the use of wetlands as a sink for urban water run-off (for example, Reuter *et al*. 1992).

There is much literature on tunnels, underpasses and overpasses; mainly on how to construct them. There seems little on monitoring the effectiveness (in term of use) and effects (in terms of populations size, fragmentation of population and gene flow) of these attempts to reduce barrier effects.

Mitigation banking is not new but is becoming increasingly popular as a topic. It involves compensating for loss or damage to habitats in one place by providing for establishment or enhancement of habitats for wildlife elsewhere. There is much room for research here, particularly with regard to ecological restoration.

TABLE 3. OBJECTIVES AND GUIDELINES FOR SITE-SCALE DESIGN OF THE WOODLANDS. FROM SMITH 1993, GREENWAY CASE STUDIES, PP. 161–208 IN SMITH & HELLMUND, (EDS), ECOLOGY OF GREENWAYS, DESIGN AND FUNCTION OF LINEAR CONSERVATION AREAS. UNIVERSITY OF MINNESOTA PRESS, MINNEAPOLIS. AFTER WALLACE, McHARG, ROBERTS & TODD 1993. THE WOODLANDS DEVELOPMENT CORPORATION, WMRT, PHILADELPHIA.

OBJECTIVE	GUIDELINE
Protect floodplains and stream channels in their natural states	Maintain the natural stream channel and floodplain in all drainages. Define drainage easements to protect the 25-year floodplain of all drainages. Easements will be at least 300 feet for primary drainages and 100 feet for secondary drainages. For Panther and Spring Creeks, the two most important perennial streams, prohibit all development within the 50-year floodplain. Permit only minimal clearing within the 100-year floodplain: no lawns allowed, and buildings must be raised above the 100-year flood level so as not to impede the floodwaters.
Retard runoff and maximise recharge to even base flow of streams	Use check dams in swales on house lots to slow flow over permeable soils to enhance recharge. Direct runoff to ponds and swales and over permeable soils with excess storage capacity
Maintain vegetation around recharge ponds for water quality and wildlife habitat	Maintain sufficient vegetation as a buffer around ponds to ensure good water quality and habitat for wildlife. Forty percent of the pond's perimeter may be developed, but a 50-foot forested buffer must be maintained. The remaining 60 percent should have a 150-foot buffer.
Protect significant forest types	Protect and minimise clearance of pure or predominantly hardwood stands, which are less common, less tolerant of development, and better wildlife habitat than pine stands.
Protect individual trees and small stands not cleared in house lots	Maintain a buffer zone (one canopy diameter for hardwoods, one canopy radius for conifers) around each tree or stand.
Maximise aesthetics of The Woodlands through use of vegetation in site planning and design	Use native vegetation to buffer narrow front yards and to limit the artificial environment along roads.
Provide for wildlife movement	Form continuous wildlife corridors that include food, cover and water. Major corridors should be 500 to 600 feet wide. Minor corridors should be 100 feet wide.
Buffer wildlife from disturbance by humans	Provide large areas offering diverse vegetation cover and water that are suitable as wildlife refuges. Natural areas not suited for active recreation should be selected as refuges. Major wildlife corridors should connect these natural areas. Minimise crossings of the wildlife corridors by pedestrian and vehicular movement. Keep human activity to the periphery of wildlife corridors to minimise disturbance.

Reducing pollution

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Reducing road mortality and barrier effects of roads bridges and railway lines

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Owens & James 1991. Brown Pelicans and bridges. Texas, USA.
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Mitigation banking

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Buffer zones and filters

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Swift 1986. Filter strips to prevent sedimentation of streams. Appalachian Mountains, USA.
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BOX 5. ADDRESSING THE DETRIMENTAL ENVIRONMENTAL AND ECOLOGICAL EFFECTS OF ROADS.

Landscaping and planting roadside verges has been widely researched, mainly for erosion control (for example Schor & Gray, 1995) and to provide habitats for wildlife (see Box 4.).

The concept of buffer zones (undisturbed areas or strips) and filter strips (undisturbed except to provide access; Clinnick (1985)) has long been popular in conservation and has been researched with respect to several kinds of impacts, not all of which are relevant to roads. For example, the use of buffer zones to minimize effects of herbicide spay drift has been researched by Marrs *et al*. (1989, 1992). Buffer zones on field margins have been developed in Britain with the aim of encouraging habitats for wildlife, including beneficial invertebrates. The use of buffer strips to absorb pollutants has been discussed by Angold (1992) and by Curzydlo (1985). It seems that some kinds of dense vegetation, including gorse (*Ulex europaeus*) may act as sinks for some pollutants.

A common question is, 'how wide should a buffer zone be?'. Very little research has been undertaken on how to identify the optimum widths of buffer strips alongside roads. One way of approaching this is to research the nature and extent of the impacts from roads and traffic on wildlife communities. Angold (1992) has carried out a very detailed analysis of the effects of roads on heathland communities in southern England.

Of all the ways of addressing ecological impacts, that of not building the road must be the most important, particularly for avoiding habitat fragmentation and subsequent incremental damage to nature.

3.12 AREAS FOR RESEARCH

3.12.1 Pollution

While there is much research on rates and levels of accumulation of heavy metals in roadside biota, the effects of the metals seem not well researched. As early as 1976, Smith reviewed lead contamination of roadside ecosystems and at that time noted that our understanding of the effects on biota are deficit. More recent reports of the late 1980s continue to mention that we know little about the chemistry of heavy metal uptake in biota. In particular, there seems to be some controversy about the effects of heavy metal accumulation on forest trees (Backhaus & Backhaus, 1987).

3.12.2 long-term effects

There is very little research on monitoring the ecological effects over time and little research on long-term effects. This could be particularly relevant in New Zealand with respect to the ecology of invasive species and dispersal of those species via roads and road traffic.

3.12.3 EIAs

There are many environmental impact assessments of road projects (in New Zealand and elsewhere) but the level and content of the biological and ecological information is varied; some leave much to be desired. There could be more research on the nature of ecological impact assessments of road projects. I recommend an appraisal of biology and ecology in EIAs on road projects in New Zealand.

3.12.4 Habitat fragmentation

Many authors recognise that fragmentation of habitats by roads is perhaps their most important ecological effect. Ecological studies of fragmentation are growing in number but meanwhile there are few very reports which analyze the effects of fragmentation by roads. There is room for research on analytical techniques as well as on modelling the likely effects.

3.12.5 Methods to reduce barrier effects

Much has been said about the use of tunnels but there seems to have been little research on their effectiveness.

3.12.6 Mitigation banking

This is an area in which little research has been done.

3.12.7 Buffer zones

The concept, like wildlife corridors, is widely used but also like wildlife corridors, the ecological aspects have been poorly researched.

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Appendix One

SERIALS CHECKED MANUALLY FOR EFFECTS OF ROADING

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Vol 46 (1986) – Vol 76 No 1 February - May 1996

Appendix Two

WEB PAGE

The ecological effects of new roading in protected areas - a literature review

Professor Ian Spellerberg and I are currently undertaking a study for the Department of Conservation entitled *Ecological Effects of New Roading in Protected Areas - A Literature Review.* We are looking for any information or literature relating to the ecological impact of new roads such as on wilderness values, hydrology, habitats of species, and roads as barriers to dispersal or as wildlife corridors. We are particularly interested in quantitive ecological studies of the effects of roads on biotic communities and ecosystems.

The research will include:

- Impacts (during construction and use) of new roads on natural environment, habitats and species of protected areas.
- Ways of mitigating impacts (such as by way of ecological buffer zones) with reference to specific case studies in New Zealand and in other similar biogeographical regions.
- Identification of future research agendas relevant to this topic.

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